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Application of a factory wide and product related energy database for energy reduction

(EnergyDB)

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1.1 WP 1: Requirement analysis and system specification

Task 1.1: Requirement analysis

This task is dedicated to the definition of general and individual requirements related to the implementation of a factory-wide energy data base and of the Energy Information and Analysis System (EIAS). The requirements are related to the factory-wide energy data base and to the Energy Information, Analysis and Control System (EIAS).
The discussions about the different aspects resulted into the following requirement list.

- The system must be modular and scalable allowing to extend its functionalities through future iterations.
- Both EIAS and the energy data bases must be designed to be capable of being integrated into existent systems in the plant (brown-field application).
- Information must be accessible from different levels of the automation system (level 2 and level 3) and for different users.
- Interfaces must be user-friendly. This way, final users should not require intensive training.
- The system must be failure-tolerant, thus some degree of robustness is required.
- Information to be included in the new data base must be consistent. It is preferred to have few but reliable data than a huge amount of inconsistent data. Validity checks of data shall be integrated
- New system must fulfil the current standards of internal security (user control, backup policies, etc.), but also it must be protected against external unauthorised access and attacks.
- Final systems should have minimum requirements for maintenance.

Task 1.2: Determination of the available process and energy consumption data

Since the different involved partners are using different process routes to produce different products, the determination of available process and energy usage data produced different lists of data.
For a detailed description of the investigated plants and the resulting parameter lists see 2.2.1 at page 19.

At ArcelorMittal Asturias (Spain), a fully integrated steelworks produces a great variety of products (tinplate, galvanised, rail, heavy plate, wire rod, etc.)

At ArcelorMittal Eisenhuettenstadt (AMEH) the situation at the hot rolling area was analysed. This area includes the reheating furnaces (walking beam type), the edger and pre-rolling stand, the hot rolling mill itself, the strip cooling facilities and the related auxiliary processes. At these plants the available electric energy data were examined and their synchronisation to process parameters was done.
The energy data used for this project are collected by an external company: VEO (Vulkan Energiewirtschaft Oderbrücke GmbH), a supplier of electric energy and service provider. VEO is commissioned by AMEH for the energy supply and the billing of delivered energy. For these purposes VEO operates an energy data acquisition system at AMEH.

CSM and DA analysed the data available in the Supervision and Execution layers (Level 2 and Level 3 systems). Both electric energy, methane and oxygen have been considered, being the main sources of energy in a typical melt shop. CSM and DA considered data from the Scrap Yard (SY), the Electric Arc Furnace (EAF) and the Ladle Furnace (LF)

Riva Caronno's process route includes an EAF, LF, VD (Vacuum Degassing) and billet/bloom casting. The boundaries of the system include scrap melting phase in the EAF station, refining and secondary metallurgy in LF station, degassing in VD station and continuous casting square 200 mm section, considering consumption of auxiliaries such as natural gas for preheating of ladles and tundishes.

Task 1.3: Detailed reporting of the handling of energy consumption information

It was analysed in which way the steel companies were exploiting the available information about energy usage in their production.
The typical assessment of energy data is done on longer time intervals like months or year. From such data compilations dedicated KPIs (Key Performance Indicators) are derived for the global process or of any subprocess (e.g. Nm^3 of O_2 per tonne of hot metal is a KPI of the steel shop). Such KPIs are used to estimate future demands and therefore to help in the energy supply management.

In case of electric energy the monitoring of 15/30 minute-values of complete workshops is used to observe the actual use of electricity concerning the maximum values agreed with the power supplier, because exceedances of such limits cost the company additional fees.

On the other hand, it was seen that steel companies are able to buy quotas of electric energy on spot markets where the price may change significantly every hour. Here more detailed estimations -one or two days in advance- of energy demands related to production plans support an improved purchase of necessary energy amounts.

Task 1.4: Definition of the target specifications

Basing on the requirements defined in Task 1.1 and considering the easy access to system the following general specifications were defined:

- The EIAS shall base on a web platform so access for users via internet will be enabled.
- Aimed modules to process the different main tasks (KPI calculation, piecewise analysis, processing route optimisation, etc) shall be implemented by web services where applicable.
- The architecture has to be modular to allow easy integration of planned tasks and to enable extension to future requirements.
- Interface functions to get access to local data bases (energy <u>and</u> process) at the industrial sites have to developed as well as suitable and ergonomic user interfaces (HMI).
- Procedures to pre-process energy and/or process data have to established to enable special calculation (like KPI) or the preparation for extended analysis and evaluation (e.g. deviation analysis of energy use for similar products).
- To assure a high level of data integrity (robustness, failure tolerance, etc) adjusted approaches (like signal validity checks, simple soft sensor models for important data) have to be evaluated if necessary.
- Still in the design of the system security aspects (user access rights, protection against unauthorised access, etc) have to be considered.
- The design and implementation of the energy data base must respect the constraints coming from the brown-field implementation.
- For different tasks an offline test environment could be useful, it should enable the test and optimization of the EIAS outside a specific plant but using industrial data.

The use case at DA considers different planning and scheduling scenarios to be analysed and weighted with proper KPIs able to define the energy efficiency relevant to each one. For this reason, DA and CSM have been taken into consideration the development of such KPIs and the integration into the planning and scheduling modules.
With respect to the tasks of KPI calculation as a measure for energy efficiency CSM and DA developed a scheme of specifications which differentiates between two categories of requirements to be considered:

- Functional specifications/requirements defining specific behaviour of an application, and
- Non-Functional specifications/requirements defining operational criteria of the solution.

Basing on that categorisation, DA and CSM developed a list of specifications for the KPIs and their implementation.

1.2 WP 2: Concept development

Task 2.1: Detailed concept of the Energy Information, Analysis and Control System

The main conclusion of the discussions was to foresee the EIAS implementation by a web server architecture, i.e. the desired functionalities (data access, analysis modules, etc) are integrated into an intra-net accessible platform. There are two main parts of foreseen in the web server architecture:

- Local Services realise the access to data
- Common Services include the aimed EIAS functionalities

The local services are different from one web server application to another. They depend on the locally existing IT infrastructures at the industrial sites and will benefit from existing tools and experiences for data access and selection.
The common services will be in accordance to agreed standards of software engineering (glob-ally and agreed between the partners) to ensure their integration and simple updating into the EIAS.

This concept was later on only partially implemented, because the detailed varying security guidelines at the industrial partners did not allow for example a full web-based access to the databases. In such cases only intranet access to the databases and executable applications for analyses could be applied.

Task 2.2: Concept development for energy efficient production routing

For the integrated steel works production at AME, UniOvi developed an optimization tool that allows the offline optimization of process routes considering the different energy consumptions over all possible alternatives. After evaluating a commonly known optimisation approach called Analytical Hierarchy Process (AHP), it was decided to develop a new fit-to-purpose optimization tool called EnergyDB by adapting and extending the UNIOVI´s proprietary modelling & simulation framework ATOS.
The framework is a windows-based programming tool where processes can be considered functions implemented as boxes that contain one or several models running sequentially, providing the tool with simulation capabilities that allow users to perform what-if analysis. Its modular structure allows the environment to be easily upgradable with new processes, models and capabilities. Moreover, to perform the same estimation, different models can be implemented and can be selected by the user or the application would intelligently select the most reliable one regarding the available input data instead. In addition, the environment allows developing each of the capabilities required for global optimisations.

Task 2.3: Investigation of suitable ontologies about energy consumption

Ontologies have proven to be a very efficient tool for knowledge structuring and exploitation. Through the definitions of concepts and relations, it is possible to describe the entire domain of interest in a detailed manner, like in this case energy flows and use in steel manufacturing. Semantic enrichment opens the possibility for automatic reasoning and inference, which leads to automatic generation of new knowledge. Finally, an ontology can enable interoperability between different systems providing e.g. a common vocabulary. All these benefits are extremely important in case of large organizations, which are struggling with ever increasing amounts of data and facing problems of exchanging knowledge between different systems used at different company and plant levels.
CSM and BFI focus their attention on ontologies related to energy efficiency in industrial environment analysing in detail the different ontologies in the field of industrial production which includes energy related aspects.

Task 2.4: Development of the energy consumption assignment concept

In this task the partners developed a formalism to describe how different types of energy have to be included when focussing on a specific production step. Type of energy means here the purpose or the impact of applied energy, like energy for the investigated process (heating, melting transforming, transporting…), for its preceding processes or energy for auxiliary purposes.
By this an equation (see chapter 5.3.2) was defined which sums-up the different energy types including factors for losses and basing on the mass of the investigated product. Mainly built for the liquid products in steel production, this equation was adapted for its application in the hot rolling use case.

1.3 WP 3: Design of the architecture of energy data base

Task 3.1: Adaptation of the methods for energy consumption assignment to intermediate and final products

As shown on the equation presented in Task 2.4, the assignment of the energy embedded in steel products need to consider the energy consumed at the final process plus the energy that was used on the previous production stages to obtain the final or intermediate product.
In case of liquid steel production, the energy assignment is being modelled on two levels of detail:
Energy will be assigned at the upstream stages to the Basic Oxygen Furnace (E_n) using average energy use data compiled and processed from the production data bases of each installation. Data from each process will be proportionally aggregated referred to ton of produced liquid steel at BOF.
On the other hand, energy assignment at the final production stage (or intermediate like the case of liquid steel) will be performed specifically for each heat as represents a discrete entity with its own features different from the previous and next heats. However, the assignment still will be done on a per ton basis in order to facilitate the aggregation of energy at other processes.
The energy assignment modelling should include 3 groups of energy usage:
Direct energy is the energy used directly for the liquid steel production like the electricity used at the converter or the chemical energy supplied by natural gas combustion. This kind of energy is easily assigned from the readings of consumption of:

- Coke Oven Gas
- Electricity
- Oxygen
- Steam
- Nitrogen
- Argon

Direct energy is represented in the basic equation of energy assignment as E_a, energy used in current step.
Indirect energy is the energy use required to maintain processes that cannot be directly assigned to a particular product. It includes the non-production times (e.g. waiting time between heats), the efficiency losses caused by process imperfections, the reheating of restarted batch processes, compensation of thermal losses due undesired intermediate products etc. This kind of energy not directly measured and is represented in the fundamental energy assignment equation as α_i, efficiency losses in current step.
Continuous energy is the energy used by auxiliary equipment (E_m) like air pressure compressors or not production related tasks like building lighting. This kind of energy is also called installation energy and it is difficult to assign as generally there are no direct readings of each equipment.

At production steps related to single pieces like in case of AMEH, electric energy usage can be synchronised by time with the related products and the process data. This enables the distinction between times of processing a certain product (e.g. slab or coil) for handling, heating, transformation etc; and times of idle or waiting times, summarised as a basic load. This basic load energy summarises the above-mentioned types of indirect and continuous energy.

Task 3.2: Method development for automatic assignment

Energy assignment is a highly complex task due the large number of equipment using and producing energy and because the many different kinds of energy used.
Therefore in case of the Basic Oxygen Furnace, energy pre-assignment is performed using data modelling clustering techniques. Data from the last 2 years were analysed in order to set a group of clusters where any heat could be allocated. Clusters were defined and their direct energy usage preassigned, based on the real and planning values of the related process parameters.

Produced energy carriers are steam and LD gas. Steam produced at the BOF is sent to AME´s steam network to be used by other facilities (mainly by the coke ovens at AME Aviles).
Most of the produced LD gas (about 80%) is sold to a nearby cogeneration plant owned by "EDP Energía" (Energias de Portugal) which mixes it with other gases to produce electricity and steam. The electricity is sold to the national grid while the vapour is sold back to AME to be used by its installations. The resting 20% of LD gas is just burnt in flare due technical reasons.
Then, the electricity and steam assignments from upstream processes from BOF (ΣE_n) are compensated by the amount of electricity and steam produced by EDP Energía. As there was no access to EDP´s production database, produced electricity and vapour will be estimated from yields reported in the literature.

Every 6 months, data from new heats will be included into the data analysis procedure in order to update the model and to improve its accuracy.

In case of a <u>piecewise allocation</u> of energy usage the time stamps of the energy measurements and the time stamps of process data allows the calculation of energy values related to single pieces like

- slab heating energy by an idealised calculation by means of the furnace in/furnace out temperatures and the assignment of the steel grade to a material group defined in the BISRA tables ([1], Annex 4.3)

- transformation energies at the edger, the roughing mill and for each rolling stand in the hot rolling mill
- dedicated processing and handling energies like descaling, usage of a coilbox and the coiling of the strip

As single basic load energies the values of electric energy were summarised for 8-hour-intervals for many different facilities in the hot rolling area:

- electric energy used in the Walking Beam Furnace (WBF) for drives and other consumers
- roller tables in the edging/roughing mill are, for the finishing mill roller tables etc,
- the abovementioned facilities
- ….

Such energy amounts are assigned to single pieces by the relation between overall product weight and the single product weight, according the second part of equation

In case of the heating in the WBF, a calculation of the overall heating energy in 1-hour-intervals was developed and includes also the calculation of the slab related ideal heating energy for those time periods.

At 5.3.2 WP 2: Concept development, under Task 3.2 an equation shows the described relations.

Task 3.3: Determination of necessary enhancements of data acquisition and data bases

Regarding the work of DA and CSM, the Energy Efficiency Indices are stored every 10 or 15 min in dedicated tables of an Energy Management System (EMS).

SSSA and Riva implemented a relational database which is hosted by RIVA to store the data.

AME and UniOvi set-up an Oracle database at AME premises and integrated on Apache Cassandra at UniOvi. This configuration provides excellent performances, works properly and meets all the requirements, including capabilities of transparent clustering, high security levels and systems for losses zero.
Insertion and data acquisition are performed by both custom software ad hoc and ETL (Extract, Transform and Load) tools. This custom software is executed on the process computer waiting continuously the arrival of data. For data exploitation custom software was developed in .NET .

In case of the piecewise assignment of energy data to single coils at the hot rolling area (AMEH) the necessary energy data and process data are available, but located in different systems and different formats. For the purposes of the project an Oracle database had been set-up at AMEH to be used as a container for the data transferred from the external energy database system. Necessary pre-processing of these energy data and the synchronisation with process data to allow a piecewise allocation of used energy are running on this data base. The resulting energy data are stored in several data tables allowing the analysis of energy data and product/process specifications.
It is foreseen to transfer the complete system in the future into the central IT system of AMEH.

Task 3.4: Definitions of methods for the assembling of energy data with process and quality data

Because the time alignment of the different data sources was a major problem at all use cases, special efforts were undertaken by the partners to synchronise energy data and the different process and product data at the plants.
Besides these time stamps of measurements, the allocation of data needs a correct assignment of data to product IDs, i.e. a complete and unambiguous system of IDs must be established throughout all involved data systems.

For AME a system to validate data from automation levels 1 and 2 has been provided in order to avoid wrong information. It is preferred to lose information for some heats or pieces than introducing wrong information that could cause important malfunctions in the modelling stage.
Data filtering is based in the univariate statistics of every variable as well as clustering of heats considered in task 3.2.

DA and CSM focussed on the calculations of the Energy Specific Index (ESI) and the Energy Efficiency Index (EEI). The first aims at calculating the energy necessary for a specific product in a specific process, and the energy necessary during idle times. The second (EEI) aims at calculating KPI for product families at a specific process step and uses the calculated KPI ESI.
The integration of product/process data with the energy data for the ESI calculation is based on the time stamps (time intervals of 15 or 30 minutes) used in the Energy Management System. Special procedures have been developed to assign portions of energy if the related product is belonging only partially to one acquisition time interval in the EMS.

1.4 WP 4: Semantic model for energy consumption analysis

Task 4.1: Definition of a semantic energy consumption model

Within this task the development of the semantic model for energy consumption has been performed. The aim of the semantic model is to define a common understanding of the used vocabulary and to provide a formal structure for data handling. For the generation of the ontology results obtained within the Task 2.3 have been analysed and as far as possible utilized within the model. Further also experiences from former RFCS projects have been considered and some ideas have been incorporated in the approach.

Task 4.2: Set-up of the semantic model

After the analysis of available tools and applying the results of the former RFCS project KNOWDEC the implementation of the ontology was done by Protégé software, a free and open-source platform. Developed by Stanford University, it provides a growing user community with a suite of tools to construct domain models and knowledge-based applications with ontologies
The semantic model developed in the project was implemented within the Protégé system.

Task 4.3: Adaptation of the methods to different production stages (casting, hot / cold rolling, annealing …)

The developed semantic model was tested concerning its capability to be adapted to process stages outside the foreseen use cases. Because the sematic model has been designed in an abstract way the extendibility to other processes can be guaranteed. However, in order to verify the extendibility a theoretical study of not covered process stages as casting, hot rolling, cold rolling, annealing has been performed. The mentioned processes have been modelled using the Protégé software showing the generality of the model. The performed activities allowed to provide the proof that the model can cover also the requirements of unforeseen plants and can be universally applied for different usage scenarios.

1.5 WP 5: Development and Implementation of the energy data base

Task 5.1: Development and implementation of a data model for the energy data

As written in the Midterm Report, the consortium decided not to define one common data model for all applications of the energy data base, because the energy data bases have to be integrated into existing IT environments of the steel works. To take advantage of the existing knowledge and tools the energy data bases are defined and implemented according the existing environments available at the plants.

This procedure has the following advantages:

- no restrictions occur regarding used data bases and their format,
- local data and information are kept confidential, because the interfaces are locally implemented at the related web servers,
- the interfaces connect directly to local data bases which reduces transmission efforts,
- security applications (fire walls etc.) existing at the plant systems are shared.

Therefore the development and implementation of data models to define the relations and interconnections of data and tables was done by the different partners regarding their existing IT systems.

Task 5.2: Realisation of the connection between energy data and process and quality data

The different requirements and approaches described in the tasks of WP3 were implemented and tested for the different systems. Thus the infrastructure and the logistics was established to collect and compile energy data together with process and product data for the applications.

Task 5.3: Data supply for the development work packages and EIAS application

At AME an extension of the data acquisition was necessary to collect some required energy values. For their acquisition a Simatic ET 200M system was installed to collect and transfer this data.

SSSA developed a basic web interface to allow the user to perform mainly two kinds of operations:

- uploading data from a database by using data exchange format
- execute the optimization tool

1.6 WP 6: Development of EIAS applications

Task 6.1: Analysis of deviations with relation to material classes, production procedures and process conditions

In case of AME, UniOvi applied two clustering techniques to assign the energy related parameters to groups of heats which have with similar behaviour and features, and whose centres could be considered as representative for the whole group.
By assigning the related used energy amounts to the found clusters and an analysis of the used process variables in relation to that energy amounts, reasons for deviations in the energy use could be found, for instance related to certain steel grades or specific amounts of injected Argon.
By means of external benchmarking (see below) and the consideration of BOF characteristics at AME, for the needed energy at BOF process two limits were defined, which are used as alarms to detect out of range values during total energy calculations by the model.

SSSA and RIVA developed a tool to eliminate automatically rare events (outliers) from the data sample provided by RIVA. This new tool uses different multi-variate approaches (Local Outlier Factor, Fuzzy C-means Grubb Test and distance-based outlier detection) and a fuzzy-based merging of the results of these methods. This approach is applicable for the examination just of big (historic) data samples.

For the hot rolled coils deviations of energy used for transformation tolerance bands can be defined defining a region of "normal production range" by calculating the average for a certain group of coils (grouped by material, geometry, slab temperature at furnace out, …).

Task 6.2: Analysis of energy optimized production routes

For the integrated steel works production at AME UniOvi developed an optimization tool that allows the offline optimization of process routes considering the different energy consumptions over all possible alternatives. For that purpose, a fit-to-purpose optimization tool called EnergyDB was developed from the UNIOVI´s proprietary modelling & simulation framework ATOS.

Task 6.3: Application of EIAS for internal and external Benchmarking

UNIOVI-AME has compiled reference values for several processes in the BOF production line that can be used for external benchmarking.
It was found that there are four main factors enhancing the complexity of such benchmarking:

- Oxygen steelmaking itself needs energy but also produces energy carriers. The reason are the strong oxidisation processes which produces exothermic behaviour. Energy carriers are the steel itself by its raised temperature, the exhaust gas heat and heated cooling water.
- Many inputs like Carbon, Silicon and other put latent exothermic energy into the BOF, this is used to melt and reduce mainly the scrap, added ore or waste oxide briquettes. Electric energy is used for pumps, coolers and handling devices.
- The variations in energy sources and the different process management at examined European BOF plants (compare Reference Document on the Production of Iron and Steel (BREF)) show remarkable variations in the used energy sources. This makes the comparison more complex, too.
- The use of external data is complicated, since databased data, e.g. compiled for Life Cycle Analysis, are based in final products like slabs or coils. Values for intermediate products have to be extracted from process stage to process stage.

Following figures have been extracted considering the characteristics of AME's BOF liquid steel production:

- Theoretical minimum to produce liquid steel at 1600C from Pig iron at 1450C 487 MJ/t
- Energy loss by vaporisation of 1% iron (80MJ/t melting + 64MJ/t vaporisation) 144MJ/t

But these values depend significantly on yield losses, heat of solution, ore reduction, amount of scrap and other constraints (see Fruehan 00).

Considering the characteristics of AME's BOF liquid steel production, following figures are assumed:

- At AME's BOF, energy needed for heats with high levels of scrap 710MJ/t
- At AME's BOF, energy needed for heats with more ore to deoxidize 587MJ/t

These are limits defined for the maximum consumption with mature technology steelmaking.

Internal benchmarking in case of the hot rolled products is done at AMEH by the comparison of the energy demands of different steel grades, different transformation ratios in the roughing and hot rolling processes. Special focus is laid on deviations inside one group of products which belong to similar/identical steel grades and product geometry.

Task 6.4: Application of process monitoring and fault prevention

UniOvi developed two energy assignment models to define the most significant variables influencing the energetic charge of the steel products, one for separated steel families and one unique model describing all steel families.
Most influencing parameters found were TIME_BLOW, followed by O2_TOTAL for all separate models and the overall one. On the opposite side, TEMP_LIQUIDUS is a less significant variable to most cases, and not included into the further analysis for the samples ALL and the steel families C, D and N.
For other variables like TEMP_OBJ_CH, TEMP_PIG IRON, WT_STEEL_OBJ, CARB_CONT and TIME_GAP, their influences were found quite similar in the different models.
Also incorporated is a system which observes deviations from the mean values according the "Rule of 7". It means, if a process produces seven consecutive times a deviation to the same side (higher/lower) a mean value, the risk of a malfunction is high and an alarm should be generated. In some cases, at AME for some parameters a sharpened "Rule of 3" was implemented, e.g. to inform plant technicians in case of the tapping time about 3 consecutive deviations. This should decrease the risk of long periods where the process may be out of control.

Task 6.5: Development of energy consumption efficiency indexes to be used as KPIs within Planning and Scheduling modules to compare different planning/scheduling scenarios

CSM and DA developed two modules, one calculating the Energy Specific Index (ESI) associated to each product and one deriving the Energy Efficiency Index (EEI) for groups of products. The EEI is integrated into the Execution Management System (EMS) for the energy evaluation of a production plan.

The first one was implemented by C# program code, whereas the second module was implemented into the OLAP (Online Analytical Processing) tool incorporated into the database system at DA. Since these calculations were done internally in the database, a dedicated Excel interface was established for the EEI calculation

Task 6.6: Discussion of the results with production experts

In order to discuss the results with the process experts from DA, the Energy Specific Indexes calculated by the application and stored in the local EnergyDB, were compared to the L2 energy data.
In particular, the total amount of energy calculated during process times by the application was compared with the total amount of energy according to EMS. This procedure was useful to validate the calculated ESI.
In case of heats processed at the EAF and the LF, the difference is quite small and reasonable, because in the calculation of the ESIs idle times are not included. On the opposite, for the CCM, the idle time has a consistent relevance in the evaluation of energy demand. In any case, the total amount is two orders of magnitude less than the EAF and one less than the LF. Considering that the Index is used for the evaluation of the energy demand associated to a specific production plan across the complete process chain, a fixed value for the energy demand at the CCM can be considered without affecting the final result.

Once final results from model were achieved, at AME a roundtable discussion was set with production experts with three main objectives:

- Make them aware of the EIAS capabilities
- Model validation
- Future improvements

Cluster philosophy and results were discussed with the experts, coming from the plant, R&D and quality.
All of them agreed on the usefulness of the tool and highlighted its potential for expel for preventive maintenance purposes, to be used for refractory walls wearing monitoring. Some other case studies were thought to continue the study of the applicability of the system. Currently an evaluation of the best route to produce a specific grade of tinplate using two routes (an alloyed steel and a standard steel) is being tested.

1.7 WP 7: System integration

Task 7.1: Integration of the components into an information and analysis system

AME/Uniovi models were implemented using software modules hosted in a server of AME R&D accessible from other factories of the company. This kind of web services, well-known techniques, were selected because they are usable whatever configuration the plants have. This will ensure its use internally as its immediate transferability to the other members of the consortium.

SW includes three main functionalities:

- Determination of the expected energy consumed for a given heat.
- Evaluation of its energetic efficiency according to internal and external standards.
- Proposal of a new configuration for the heat optimising the energy consumption.

And other Non-functional features as:

- Export/Import data from Excel files.
- Administrative tools to manage and update the system.

CSM integrates the calculation of Energy Specific Index in a dll to be executed offline each day. A specific dll can be incorporated in the MES system for extemporary calculation or integrated in a console application to run each day on the new acquired data.
EEI can be calculated and used within the MES system for evaluating the energy demand profile of a production plan or can be calculated and visualized within EnergyDB web application.

In case of the energy information and analysis tools developed at AMEH, an incorporation into the web application was not possible, because the security guidelines at AMEH hindered a connection to databases or applications running into the enterprise network via http or https ports.

Task 7.2: Realization of an offline test environment

The offline simulation environment was implemented in a dedicated server, equipped with a SQLServer database hosting the same DB structure of the L2 and EMS data of DA.
The DBs were configured accordingly to DA specifications for both L2 and EMS data and were populated with a selected set of data coming from specific acquisition campaigns. The server also hosts a selected set of MES and EIAS modules relevant to the scenario analysis.
The test of the EIAS application, for the DA and CSM parts, was performed using this offline environment.

Task 7.3: Realisation of the automatic storage of the energy consumption information into the database

The automatic storage of the energy data into the database is solved locally. Both AME´s production DB and UNIOVI simulation & research BD are integrated and inn operation. Original sources are the process database and the business (Level3) database, both realised Oracle database systems. Although during the modelling stage a non-SQL DB was used, the final DB installed for the common framework is developed on MySQL in order to ensure accessibility and compatibility with the DB of the rest of the partners (SQLServer, Oracle and MySQL). All partners use ANSI standard statements, avoiding system specific SQL statements to facilitate the integration.

Final integration requires the distribution of a pre-designed template. Once all template parameters are defined, the integration is expected to be immediate. (see 4.4, User guide for ENERGYDB – Implementation at AME and UniOvi)

At AMEH the derived energy data per product/process step are stored in an Oracle database running at AMEH's site. This includes a piecewise storage of mentioned energy values for product-related transformations or specific handlings, the storage of basic load energy amounts for aggregates and devices of which the electric data are available for 8-hour-periods, and the storage of energy data of the walking beam furnace for 1-hour-periods.

Task 7.4: Implementation and installation of the EIAS

AME´s and UNIOVI´s databases are fully integrated and in operation. AMEs contribution to the final EIAS runs through by web service so it does not require local installation and therefore establishing local links is not necessary and it is accessible from everywhere.
Consequently, the EIAS will not be installed straight into the production PCs but will run from the specific process server just with a click on a link. Then it will support experts to assess the correct production operation and optimize the production planning processes.

Task 7.5: Guidance of the target user and activation of the developed system

AME generated a written user guide and prepared a video which explains the use of their application (see Annex 4.4).

In case of AMEH a detailed documentation was produced concerning the database internal assignment of energy data and the use of the reporting tool.

1.8 WP 8: Test and evaluation

Task 8.1: Test of the system

The EIAS module developed by UNIOVI is running by web service means and so is accessible to AME´s production experts.
New data has been incorporated to the database and system remains with a correct behaviour keeping the required precision.
The new buttons developed over Task 7.1 have been tested with successful results.
The ESI and EEI calculation have been tested on the offline test environment with industrial sample data.

Task 8.2: Evaluation of the reached results

The tools implemented at the different industrial sites offer new insights in the relation of processes and products to the energy used to execute the processes and to manufacture the products. These relations and deducted results have been investigated by the process experts of the plants.
A general evaluation of the concepts, the approaches and the tools is given below in chapter 5, Task 8.2, Evaluation of the reached results.

Task 8.3: Tuning of the system, if necessary

The system was already completed and no tuning was expected to be necessary. However, all steel manufacturers, including AME, are continuously developing new products to fulfil the market needs so new steel products are arising at BOF. Therefore, some maintenance is expected to accommodate the evolution of the BOF´s product mix.
During this task, new steel products and grades produced at Avilés BOF were being assessed in order to incorporate them into the EIAS keeping the same philosophy presented over the previous tasks. However, it had to be noticed that the reliability of this analysis depended on reaching a minimum amount of heats to each assessed product, so new products were not be included into the EIAS until reaching a minimum number 500 heats.
Moreover, UNIOVI and AME were working co-ordinately to find new ways to ease the tuning process when changes in production processes and/or the product mix occur, so AME production experts would be able to perform the EIAS maintenance without UNIOVI experts' intervention.

At AMEH hot rolling plant the acquisition of energy data and its assignment to process data was established finally by procedures in the script language PL/SQL which is an integral part of the Oracle database system. This allows the fast access to data in the AMEH's IT environment which is build-up of many databases at the different plant locations. Additionally the use of PL/SQL is the fasted solution to handling and assigning data. So all developed functions which are related to the acquisition, the administration, compilation and aggregation of data was implemented finally in PL/SQL to achieve highest processing speeds for that tasks.

In case of the developments of CSM and DA, the tuning was already done during the discussion with production experts when the comparison between L2 and EnergyDB calculated data has been performed leading to several correction during that phase.

Task 8.4: Evaluation of the transferability

Definitions made in the project for the categorisation of different energy types and the approaches defined and implemented at the different sites seems to be of general validity. Adaptations of approaches are necessary when transferring them to other systems or plants, but that is a normal fact when developing new systems for long-growing IT environments.
The ESI and EEI calculation has been developed in such a way that it is very easy to insert them in new Danieli Automation industrial systems if the final customer is interested in the developed functionality. Some tuning up may be necessary depending on the specificity of the customer plant layout and available processes.

Task 8.5: Final report and presentation

The draft final report was prepared with a delay and presented at the TGS9 meeting in May, 2019 in Duisburg, Germany.

2 SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE RESULTS

2.1 Objectives of the project

The overall aim of this project was the reduction of energy consumption of the complete steel production process chain by means of the construction of factory-wide energy databases, its connection to process and plant variables and the development of evaluation tools with user-friendly interfaces for querying, analysing and providing possible solutions in order to improve the global energy efficiency.

In detail the following sub-objectives were defined initially and pursued in the course of the project:

- Design of a factory-wide energy database with intermediate and final products as references
- Development of solutions/models for the correct assignment of energy consumption to intermediate and final products
- Connection of this energy database to existing product and process databases
- Development of a semantic model for the energy consumption of the different process steps related to the product.

Based on the results of the sub-objectives different industrial cases were used to proof the benefit of this new approach of energy data handling and its combination with process data to perform an energy information and analysis system:

- By application of advanced data exploration algorithms in combination with reasoning on the semantic model detailed cause&effect analysis of energy consumption deviations with relation to material classes, production procedures and other process conditions will be performed to find energy leaks and increase energy efficiency.
- By application of the energy information system to assess each single process step under environmental aspects it will be possible to create a system capable to propose best possible production routes with reference to energy efficiency.
- The information prepared will be used for benchmarking between different factories/facilities, providing standard values which can be used for the European steel companies to determine its efficiency for every specific product.
- The energy information system will be applied to the fault preventions and for the identification of possible solutions for energy consumption reduction.
- The energy consumption efficiency indexes calculated in the energy information system will be used as KPIs within Planning and Scheduling modules to compare different planning/scheduling scenarios.

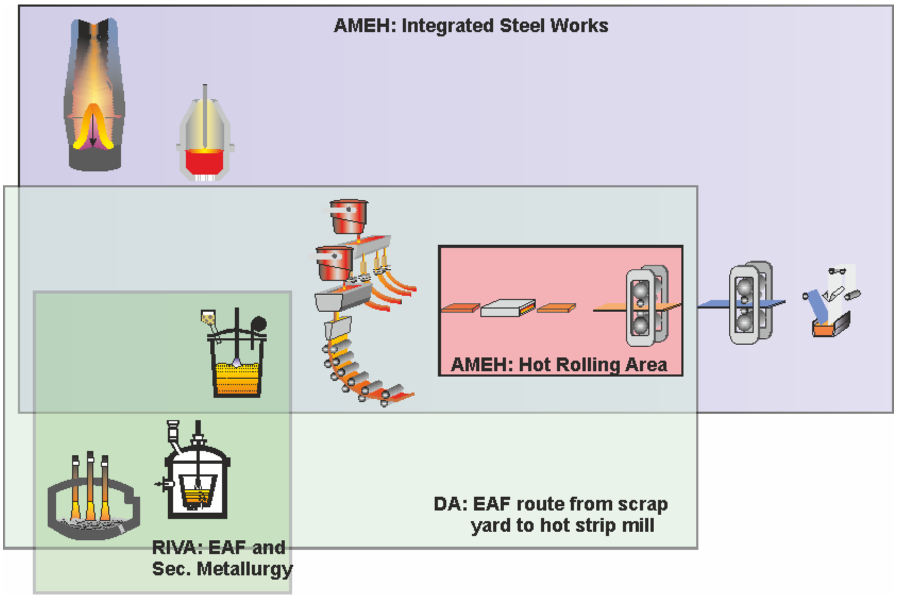


Figure 2.1: Sketch of the application cases and the related industrial partners

The industrial applications of the EIAS within this project reflect different stages and resolution levels of steel production:

- AME's investigations were related to the factory-wide consideration of energy use.
- At AMEH the focus was put on the hot rolling area including reheating furnaces (walking beam type), the hot rolling mill itself, the strip cooling facilities and the related auxiliary processes.

- The activities of CSM and DA focussed on the EAF route. In particular, for the preliminary analysis, all energy consumptions of the EAF route machines from scrap yard to hot strip mill were considered.
- Riva payed its attention on the process parts that concern the production of vacuum degassed steel.

From a methodological view, the EIAS includde procedures

- to analyse the relations of used energy quantities to process, plant and product data,
- to calculate energy efficiency indexes for further use as KPI,
- to suggest best production routes regarding energy efficiency and environmental aspects,
- to develop a semantic model describing the energetic relations of different production steps and inserting the experts' knowledge about this topic for computational processing.

These different applications and different aimed procedures resulted in different resolution levels of energy information to be observed, and to different but complementary approaches how to process data and information.
E.g. at AMEH the energy data was observed on a small time base (sample rate of seconds) to reflect the fast rolling process of single coils, whereas at RIVA the focus was set to single melts. AME's aimed to optimise the process routing in the steel works. i.e. to look at the specific energy use of single plants. So the found solutions were not representing one procedure for all tasks which is analysing data at highest sample rates at the highest imaginable resolution, but solutions tailored to the needs of the specific application and the related objectives.
Where necessary special constraints, e.g. for the assignment of used energy amounts during idle times, were considered by simple approaches like averaging and assigning on a per-weight basis. The design of EIAS should allow the later extension of the system if such simplifications were showing important drawbacks.

2.2 Description of activities and discussion

2.2.1 WP1: Requirement Analysis and System Specification

Because in WP 1 the initial actions to collect use case requirements and to define the target specifications were executed, the activities are described in detail.

At the industrial sites deeper reviews were done to answer individually the main questions “What is needed to develop an Energy Information and Analysis System (EIAS)?”, “What shall be achieved by the system?” and “What has to be done to meet the requirements of an EIAS?”

Hence, at **ArcelorMittal Spain** (AME) a working group has been created in order to assess the initial situation and to determine the boundary conditions which have an influence into the project. The group included staff from all the relevant departments (R&D, Energy, Production, Production Planning and Quality) as well as experts from the research partner **UniOvi**. The demands to the target system to be developed during the project differed due to the different point of view of the experts located at different positions of the production chain.
Once the available information was identified (see Task 1.2) and the current handling of this information was investigated (see Task 1.3), the group began to work in the definition of the requirements which will be the basis for the common target specifications of the aimed system (Task 1.4).

At **Betriebsforschungsinstitut** (BFI) and **ArcelorMittal Eisenhüttenstadt** (AMEH) the investigations in the available energy consumption and process/plant data were investigated and first definitions for a preliminary data base installation were implemented. At this early stage, members of the Energy Department, the Process Data IT Department and representatives of the external energy supply company, which controls the energy data acquisition systems at AMEH, were working together.

At **RIVA** the analysis of the existing systems at RIVA has been carried out by members of the Process measuring and Control Technology Department, supported by their subcontractor **Scuola Superiore di Santa Anna** (SSSA). They paid their attention to those process parts related to the production of vacuum degassed steel.

Centro Sviluppo Materiali (CSM) and **Danieli Automation** (DA) started their investigations by the preliminary analysis of all energy consumptions of the EAF route from scrap yard to hot strip mill.

Task 1.1: Requirement analysis

This task was dedicated to the definition of general and individual requirements related to the implementation of a factory-wide energy data base and of the Energy Information and Analysis System (EIAS).

Main questions which had been investigated were:

- Which parts of production must be considered for the aimed task at the aimed application?
- Which data concerning energy use have to be considered and how are they/can they be observed?
- Which existing data bases must be used and evaluated for those applications?
- How can energy data be collected and transformed to fulfil the needs of the desired objective?
- Which interfaces are existing, and which have to be developed for the project?

Concerning the different application cases the following targets were defined.

- The factory-wide consideration of energy use for production routing optimisation
- The relationship analysis between energy inputs and process conditions at a hot rolling area including reheating furnaces
- The analysis and semantic modelling of the energy use at a EAF route based production line from scrap yard to hot strip mill and
- The steel grade specific analysis and optimisation at the production of vacuum degassed steel.

As a conclusion arisen from the discussion about these questions the requirements for the Energy Information and Analysis System (EIAS) were defined as listed below.

- The system must be modular and scalable allowing to extend its functionalities through future iterations.
- Both EIAS and the energy data bases must be designed to be capable of being integrated into existent systems in the plant (brown-field application).
- Information must be accessible from different levels of the automation system (level 2 and level 3) and for different users.

- Interfaces must be user-friendly. This way, final users should not require intensive training.
- The system must be failure-tolerant, thus some degree of robustness is required.
- Information to be included in the new data base must be consistent. It is preferred to have few but reliable data than a huge amount of inconsistent data. Therefore validity checks of data shall be integrated.
- New systems must fulfil the current standards of internal security (user control, backup policies, etc.), but also it must be protected against external unauthorised access and attacks.
- Final system should have minimum requirements for maintenance.

Task 1.2: Determination of the available process and energy consumption data

At the industrial involve sites a comprehensive study was executed to collect information the available process and energy data.

ArcelorMittal Asturias (Spain, AME) is a fully integrated steelworks which produces a great variety of products (tinplate, galvanised, rail, heavy plate, wire rod, etc.) as it is shown in Figure 2.2.

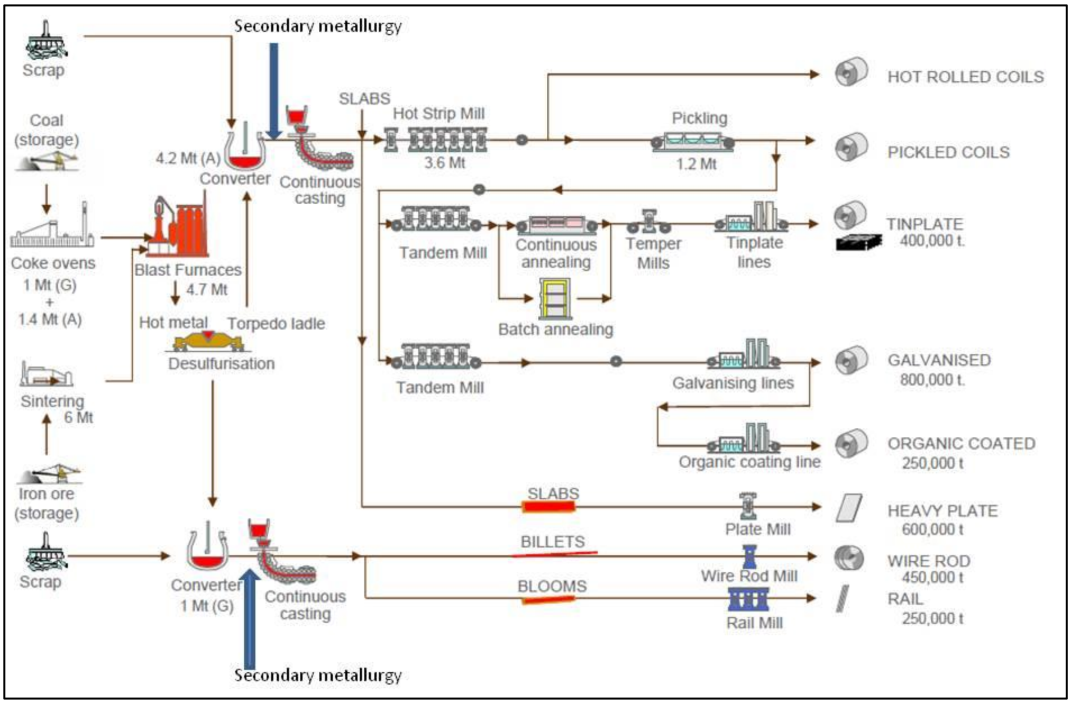


Figure 2.2: Production process in Asturias factories (ArcelorMittal Spain)

The secondary metallurgy process route was depicted separately because of its complexity and of its importance for the production of high-quality steel.
Main objective was to deliver the aimed chemical analysis, with the required cleanliness level at good temperature and controlled flow to ensure casting sequence and quality issues. As a consequence, this process is focused on:

- Steel composition adjustment
- Removal of some elements such as O, C, H or S.
- Control of non-metallic inclusions (quality composition).

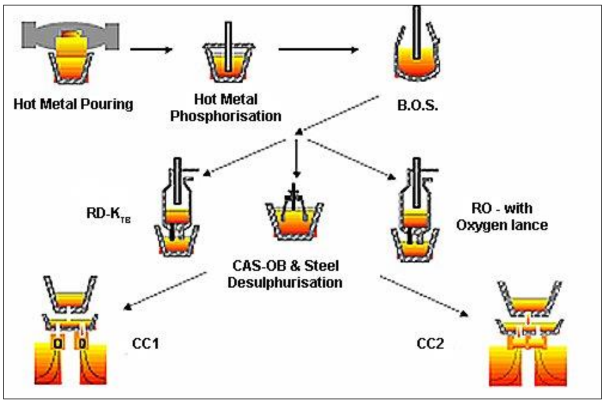


Figure 2.3: Secondary metallurgy layout

There are different production routes in function of the process and quality product issues:

- Secondary metallurgy with or without heating facilities: Ladle furnace- Aluminothermy.
- Ladle metallurgy atmosphere pressure: basic tools as trimming station or CAS and desulphurization: STAD, IRUT (metal/ slag reaction).
- Ladle metallurgy under vacuum: RH, VTD for carbon steel and VOD or VAD for stainless alloyed steel.

Every facility of the production chain has its own data base to gather all the process and product data. Moreover, there exists a global data base which integrates all this information in a piece-related basis. This way, the traceability of the products across all the production steps is guaranteed. Unfortunately, few energy consumption data could be found in this data base and, in most cases, this information was not directly assigned to the final product. For instance, for a given coil, information regarding its processing in the steel shop was available, but obviously on a per heat basis, so the amount of oxygen which was blown in the converter to produce that heat was known, but not the amount of oxygen that could be directly assigned to the production of that specific coil (as several coils are produced from the same heat).
Energy information was mainly recorded in a time-related basis and the accessibility to that information was not easy as data were not often gathered in data bases but only used for billing purposes.

In Table 2.1 an overview of the main energy sources and their main uses within the integrated process is given.

Table 2.1: Overview of the main energy types at ArcelorMittal Asturias

Energy source	Unit	Main consumers	Sample Rate
Coking coal	ton	Coke oven	In every battery charge
Pulverized coal	ton	Blast furnace	In every storage tank charge, then injected in N2 stream which is also measured
Electricity	MWh	Hot rolling Cold rolling Steel shop Auxiliary equipment Blast furnace (electric blowers)	1 minute
Natural gas	Km^3N	Hot strip mill Galvanising line	1 minute
Steam	ton	Coke oven Pickling line Continuous annealing	1 minute
Oxygen	Km^3N	Blast furnace BOF Other internal consumptions	1 minute
Propane	kg	Continuous casting Blast furnace	1 minute
Argon	km^3N	Secondary metallurgy Steel shop	1 minute
Nitrogen	km^3N	Blast furnace Secondary metallurgy Steel shop	1 minute
COG (coke oven gas)	Km^3N	Coke oven Reheating furnaces	1 minute
BOG (basic oxygen furnace gas)	Km^3N	Steel shop Sold to power plant	1 minute
BFG (blast furnace gas)	Km^3N	Blast furnace Coke oven	1 minute

It had to be taken into account, that some of these energy carriers (process gases and steam) were generated during the process and then used in other parts of the factory. As an example, coke oven gas is produced in the coke ovens and then used in several subsequent processes (see Figure 2.4).

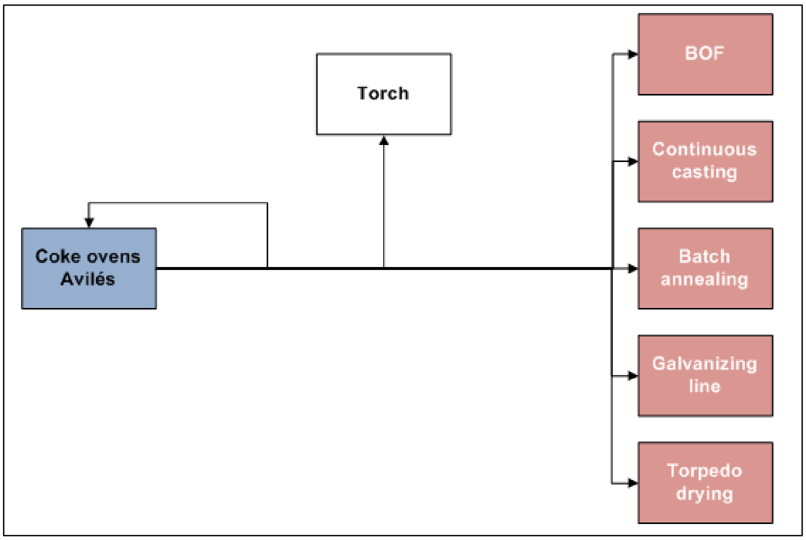


Figure 2.4: Coke oven gas flow across Avilés factory

At that time, at ArcelorMittal Spain the energy information was mainly analysed from a time-related point of view. Reports were generated to analyse energy use in a determined period of time (usually per month) and only average values per produced tons were provided. Moreover, not all the information was recorded with the same frequency depending of the measurement devices. Therefore, at this moment, it was impossible to exactly determine the amount of energy used in the manufacturing of a specific final product.

Several Life Cycle Inventories (LCI) were consulted by UniOvi in order to compare their values with the energy consumption of industrial partners. Such inventories compiled all relevant quantitative information addressed to perform environmental impact assessments. Given the importance of energy consumption to environmental evaluation, they usually included information regarding the energy and sources of energy used to produce a particular product or perform a particular service. The standard LCI databases consulted over this term were:

- EcoInvent, developed by the Swiss Centre for Life Cycle Inventories. Energy consumptions of this database are calculated mainly based on data from IPPC reports.
- World Steel, whose primary data is collected from World Steel member companies.
- GaBi database, compiled by PE International that supplements the previous data bases with regionalized inventories.
- ELCD database, compiled by the European Platform on Life Cycle Assessment from a wide range of sources.

Moreover, information provided by the BREF's (Best available techniques REFerence documents) had been also compiled. A BREF is a BAT Reference Document and is the result of the exchange of information for the guidance of decision makers involved in the implementation of the IPPC Directive (see [2]). Specifically, there were three main BREF documents which include useful information about energy consumption in iron making and steelmaking:

- Best Available Techniques (BAT) Reference Document for Iron and Steel Production, which covers the processes involved in the production of iron and steel in an integrated works as well as the production of steel in electric arc furnace steelworks [3]
- Best Available Techniques (BAT) Reference Document for Ferrous Metals Processing Industry, which includes activities for the processing of semi-finished products (i.e. ingots, slabs, blooms and billets) obtained from ingot casting or continuous casting, like hot rolling, cold rolling, drawing, hot dip metal coating and the related pre- and post- treatment of the shaped steel [4]
- Best Available Techniques (BAT) Reference Document for Energy Efficiency. This document addresses energy efficiency improvement in industrial installations by giving generic guidance on how to approach, assess, implement and deal with energy efficiency related issues along with corresponding permit and supervising procedures [5].

On the other hand, it is a fact that the energy used to produce liquid steel in today's integrated and electric arc furnace (EAF) facilities is significantly higher than the theoretical minimum energy requirements. To give insight into the theoretical and practical potentials for reducing steelmaking energy requirements, UniOvi had also compiled theoretical studies as the one described in [6] which presents the absolute minimum energy required to produce steel from ore and mixtures of scrap and scrap alternatives.

All this information (LCI, BREF and theoretical studies) provides standard values which can be used for the companies to determine their efficiency for every specific product and every step of the production chain.

The situation of energy data acquisition was analysed at **ArcelorMittal Eisenhuettenstadt** (AMEH) for the hot rolling area. This included the reheating furnaces (walking beam type), the edging and roughing stand, an interposed coilbox, the hot rolling mill itself, the strip cooling facilities and the coiling device. For all these aggregates and related auxiliary processes, the available electric energy data were examined and their synchronisation to process parameters was realised.

The energy data used for this project were collected by an external company: VEO (Vulkan Energiewirtschaft Oderbrücke GmbH), a supplier of electric energy and service provider. VEO is commissioned by AMEH for the energy supply and the billing of delivered energy. For these purposes VEO operates an energy data acquisition system at AMEH.

The following Table 2.2 shows a condensed list of the available energy data in the hot rolling area of AMEH.

Table 2.2: Energy data available at AMEH's hot rolling area

Energy source	**Unit**	**Main *consumers***
Electricity	kWh	hot rolling works ventilation cranes walking beam furnace roller tables combustion air fan auxiliary drives roughing mill drives edger drives roller tables auxDrives hot rolling mill drives stand F1-F5 descaler pumps cooling facility pumps roller table coil box auxiliary drives roller tables furnace coiler drives coil transportation water supply and distribution
Natural gas (NG)	Nm^3/h	walking beam furnace

These data were available on a per-minute-base (gas) or by change telegrams (electric current and voltages: a new value is sent to the acquisition system only if its difference to the preceding value exceeds defined threshold).
The change telegram data included more than 50 different measurements. One main problem were the not-equidistant sample times of these measurements, because a measurement was inserted into the database when the new value differed from the previous one by predefined tolerance bands. See Annex 4.1, Guidelines for structure of energy databases, for a detailed description.

Process data related to the single products, slabs and coils, are stored in a central database. The next table lists exemplarily some of the piece related process data available at AMEH.

Table 2.3: Process data available at AMEH (excerpt)

e/Description	Unit	sample rate
StripID	number	per piece
MatID	code	
Slab Geometry (length/width/thickness)	mm	
TimeFurnace Charging/Dropout	date/time	
TimeStartRM (Reverse Mill)	date/time	
TimeStart Rolling Stand F1	date/time	
RMPasses (Reverse Mill)	#	
Coil geometry	mm/m	
Duration Rolling RM	s	
Duration Rolling Stand F1	s	
Temperatures slab (WBF in/out)	°C	
Temperatures coil	°C	

CSM and DA analysed in this task the data available in the Supervision and Execution layers (Level 2 and Level 3). Electric energy and chemical energy supplied via Methane and Oxygen have been considered, because they are the main sources of energy in a typical melt shop.
For the Scrap Yard (SY), the Electric Arc Furnace (EAF) and the Ladle Furnace (LF) some energy use data were available in Level 2 process databases. For the remaining machines in the EAF route, energy use data were stored in Level 3 databases on a time basis (every 10-15 minutes). In Level 2 DBs the start date and ending date and clock time for each intermediate product (slab, coil) were stored and used to create the link with the energy consumption data. In practice the data in the DB were triggered and roughly synchronized by means of such information.

Data coming from process databases (L2) were well suited to be combined with energy use recorded on a time basis, because of the numerous timestamps in process data, filed at the entrance and exit of the various machines. It was very important for this purpose to guarantee that all the systems (namely L2 management and Energy Management System EMS) were timely synchronized and aligned.
In case of a failure of the automatic recording system for systematic plant consumption monitoring, the energy monitoring should be done manually by responsible personnel recording energy use associated to the main machines once a month. They could read meters located upstream of the various process areas and could assign these data to final products. Because this procedure was not delivering very accurate measurements, the allocation of energy use based on consumption data measured with sufficient temporal resolution (10-15 minutes or less) to allow an appropriate allocation based on data from Level 2.

The following table shows the data registered in Level 2 and L3 systems that are taken into consideration for KPI evaluation.

CSM and DA analysis was based on data retrieved in a steel making plant. The data sample included the listed data (see Table 5.4) collected for a time period of about 2 and a half months and contained around data samples of the whole production chain considered with more than 20000 final products.

Table 2.4: Available process and energy data at DA systems

Name/Description	Unit	*Place*	sample rate
Hot heel weight	Kg	*EAF Available data L2*	per heat
Injected fuel	Nm3		
Injected O2	Nm3		
Injected C	Kg		
Tapped weight	Kg		
Start date	UTC		
Stop date	UTC		
Practice			
Steel grade			
El. Energy	kWh	*EAF Available data on EMS*	10-15 min
Electric energy input	kWh	*LF Available data L2*	per heat
Start date	UTC		
Stop date	UTC		
Steel grade			
El. Energy	kWh	*LF Available data on EMS*	10-15 min
Vacuum time	s	VD *Available data L2*	per heat
Start date	UTC		
Stop date	UTC		
Steel grade			
Fuel CH4 (Steam generator)	Nm3	*VD Available data on EMS*	10-15 min
Tundish preheat time	s	CCM *Available data L2*	per casting sequence
Ladle arrival date	UTC		per casting
Ladle opening date	UTC		
Ladle close date	UTC		
Tundish weight at ladle opening	kg		
Average casting speed	m/s		
Slab Length	m		per semi-product
Slab Width	mm		
Slab Thickness	mm		
Slab Weight	kg		
Steel grade			
Slab Width	mm		
Creation Date	UTC		
El. Energy	kWh	CCM *Available data on EMS*	10-15 min
Fuel CH4	Nm3		
O2	Nm3		
Time in furnace	s	RHF *Available data L2*	per semi-product
Charging date	UTC		
Discharging date	UTC		
Fuel CH4	Nm3	RHF *Available data on EMS*	10-15 min
Rolling start date	UTC	RM *Available data L2*	per semi-product
Rolling stop date	UTC		
Target weight	kg		
Measured weight	kg		
Measured length	m		
Entry thickness	mm		
Entry width	mm		
Exit thickness/Target thickness	mm		
Exit width/Target width	mm		
Rolling time	s		
Set rolling power	KW		
Steel grade			
El. Energy	kWh	RM *Available data on EMS*	10-15 min

Riva Caronno's plant layout is represented in Figure 2.5. The boundaries of the system included scrap melting phase in the EAF station, refining and secondary metallurgy in LF station, degassing in VD station and continuous casting square 200 mm section, considering consumption of auxiliaries such as natural gas for preheating of ladles and tundishes.

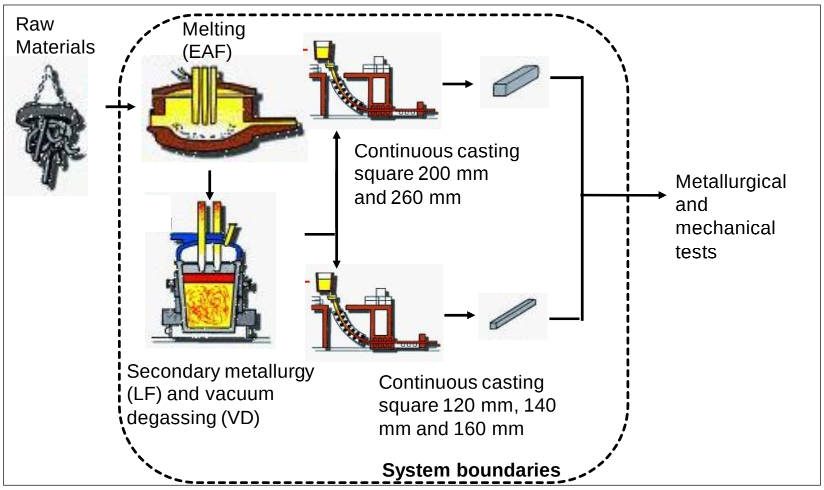


Figure 2.5: System boundaries of the considered EAF process at RIVA.

Table 2.5 lists the data of interest in the frame of the project that were available on Level2 system of Riva's steel plant and that covered all production stages (EAF-LF-VD-CCM).

Table 2.5: Available process and energy data at RIVA

Process stage	Parameter	Unit
ALL	Heat number	
ALL	Steel grade	
ALL	Date of production	
EAF	Tap-to-tap	Min
EAF	Power On/Power Off	Min
EAF	Mean voltage for each phase of the EAF electrodes	V
EAF	Mean current for each phase of the EAF electrodes	kA
EAF	Primary and secondary voltage and current	V, kA
EAF	Active and reactive EAF avg. power	MW, MVAr
EAF	Total electric energy consumption	MW
EAF	Composition of the basket (scrap type, pig iron, fluxes)	T
EAF	Fuel	Nm^3
EAF	Liquid steel	T
EAF	Ferroalloys and deoxidizers added	kg
EAF	Temperature	°C
EAF	Oxygen	Nm^3
LF	Time	Min
LF	Total electric energy consumption	MW
LF	Ferroalloys and deoxidizers added	kg
LF	Temperature	°C
LF	Argon	Nm^3
VD	Vacuum time	Min
VD	Vacuum pressure	mbar
VD	Temperature	°C
VD	Argon	Nm3
VD	Ferroalloys and deoxidizers added	kg
CCM	Time	Min
CCM	Position in a continuous casting sequence	
CCM	Electric energy	MW

Task 1.3: Detailed reporting of the handling of energy consumption information

In order to get a right interpretation of all the gathered data described in task 1.2, UniOvi and ArcelorMittal Spain had investigated the current handling of the energy consumption data in the factories of the steel producer.

It is obvious that energy is a key cost factor for any steel producer. ArcelorMittal Spain had special contracts with several energy providers and energy consumptions had to be recorded in detail for billing purposes.
For instance, oxygen is bought from Praxair. In this case, AME has an oxygen flat rate until a fixed a fix quantity of oxygen (by contract). If this volume is consumed, the extra oxygen must to be paid according a contract price but per cubic meter.
In the case of electricity, ArcelorMittal as a high voltage consumer, is attached to the so-called "in-terrupt ability rate", a special price enjoyed by some large industrial consumers in exchange for assuming the risk that they may experience power cuts. In order to compensate for this possible situation, ArcelorMittal obtain benefits from electric system operator, "Red Eléctrica Española", who is in charge of electric system. Electricity market is influenced by many factors (renewable energy, weather, day/night, etc.). As a consequence, electricity price changes a lot from 0 €/MWh to 80 €/MWh. Market is based on auctions for each hour following marginal pricing model. Agents make bids for different energy amount and for each time period. As reflects Figure 2.6, electricity price changes significantly along a normal day.

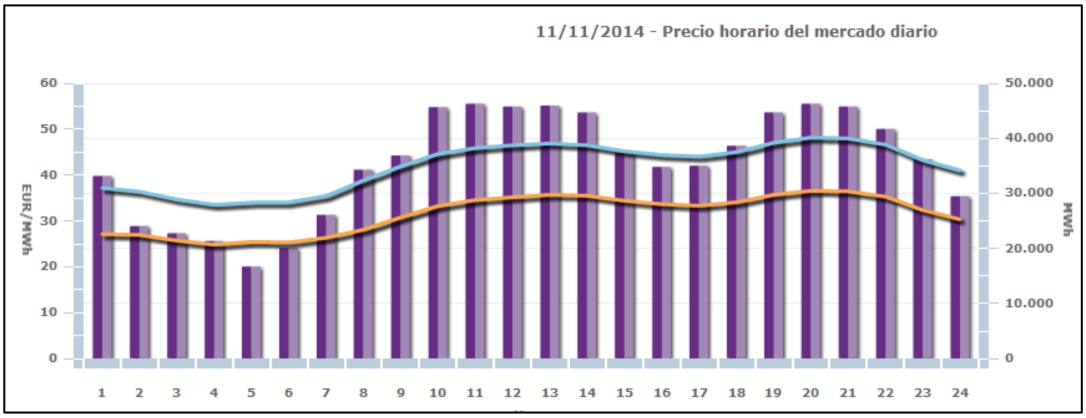


Figure 2.6: Hourly electricity price on a November's day

With a price range between 20 and 55 € per kWh during one day one can see the importance of an optimised energy management for the company.

Special attention was also paid to the gases which are produced during the steelmaking process. These gases are important energy carriers due to their high calorific power. Not all the gas is used inside the factory. A part of it is sold to the electricity producer "EDP Energía", which burns these gases in two different power plants. One of them, Sidergas, generates electricity and also steam, which is then sold back again to ArcelorMittal.
All the data related to energy consumption is managed by the Energy department which generates monthly reports about the energy balance of the factory. These reports include the monthly con-sumptions of every energy source broken down into the different sub processes. Not only energy consumptions are reported but also internal energy production (process gases and steam).
This information about energy has mainly two usages:

- To calculate KPIs (Key Performance Indicators) of the global process or of any subprocess (e.g. Nm^3 of O_2 per tonne of hot metal is a KPI of the steel shop).
- To estimate future demands and therefore to help in the energy supply management.

In case of CSM and DA, which are both not steel producers, an analysis of general contracts with electric energy providers was performed.

As seen for Spanish market, also in Italy, it is possible for large consumers to insert in the contract interruptible loads that are paid based on the result of an auction at the beginning of each year in which each company offers its available interruptible loads. The company is than paid based on the offered load and the number of the actual disconnections during the year.

Steel plants in Italy can access directly the Power Exchange market. The energy market in Italy is organized in a day-ahead spot market and an intra-day spot market. The energy on the day-ahead spot market is paid on an hour time slot and has the same price all over Italy, while in the intra-day spot market there can be two different prices for North and South Italy.

Instead of acting directly on the Power Exchange market, energy can also be bought by a supplier, at an agreed price defined according to specific consumption profiles or paying the energy at the day-ahead spot market price.
In any case, contracts with a supplier are in general less flexible than purchases on the Power Exchange.

The steel plant usually provides a forecast profile of electric energy usage for each hour of a day, normally one or two days before the utilization day. All the discrepancies from the planned demand in both directions imply fees or revenues depending on the concordance or discordance of the imbalance sign with the sign of the overall imbalance of the zone where the consumer is located (that is out of Steel plant control). This can lead to unforeseen additional production costs or revenues due to the higher or lower demand with respect to the forecast. In order to limit consequences, steel plants can dynamically rearrange the requested network power loads.

As the typical assessment of energy data across melt shop and continuous casting, CSM and DA found it to be done on a time base, conventionally on a per-month base.

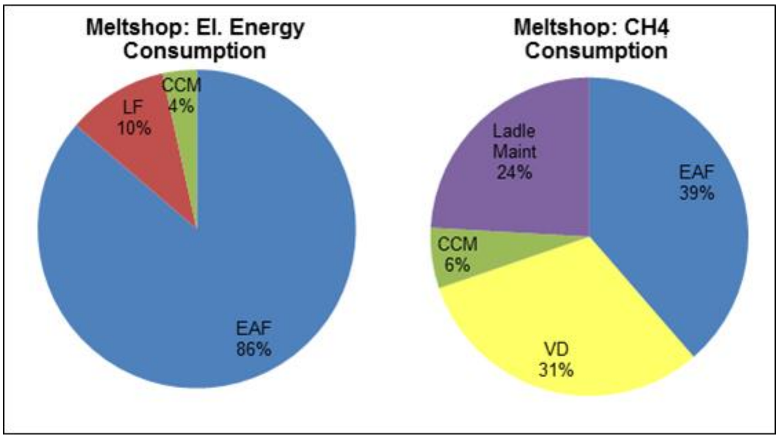


Figure 2.7: Electric energy and Methane consumption in a melt shop

Just this type of diagram was also typical for the assessment of energy use at AMEH and RIVA. These companies recorded the information about energy use only on medium time intervals (15/30 minutes), but the main application was to give an overview about the monthly/annual use of energy at different consumers. Neither time-related nor piece-related assignment of energy uses was evaluated till now. Typical diagrams of energy use at AMEH and RIVA on a per-year-relation are shown in the following figures.

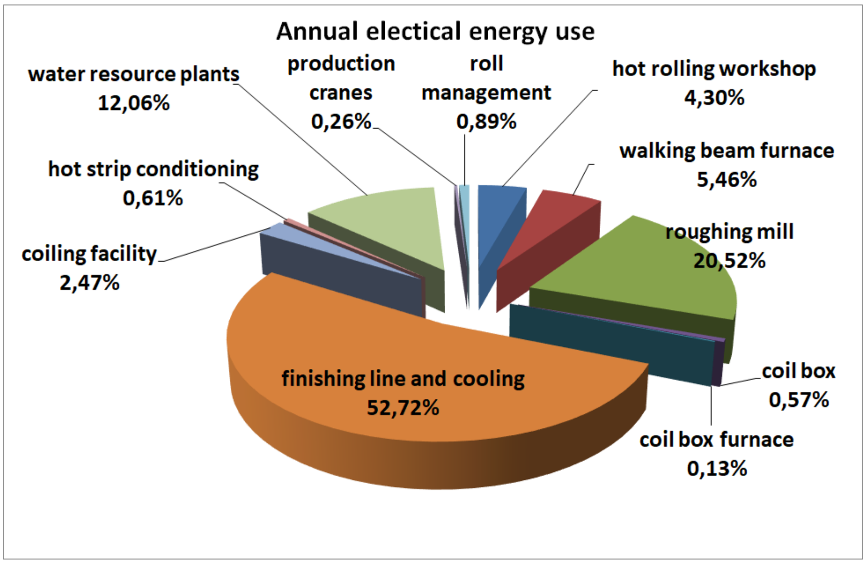


Figure 2.8: Annual electric energy use at AMEH's hot strip mill by main facilities

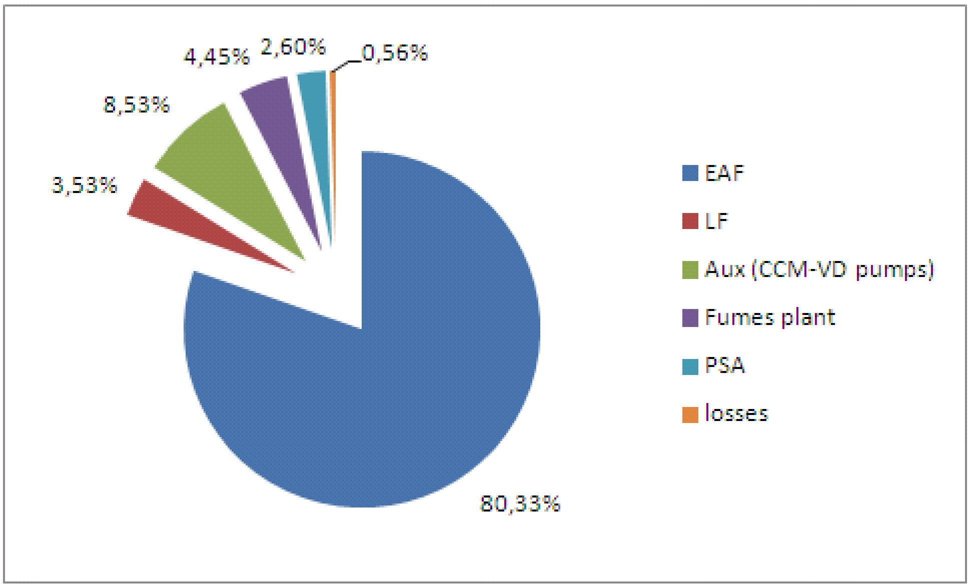


Figure 2.9: RIVA: typical annual electric energy use report
(PSA = Pressure Swing Adsorption technology for Oxygen production)

Task 1.4: Definition of the target specifications

For an Energy Information and Analysis System general specifications were defined after the investigations and definitions made in the previous tasks:

- The EIAS shall base on a web platform so access via internet will be enabled.
- Aimed modules to process the different main tasks (KPI calculation, piecewise analysis, processing route optimisation, etc) will be implemented by web services.
- The architecture has to be modular to allow easy integration of planned tasks and to enable extension to future requirements.
- Interface functions to get access to local data bases (energy and process) at the industrial sites have to developed as well as suitable and ergonomic user interfaces (HMI).
- Procedures to pre-process energy and/or process data have to established to enable special calculation (like KPI) or the preparation for extended analysis and evaluation (e.g. deviation analysis of energy use for similar products).
- To assure a high level of data integrity (robustness, failure tolerance, etc) adjusted approaches (like signal validity checks, simple soft sensor models for important data) have to be evaluated if necessary.
- Still in the design of the system security aspects (user access rights, protection against unauthorised access, etc) have to be considered.
- The design and implementation of the energy data base must respect the constraints coming from the brown-field implementation.
- For different tasks an offline test environment could be useful, it should enable the test and optimization of the EIAS outside a specific plant but using industrial data.

The use case DA and CSM worked on makes it necessary to consider different production planning and scheduling scenarios for analysis, described by proper KPIs defining their energy efficiency.
The specifications defined for the calculation and application of such KPI could be divided into two groups:
- Functional specs (or requirements), which define a specific behaviour of an application,
- Non-Functional specs (or requirements), which define the operational criteria of the applied solution

The following aspects had been taken into consideration from the functional point of view:
- Definition and implementation of KPI: two types of KPI had been identified, the first one that account for the energy necessary for the production of a specific product, the second one that will be used in the scheduling that account for the energy necessary for a group (family) of products in a specific process.
- Integration of KPI into Manufacturing Execution System (MES): the calculated KPI should be in a form that can be easily used by the MES for the valuation of a specific production planning from an energetic point of view.
- User Interface: specified the interaction with operators. The user needed a specific interface to set up the parameters for KPI calculation. The interface for KPI use will be integrated into the MES system adding the requested functionalities directly inside the MES GUI.

- Ontologies: specified the integration of ontologies in the system. The ontology was needed to uncouple the system with the specific plant helping in the deploying of the system.
- Integration with external databases: specified the integration of the EnergyDB system with L2 and L3 databases.
- Integration and synchronization with external systems: The EnergyDB system must be linked to several often existing systems working with different time scales: the production came from seconds to some minutes when available energy data were often sampled every 10 - 15 minutes; at higher level, for planning reasons, hours and days were needed. This led to the necessity to synchronize each phase.

From the Non-Functional point of view the following aspects had been taken into consideration:
- Performance: response time for KPI calculation
- Usability: ability to integrate new functions in the system
- Deployment and Commissioning: requirements on installation procedure
- Security: ability: The new system must fulfil the current standards of IT security (user access control, backup policies, etc.)
- Scalability: ability to handle a growing demand on work

2.2.2 WP 2: Concept development

Task 2.1: Detailed concept of the Energy Information, Analysis and Control System

A general concept of the EIAS was discussed between the partners and finally approved under consideration of the defined requirements and the target specifications and the aimed brown-field implementation. i.e. the integration of the system in existing measurement and automation systems as well as into heterogeneous data infrastructures. The following figure shows that general concept.

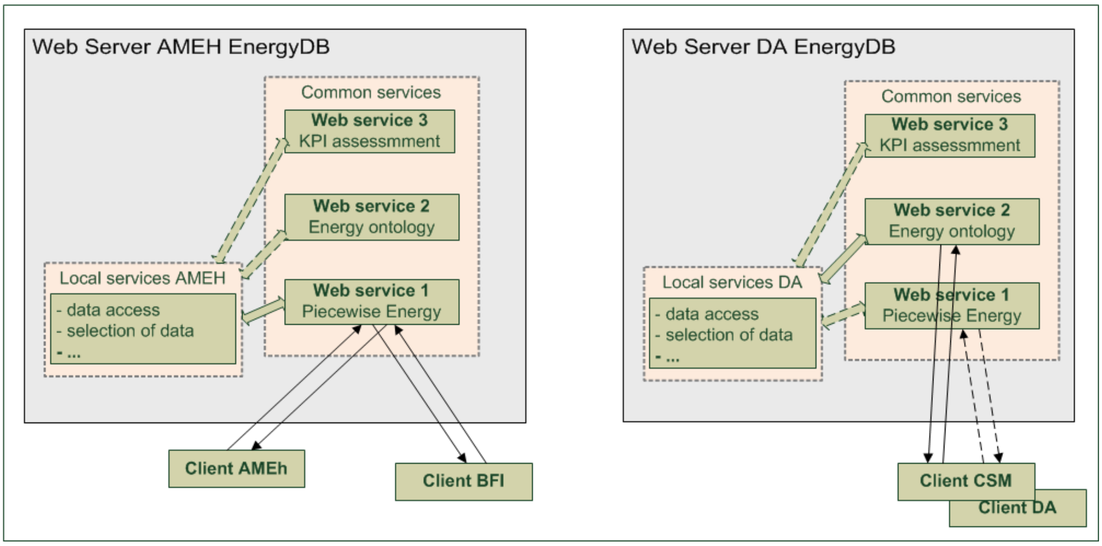


Figure 2.10: Concept of EIAS, exemplarily shown on two examples
(solid/dashed arrows: access to internal tools via intranet/access to external tools via internet)

The main conclusion of the discussions was to plan the EIAS as a web server architecture, i.e. the desired functionalities (data access, analysis modules, etc) are integrated into an intranet accessible platform. There are two main parts of foreseen in the web server architecture:
- Local Services realise the access to data.
- Common Services include the aimed EIAS functionalities.

The local services are different from one web server application to another. They depend on the locally existing IT infrastructures at the industrial sites and will benefit from existing tools and experiences for data access and selection.
The common services should be in accordance to agreed standards of software engineering (globally and agreed between the partners) to ensure their integration and simple updating into the EIAS.

This concept has the following advantages:
- Modules developed by the different partners are integrable into the web server. These "Common services" could be identical at all installed web servers, so everybody can use these services (if requested data/information exists locally).
- Access to local data bases will be established by "Local services", each adapted to the locally existing data bases and information sources. This ensures the brown-field implementation, reduces the data traffic on networks and improves the IT security.

- The development and maintenance of such Local Services is much more easier and cheaper than a globally energy data base solution, because existing knowledge of the experts at each company can be used, already existing tools can be applied easily to such a locally adapted data base, and the acceptance is much more higher because such an energy data base will be designed in accordance to the company's common guidelines of the existing process data bases.
- The planned web servers can be installed inside the company's intranet network. This will simplify the efforts for the necessary security of applications and data to avoid unauthorised access. This point was especially discussed against the background of internet security and cyber-attacks on production companies in the recent past.
- The existing rights' system to control user access to the different data sources can be used directly to control the user access to the EIAS: having no permission to read specific data or to write results of EIAS modules into a data base will disable automatically the related EIAS actions. Additionally the web platform and the services provide functionalities to limit user access and actions ("normal" user, administrator, etc).

By using standard programming platforms and languages like Java or C#/.net, and detailed descriptions of interfaces, module parameters and standardised HMIs (Human-Machine-Interface) the interoperability of the services is guaranteed.

The following sections of WP2 describe the approaches investigated for the different use cases of the industrial partners.

Task 2.2: Concept development for energy efficient production routing

The aim of this task was to develop an intelligent support system to evaluate the energy cost of every product as well as an optimisation tool to be implemented into the EIAS capable to find the most efficient production schedule or route when alternatives exist. The optimisation should consider several constrains such as minimising electric energy consumption, or minimising CO_2 emissions.

One possible solution considered to use Analytical Hierarchy Process (AHP) to perform the optimisation. This technique presents goals, constrains and a set of possible solutions in a hierarchical way to assist the decision process. However, in order to be fully reliable, AHP needs the opinion of a large number of experts on the field and currently there is no possibility to access to a significant number of them to fulfil this project, so the application of AHP application was withdrawn.

As an alternative solution a fit-to-purpose optimisation tool called EnergyDB was developed for this project. This tool is the particularization for this project of a modelling & simulation framework named ATOS that allows generating further modelling applications to particular situations. This framework has been previously proved in the steel industry as it was the base for the development of the decision support system of ICONSYS project ([7]).

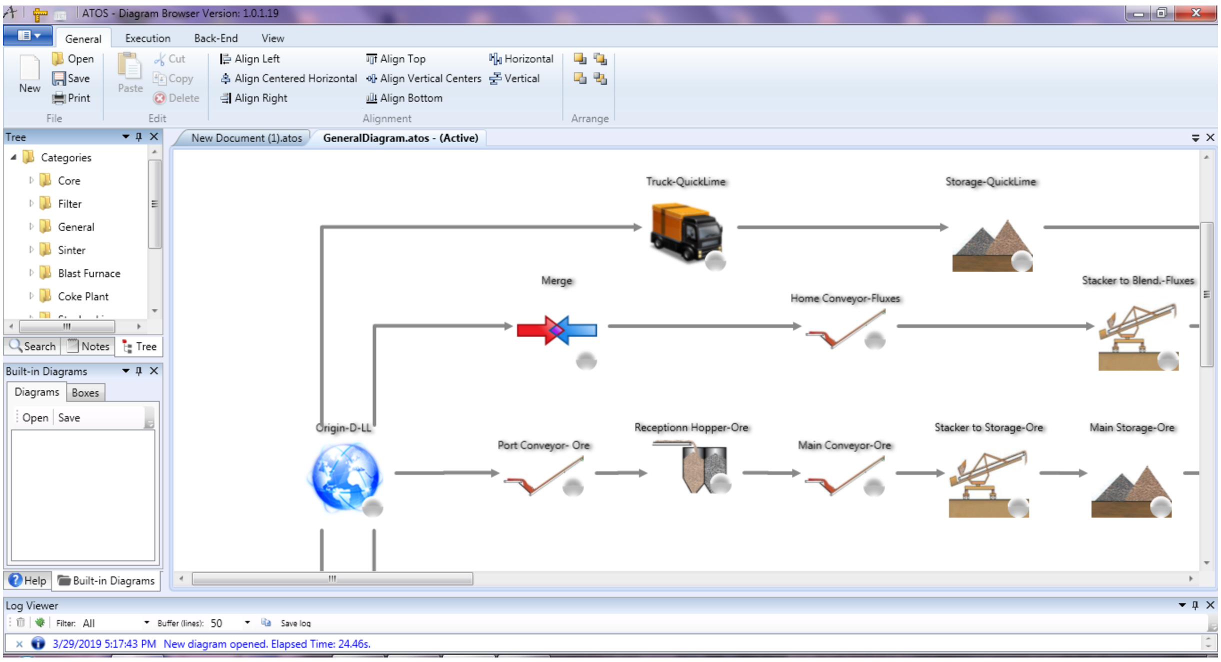


Figure 2.11: Visualisation of ATOS framework

The framework is indeed a windows-based programming tool where processes can be considered as functions implemented as boxes that contain one or several models running sequentially, providing the tool with simulation capabilities that allow users to perform what-if analysis. Its modular structure allows the environment to be easily upgradable with new processes, models and capabilities. Moreover, to perform the same estimation, different models can be implemented and can be selected by the user or the application would intelligently select the most reliable one regarding the available input data instead. In addition, the environment allows developing each of the capabilities required for global optimisations.
Each process is connected to the previous one by means of input data flows represented by arrows. Then, input data are used by the models included into the process and the results can be sent to the next process using another output data flow.

As this feed forward approach of the framework did not provide with the retrofit capabilities required to perform optimisations, EnergyDB tool was extended by a new complex feature, the loop capability that can iteratively execute diagrams until reaching the optimal solution.
This new feature represented a dramatic change from the original approach, where the Tree data structure forces to firstly execute all parent nodes to then sequentially execute their children nodes and so on. As a result, EnergyDB tool required a full set of new capabilities:

1. If-then-(else) capability to evaluate a condition that when true, the statements following the then are executed or otherwise, the execution continues executing the else statements.
2. Loop Diagram, that allows to create sub-diagrams inside a diagram that can be executed either n times (for execution) or as many times as needed to accomplish a particular condition (while execution).
3. Initializer to start the execution of one retrofitted box or a group of retro-fitted boxes
4. Custom execution order, a capability that will be developed to set in advance the execution order of a diagram or Loop Diagram.

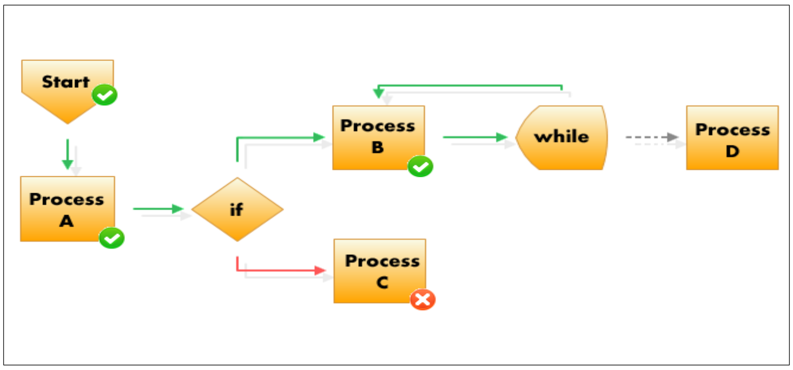


Figure 2.12: Flowchart of route optimisation concept

Task 2.3: Investigation of suitable ontologies about energy consumption

Main aim of this task was to investigate and discuss suitable ontologies for energy flows and use regarding their applicability and possible exploitation for the flat steel production.

When approaching knowledge formalization in the field of energy conservation, it is essential to consider existing works and standards in this domain, especially since the aim is motivated by industrial needs. Using ontologies, it is possible to structure knowledge in a manner that it can be read by both machines and humans. This allows automated and distributed processing and analysis of energy-related information.
Ontologies are proven to be a very efficient tool for knowledge structuring and exploitation. Through the definitions of concepts and relations, it is possible to describe the entire domain of interest, like in this case energy in steel manufacturing, in a detailed manner. Semantic enrichment opens a possibility for automatic reasoning and inference, which leads to automatic generation of new knowledge. Finally, an ontology can enable interoperability between different systems providing e.g. a common vocabulary. All these benefits are extremely important in case of large organizations, which are struggling with ever increasing amounts of data and facing problems of exchanging knowledge between different systems used at different company and plant levels.

These statements were the motivation for the analysis and discussion of the following described ontologies.

In the proceeding of Linnenberg et al. ([8]) a lightweight ontology (OntoENERGY) is described which allows for continuous handling of energy-efficiency issues in technical systems throughout their entire lifecycle. This conceptual approach was adopted as a basis for our purposes and further adapted and developed.

In the design and planning phase of products, simulation tools are today already used. These tools enable the most appropriate automation equipment to be selected and the optimal production process to be defined. Unfortunately, these tools are not fully integrated with the other functions in the automation systems, often for semantic reasons. To achieve this, a common understanding of data is necessary.
In fact, energy (management) systems and automation systems offer a wide range of perspectives and glossaries with a variety of interpretations when it comes to collecting the required energy-related information. An explicit definition of the terms common to these fields of application as well as the formalization of their correlations is therefore essential in order to facilitate a sound analysis and understanding of the energy efficiency of a given system design.

Although motivated by industrial needs in the field of automation systems in the manufacturing industry, OntoENERGY is applicable to any domain with the need for the evaluation of energy efficiency issues. Several basic decisions were made in order to achieve a clear and understandable hierarchy of the terminology according to the following reasons.

1. OntoENERGY should, insofar as possible, be usable as a single, small, stand-alone ontology without external dependencies, in order to be easily portable and integrable.
2. The distinction of the three main interpretations of energy (physical, industrial, and automation) should be retained. These are used to sub-classify the associated forms of energy. With their aid, tools can perform detailed energy analyses.
3. Emphasizing OntoENERGY's objective of supporting energy-efficiency analysis, the awareness of the quantity of energy dissipation is regarded in this context as the most important result of a system's energy efficiency evaluation. In OntoENERGY, it shall be classified as "non-productive consumption" of energy. This is due to the nature of energy dissipation, which stands for "consumption" of energy without increasing the value of the absorbing system.
4. Mathematical correlations are treated as terminological and modelled in the ontology in a way similar to that in SWEET ([9]), but in a compact and simplified form using explicitly defined roles.

The resulting hierarchy regarding OntoENERGY (see [8]) is shown in Figure 2.13.

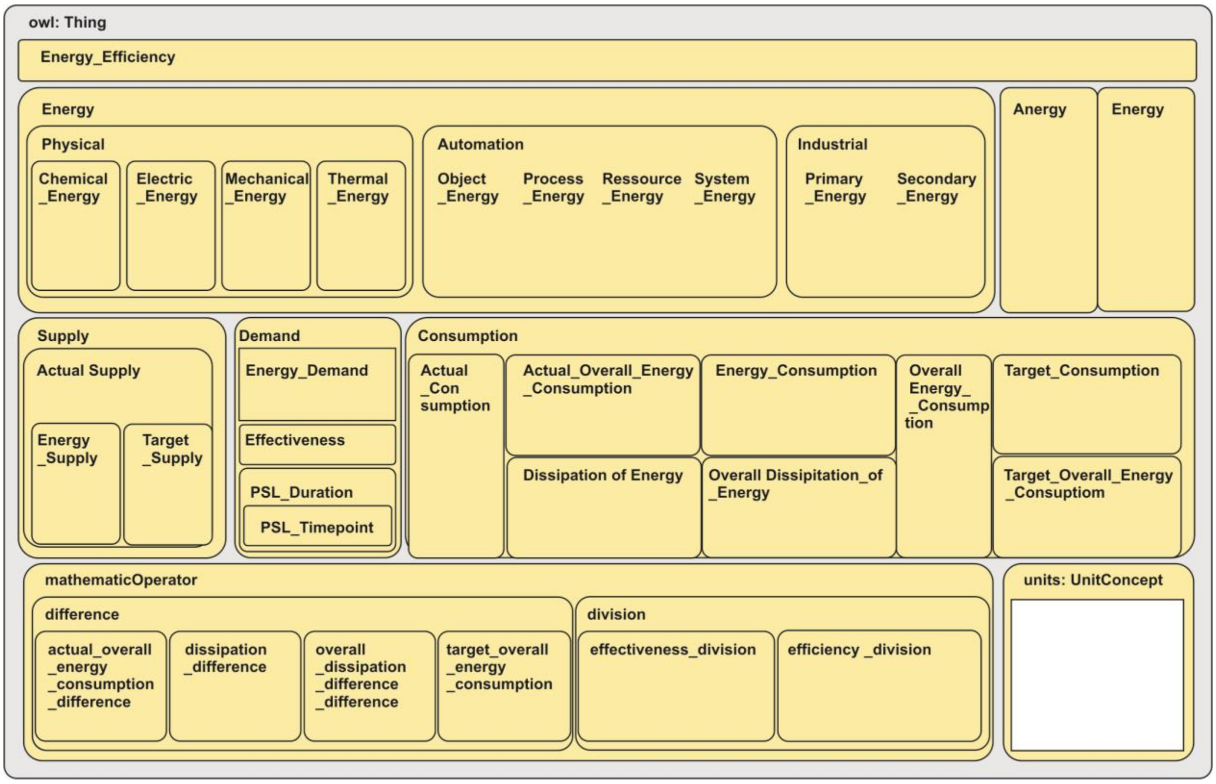


Figure 2.13: Hierarchy of OntoENERGY

The main objective of OntoENERGY is to define semantics of the fundamental physical quantities and their interrelations as found in the energy domain. OntoEnergy was initially developed to evaluate energy-efficiency of automated processes in order to identify related potential shortcomings and pitfalls already in the early plant engineering phase. We envision that it is applicable to any application or domain in which such energy analyses are needed.

In order to cover a wide spectrum of different domains, the following three goals were regarded as equally important:

- Applicability on factory automation machinery and its operation.
- Extensibility and upgradeability in subsequent usage scenarios.
- Portability and applicability to different domains or proprietary software tools.

For the EnergyDB project, OntoENERGY should act as a lightweight upper ontology on which applications or domain-specific ontologies can easily build. Furthermore, it must be easily integrable into various software tools, such as plant design tools or energy.

In the project e-SAVE (see [10]), an ontology was developed which defines semantically and syntactically concepts in the energy efficiency monitoring domain across the supply. Its aim was to define and present the implementation of an initial generic ontology that will model the supply chain from the energy efficiency perspective.
Scoped using the industrial partners' business requirements and the available literature in the area, the ontology was created with the intention to be a living model that will be extended as the project progresses and new concepts are discovered.
The main target of the e-SAVE ontology was to increase the energy efficiency across the supply chain, by merging the increased demand for energy with the need for environmental protection, thus ensuring a move towards a more sustainable energy future. The scope of the project extended the investigated supply chain from the final product in the supplier's facilities to the retailer's store, covering all the transportation activities in the Energy Consumption and Carbon Footprint context.
The key e-SAVE services to be provided in the supply chain were:

- Energy Consumption & Carbon Footprint Monitoring Service in the warehouse, the store and the transportation across the supply chain.
- Environmental Impact Assessment by using simulations to identify repercussions of possible changes in the supply chain.
- Collaborative Ordering & Distribution using environmental Vendor-Managed Inventory (VMI) for warehouse/store ordering.

Concerning the energy efficiency aspect of the requirements, the Smart Meters measure and monitor the energy consumption of the facilities and their sections and the vehicles' fuel consumption during the transportation of products. Every type of consumption is mapped and corresponded to a carbon footprint value, in order to extract the sum of all CO_2 emissions, which are induced by the supply chain activities over a given time frame.
Environmental and operation KPIs were used in order to indicate the success of an energy efficiency policy and the operational goals that were previously set.

In the work of Wang e.a. ([11]), ontology is defined as plant-wide definitions of tasks and services. An ontology base is used as a database for ontology models providing virtual physical devices with information about knowledge objects. Unless under the support of ontology bases, the device services of virtual physical devices could be described by semantic services. So far, energy resources have been considered complete semantic services that experience device linking in the physical layer, virtualization in the perception layer, service in the network layer, and ontology-based semantic description in the modelling layer.

Industrial IoTs for energy measurement requires a certain amount of domain ontology for knowledge preparation, especially under conditions of incomplete data and unobservable states. The lifecycle of an ontology design can be summarized as three major stages, i.e. building, manipulating and maintaining. In the building stage, requirements are first identified, including the purposes, scope, and requirements of ontology. Then, correlated data and information are collected about the concepts behind these requirements. The third step is to analyse the collected data and information. Based on the analysed ontology, the ontology can be filtered and input into an ontology base in the ontology implementation step. In the manipulating stage, the ontology and knowledge bases both are deployed to the knowledge sharing system, which receives legal access from users. A feedback loop exists between the knowledge base and the ontology base via both ontology analysis and ontology implementation.

Energy efficiency is a keyword that can be found nowadays in all domains in which energy demand exists. The steadily rising energy demand, the consequent energy scarcity and rising prices of energy resources are forcing companies and people to redefine their activities in a more energy efficient way. Besides industry and transportation, the building sector is the most important energy consumer, as a study for European countries.
There are many studies and result on the specific ontology but for our scope we inspected the industrial domain.

Task 2.4: Development of the energy consumption assignment concept

The energy needed to produce an intermediate or final product includes all the energy required from the earliest production stages until the attainment of the desired product. Final products could be assigned directly to single pieces when the result is a discrete entity (e.g. slab) or on length related basis (coil or plate). However, the continuous nature of liquid phases required energy consumption to be expressed on either volumetric or weight bases. Due the high temperatures required to achieve liquid phase of ferrous materials, temperature changes could result on density differences, so it is more convenient to refer energy use to liquid phases on a per ton basis.
In order to study the energy assignment of liquid phases into the Steelmaking process, the Basic Furnace Oxygen was selected as exemplary process as it is the last liquid product of the production chain (joint with the secondary metallurgy) and it has a larger influence on the final product quality than previous processes like the Blast Furnace.

Energy assignment from process to product must include:

- Process energy
- Services/auxiliary energy
- Machinery efficiency and its variation over time
- Planning and scheduling effects as "exotic heats"
- Material losses and reprocessing

That last factor adds the excess energy that was used to produce rejected products due under quality or reassignments, whose value has to be distributed over the whole production balance. Moreover, the differences on energy utilization due the use of different input materials like ores or flux have to be considered, so the energy consumption for liquid steel production cannot be assigned in isolation at the Basic Oxygen Furnace but must reflect the complete upstream production chain.
As a result, the following equation is proposed to be used as the basis for energy allocation to the liquid steel production at the Basic Oxygen Furnace:

$$E_{T,i} = \left(\sum_{k=1}^{i-1} E_n(k) + E_{a,i}(1+\alpha_i) + \frac{E_{Aux}}{\frac{M}{m_i}} \right)(1+\beta)$$

Where:

- E_T, total energy use
- E_n, previous processes energy
- E_a, energy used in current step
- E_{Aux}, auxiliary energy
- M, global production (mass)
- i, number of production step
- m_i, specific production at step i (mass)
- α_i, efficiency losses in current step
- β, global efficiency losses

For an analysis in order to evaluate the differences in rolling work when producing similar products at the hot rolling mill this equation was adapted was simplified to (and is limited to the hot rolling area)

$$E_{a,coil} = \sum_{k=1}^{l-1} E_{a'}(l) + E_{WBF} + E_{a',l} + \frac{E_{Aux}}{\frac{M'}{m_{Coil}}}$$

Where:

- $E_{a,Coil}$, total energy used for one coil (only hot rolling area)
- $E_{a'}$, energy used in step, includes losses
- $E_{WBF,Coil}$, energy for heating one coil
- E_{Aux}, auxiliary energy
- M', total production (mass) at hot rolling area, calculated as sum of slab masses
- l, number of aggregates in hot rolling mill (rougher, descaler, mill stands …)
- m_{Coil}, coil mass

Considering the intention of at hot rolling to calculate the energy costs of single products (coils) or to compare the used transformation energy of single coils related to specific features like material class or geometry, defined $E_{a,coil}$ includes all necessary information. Specific losses in current step (α_i) can be omitted because they are similar for production within a certain time interval (no consideration of wear). They are included into the energy measurements (e.g. drive currents) and thus are included in cost calculations or in comparison analyses. Global efficiency losses were omitted for the same reason.

E_n (energy amounts at previous production steps) is left out because the hot rolling area is seen as a closed system on the one hand. Energy transport from preceding production steps is included by the given temperature of the delivered slabs and is considered in the calculation of the needed slab heating energy.
E_{Aux} is calculated by energy values which cannot be related to single products or which don't contribute to the transformation of a product (e.g. idle times of rolling drives, transportation of coil). They can be assigned by an average value in an 8-hours-interval on a per-ton base to single coils.

A special problem is the handling of production scrap e.g. from hot rolled coils.
In case of a cost or total amount related analysis, energy efforts for the production of scrap have to be included into the calculation of the overall energy costs of intermediate and final products.
But in most cases the energy used for scrap "production" is automatically included when assembling the energy used during/for the production of one hot strip coil. Head and tail scrap will not change the total sum of used energy for this coil, only the relation between usable coil weight and the used production energy will become worse with increasing scrap appearance.
Also in the liquid phase of steel production such production scrap is not included into energetic calculations because the portion of included chemical energy resources is much more lower than in other scrap types.

2.2.3 WP 3: Design of the architecture of energy data base

Objectives of this work package were
- The design and development of methods for the (automatic) assignment of energy data to products/pieces (synchronisation to process data)
- The definition of strategies to assemble measured energy data
- The definition of enhancements for the energy data bases

Task 3.1: Adaptation of the methods for energy consumption assignment to intermediate and final products

As shown on the equation presented in the previous task, the assignment of the energy embedded in steel products needed to consider the energy consumed at the final process plus the energy that was used on the previous production stages to obtain the final or intermediate product.

As there wre no energy assignment models yet for all the processes included at the integrated steel production process, the energy assignment of liquid steel production was being modelled on two levels of detail:
Energy was assigned at the upstream stages to the Basic Oxygen Furnace (E_n) using average energy use data compiled and processed from the production data bases of each installation. Data from each process were proportionally aggregated by per-ton values of produced liquid steel at BOF.
On the other hand, energy assignment at a final production stage (or intermediate like the case of liquid steel) was performed specifically for each product (heat) as it represented a discrete entity with its own features different from the previous and next product (heats). However, the assignment still was done on a per ton basis in order to facilitate the aggregation of energy at other processes.
The energy assignment modelling should include 3 groups of energy usage:
Direct energy is the energy used directly for the liquid steel production like the electricity used at the converter or the chemical energy supplied by natural gas combustion. This kind of energy was easily assigned from the readings of consumption of:
- Coke Oven Gas
- Electricity
- Oxygen
- Steam
- Nitrogen
- Argon

Direct energy is represented in the basic equation of energy assignment as E_a, energy used in current step.
Indirect energy is the energy use required to maintain processes that cannot be directly assigned to a particular product. It includes the non-production times (e.g. waiting time between heats), the efficiency losses caused by process imperfections, the reheating of restarted batch processes, compensation of thermal losses due undesired intermediate product etc. This kind of energy not directly measured and is represented in the fundamental energy assignment equation as α_i, efficiency losses in current step.
Continuous energy is the energy used by auxiliary equipment (E_m) like air pressure compressors or not production related tasks like building lighting. This kind of energy is also called installation energy and it is difficult to assign as generally there are no direct readings of each equipment.

Task 3.2: Method development for automatic assignment

Over Task 2.4 and Task 3.1, the general concept for energy assignment and the description of the adaption of such concept were presented. At this task, the model for the complete energy assignment at the Basic Oxygen Furnace, which was at that time under development, was described.

Energy assignment is a highly complex task due the large number of equipment using and producing energy carriers and because of the many different kinds of energy forms used.
Energy pre-assignment at the Basic Oxygen Furnace is performed using data modelling clustering techniques. Data from the last 2 years were analysed in order to set a group of clusters where any heat could be allocated. Clusters were defined and their direct energy usage preassigned, based on the real and planning values of the following parameters:

- Coke Oven Gas consumption
- Electricity consumption
- Additives weight (each additive weight is an input to the cluster)
- Liquid steel temperature (at metal runner)
- Liquidus temperature
- Chemical composition
- O2 injected
- Ar injected
- Steel class
- Steel destiny
- Tapping time
- Heat weight

BOF process does not only use energy but produces energy carriers in form of steam and LD gas. BOF produces steam in excess (about 5 times its consumption) that is sent to AME´s steam network to be consumed by other facilities (mainly by the coke ovens at AME Aviles). However, the contribution of steam generated from LD gas to the whole balance of vapour use is very limited (about 3% of total usage), so energy assignment model will assume BOF as vapour self-sufficient and keeping vapour out of the balance.
A different consideration is to be taken from LD gas. Most of this gas (about 80%) is sold to a nearby cogeneration plant owned by "EDP Energía" (Energias de Portugal) which mixes it with other gases to produce electricity and steam. The electricity is sold to the national grid while the vapour is sold back to AME to be used by its installations. The resting 20% of LD gas is just burnt in flare due technical reasons.

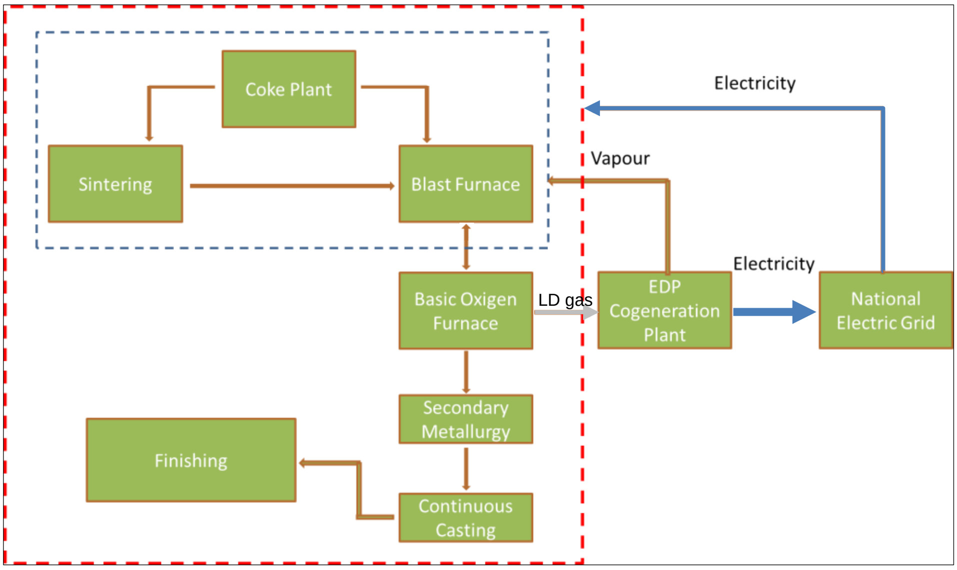


Figure 2.14: Energy distribution diagram

Then, the electricity and steam assignments from upstream processes from BOF (ΣE_n) were compensated by the amount of electricity and steam produced by EDP Energía. As there was no access to EDP´s production database, produced electricity and vapour was estimated from yields reported in the literature.

Models define baseline heats that represented the average conditions obtained after analysing the energy assigned to all heats without production issues. Afterwards, "additional" energy usage was added due several factors.

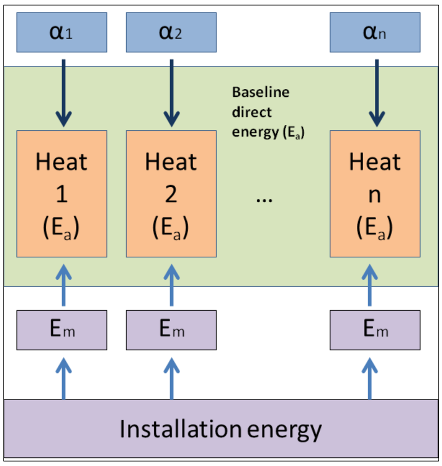


Figure 2.15: Energy assignment model concept

Based on the concept shown in Figure 2.15, energy amounts were assigned following different levels of aggregation.

Energies associated to installation operation. These energies were directly measured but could not be assigned to a particular heat, like for instance the installation's lighting. Those energies relate to the factor (E_m) in the basic energy assignment equation on Task 2.4. This energy was assigned proportionally to the tapping time of each heat.

Energies associated to heat classes. Some heat classes were more energy inefficient than others, generally due to stricter technical restrictions, temperature conditions, etc. As the excessive energy consumption caused by an unsuccessful heat (rejected or degraded) could not be assigned to any particular case, average energy performance to each heat class were considered. Then, performance of heats per ton of steel successfully produced were calculated to increase the energy usage to each heat class. These energies are related to the term α_i in the basic energy assignment equation.

Heat specific energy. Often, due to alterations during the steel production some heats had increases in energy use compared to the energies calculated for the baseline cases. During this term, a great effort was done to identify, characterize and quantify those values. Finally, it was considered that the main aspects to be included for energy correction to each particular heat were:

- Converter inactivity time
- Converter lining
- Tapping time
- Ladle temperature
- Ladle lining
- Presence of skull in ladle
- Waiting time in secondary metallurgy
- Waiting time continuous casting
- Waiting time in ladle tower
- Tundish time

Those factors were additive and were used to define the term E_a to each particular heat.

The proposed model allows an agile and dynamic energy assignment to each particular heat.
This real value is subjected to improvements and could be optimized up to the best levels of energy use found for similar cases. The achievable optimal value (always above the theoretical minimum) is defined by the energy usage of those heats that, belonging to the same cluster, showed better performance.
Then, even in case that production re-routing would not be possible, this model could learn the most favourable production conditions that give as a result the optimal energy usage for one particular case.

This data model was validated by comparison with external benchmarks that were developed in parallel for Task 6.3.
Every 6 months, data from new heats were included into the data analysis procedure in order to update the model and to improve its accuracy.

In case of a coil-wise evaluation of energy uses, for each coil two values of used production energy were considered:

- On the one hand only such energy which was used during rolling a hot rolled coil. This information was necessary for the deviation analysis: Why do similar product classes need varying production energy? In this case indirect and continuous energy (see definition in section 3.3.3.1) were not considered. Pre-conditions for rolling like temperatures were taken from the connected process data.
- On the other hand, to assign the total energy amount used for the production of a single coil, all energy types were included. In that case also indirect and continuous energy amounts were taken into account, e.g. by average values basing on longer observed time periods.

Task 3.3: Determination of necessary enhancements of data acquisition and databases

Regarding the Energy Efficiency Index calculation, the data were available on the L2 DBs of the involved processes and in the EMS system in which the energy data were stored every 10 or 15 (as described in Task 1.2 and Task 3.1). These already available data were sufficient for the purpose of defining the KPI to be integrated into MES having checked the alignment of the timestamps of the different DBs.

In case of the piecewise assignment of energy data to single coils at the hot rolling area (AMEH) the necessary energy data and process data were available but located in different systems and different formats. Because of the complex and time-consuming operations for this assignment it was necessary to change the initial plan to use Delphi coded tools. These operations were incorporated directly into the Oracle database by means of the script language PL/SQL. Because PL/SQL uses the basic functions and routines of Oracle core programming, the execution of typical database operations is extremely fast.
For the purposes of the project an Oracle database was set-up at AMEH to uncouple necessary tables and procedures from the process databases and to use it as a container for the data transferred from the external energy database system.
Results of pre-processing and synchronisation as well as the calculated energy values were stored in that database but were accessible from the central data base of AMEH for further use.

RIVA implemented a relational database to store the data on a MS SQL Server system. Data provided by the Riva level 2 system are stored in a server. As well necessary GUI tools (exploiting either C++ or Visual C#) were developed and installed. Two kind of measurements were extracted from the Riva IT system: average data (for EAF, VD, LF, CC plants) and punctual data (just for EAF) usually sampled every five seconds. Several pre-processing technics, such as data cleaning and data reduction, were applied in order to avoid the storing and, at a later stage, to improve the analysis of anomalous and incorrect data values.
The server was located at RIVA plant and could be accessed remotely by SSSA.

AME provided actual and historical data from the two BOF converters of Avilés LDA steel plant. Because to develop the statistical modelling as foreseen in this project it was necessary to have large sets of historical data. For every modelling problem a minimal dataset was defined as the trigger to begin the data analysis.
Data of more than 12000 heats were recorded during the project.
The process database was built in Oracle at AME premises and integrated on Apache Cassandra at Uniovi. This configuration provided excellent performances, works properly and met all the requirements, including capabilities of transparent clustering, high security levels and systems for zero losses during information transmission.
Insertion and data acquisition were performed by both custom software ad hoc and ETL (Extract, Transform and Load) tools. This custom software was executed on a process computer waiting continuously for the arrival of data. Data exploitation software was developed in .NET .
Due to the problems of network access and trying to avoid any conflict with operation computers, a full repository was created by Uniovi with a replica of the data base to accelerate data extraction and queries.
This was created in an environment created specifically for this project. System includes 4xvCPU, 16GB RAM, 500 GB SAS-storage and it was specifically designed for the development of map/reduce techniques of big sets of data. It was provided with a public IP address and a 1MB/s VPN access with a fault tolerant and high reliability configuration. Data were completely protected with restricted access and automated backup systems.

Additional efforts were necessary to introduce data from other sources, mainly from the energy and fluids team in the central services of AME.

Task 3.4: Definitions of methods for the assembling of energy data with process and quality data

SSSA developed a system to validate data from automation levels 1 and 2 in order to avoid wrong information. It was preferred to lose information for some heats than introducing wrong information that could cause important malfunctions in the modelling stage.
Data filtering used univariate statistics of every variable as well as clustering of heats.

DA focussed on the assignment of the energy efficiency indices to the same entities recognised by MES.
The correlation between energy and product/process data based on process step and time stamps. As depicted in Task 1.2 for a specific process step both L2 and EMS data were available, and they could be linked using the time stamps. Therefore, the alignment of all measured times in all systems was a fundamental prerequisite.

The calculation consisted of two steps. In the first step the energy necessary for a specific product in a specific process and the energy necessary during idle times was calculated. In the second step KPIs for product families in a specific process step were calculated.
For each heat in EAF,LF,VD, each as-cast product in CCM and each reheated product in RHF and as rolled product in RM, an Energy Specific Index (ESI) was calculated. Moreove,r the energy necessary during the idle times at each plant were also calculated because it had to be included into the evaluation of total energy demand necessary for a given production plan.
The results of this calculation were used to evaluate a KPI related to a specific plant and product family. The data were stored in the database to calculate the product family specific indices (Energy Efficiency Index EEI)).
A first hypothesis for product family identification had been done on the basis of CSM and DA experience: in EAF the index was calculated based on steel type and practise while in RM it was calculated based not only on steel type but also on ranges of thickness and width. This first hypothesis had been verified performing some statistical analysis on the calculated data.

Following previous considerations, the calculation module of energy indexes of EIAS was divided into two parts: Calculation of Energy Specific Index (ESI) and Calculation of Energy Efficiency Index (EEI).

The calculation of the ESI based on L2 and EMS data, and the results were stored into a local energy database (see Task 5.1 for Database structure).
The calculation of energy indices was made by performing statistical evaluation on ESI previously calculated.

<u>Specific index (ESI) calculation</u>
Starting from data acquired from L2 (process, product and some energy data) and EMS (energy use mediated on 10-15 min) ESI are calculated for electric power (kW), FuelCH4 (Nm3) and O2 (Nm3). The following shows the class diagram of the ESI calculation.

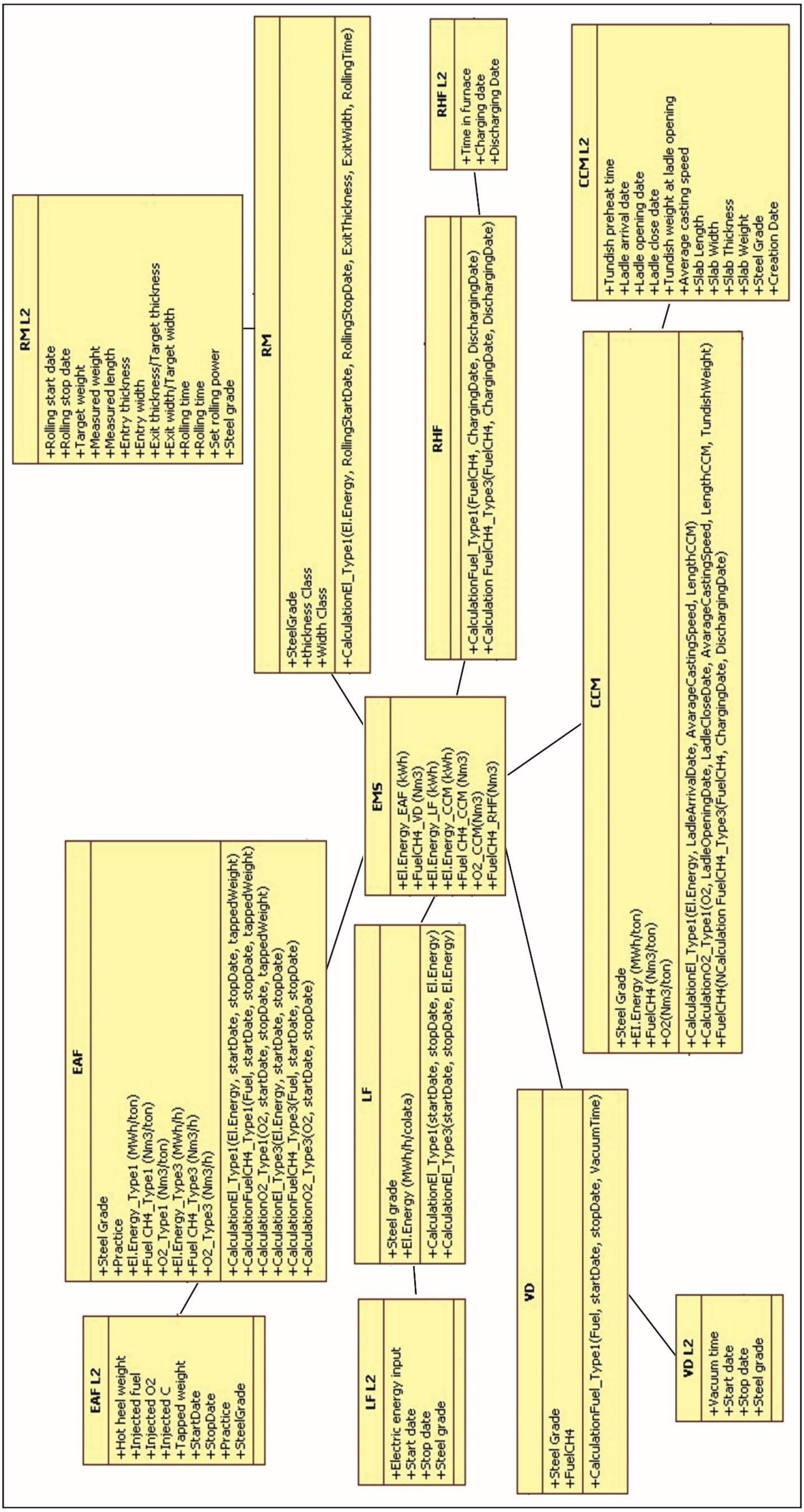


Figure 2.16: Class Diagram - ESI calculation

The functions for the energy use calculation were logically divided into two types:

- Functions related to a process that has a production time for a single product greater than EMS time slot (e.g. EAF: tap to tap interval greater than 30 min). The calculation can be in this case performed by numerical integration of the values acquired by EMS. The same calculation can be made for idle time considering the EMS time slots between the stop of previous production batch and the start of the following one.
- Functions related to process with production time for a single product less than EMS time slot (e.g. in RM throughput time is few minutes). In this case it's necessary to previously calculate the number of products in production during each EMS time slot. This means that the calculated index is a mean value of all the products in production in each time slot. An evaluation of reliability of the calculated index was performed by comparing it with previously calculated ones and corrective actions base on statistical concept.

Energy Efficiency Index (EEI) calculation

Based on DA and CSM experience a first hypothesis for product families for each process step was done. In the complete list of EEI for each process step and the relative product families were listed. A statistical analysis on the calculated index was performed in order to verify the correct identification of the product families. In case of negative response clustering calculation could be done on available data in order to identify more suitable product families.

Energy Efficiency Indexes are the mean value of the ESI calculated previously for each member of the product families. The standard deviation gave a first evaluation of the reliability of the calculated index. These indexes need edto be updated regularly because they depend on the actual conditions of the production plant. The system provides a default range (evaluated as described above) that can be changed by the user (e.g. if a revamping of a specific process step occurs, it's senseless to take the ESI calculated before the revamping into consideration).

Table 2.6: Energy Efficiency Indices to be calculated

Process step	product families	Energy Efficiency Index
EAF	Steel Grade, operative practice	Index_El.energy (MWh/ton); Index_FuelCH4 (Nm3/ton); Index_O2(Nm3/ton).
LF	Steel Grade	El. Energy (MWh/h/colata)
VD	Steel Grade	Fuel CH4 (Nm3/ton)
CCM	Steel Grade	El. Energy (MWh/ton); Fuel CH4 (Nm3/ton); O2 (Nm3/ton)
RHF	Steel Grade	Fuel CH4 (Nm3/ton)
RM	Steel Grade; class width (mm); class thickness (mm)	El. Energy (MWh/ton)

Those indices are suitable to be integrated into the MES.

For each production plan an evaluation of the necessary energy in term of electricity, methane and oxygen could be performed taking into account both production and idle times and product families. The objective of KPI use was the comparison among different production plans in order to be able to optimise the production on the basis of energy utilization.
In the MES interface the expected quantity of energy necessary for each element of the production plan and the total amount of electric energy, methane and oxygen was available. This allowed a ranking of several production plans.

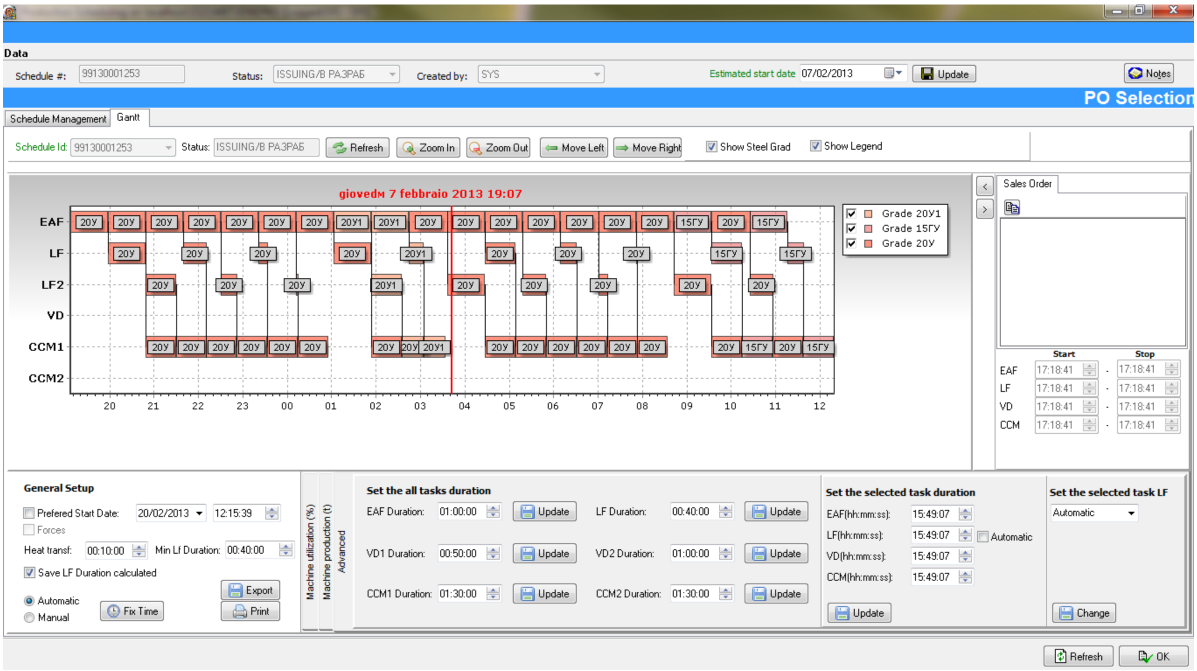


Figure 2.17: Example of MES interface

For the hot rolling use case the energy measurements were synchronised by the time stamps of the process data. These time stamps were used to define the interesting time period in which the start of transformation was exactly defined by passing limit values of the drive currents. Integration of related values (over the time differences to the next measurement) till the end of transformation phase delivered for example the related rolling work at a rolling stand.
In terms of basic load calculations and the furnace operation data, the start and end of the investigated time periods were fixed (basic load in 8-hour intervals according shifts, furnace operation in 1-hour intervals).
In 4.1, Guidelines for structure of energy databases, a detailed description of the implemented procedures and a discussion of this kind of energy data acquisition is given.

The following tables list the calculated energy values which were available for each coil, as basic load of single aggregates and for the Walking Beam Furnace operation.

Table 2.7: Table of calculated coil-wise energy data and related process data

Calculated energy (per coil)	Unit and description
EN_SLABHEATING	kWh/t, energy for heating a slab from furnace in to out temperature
EN_RM_DRIVES	kWh, used energy for all rolling passes in roughing mill (drives)
EN_RM_EDGER	kWh, used energy for edger drives
EN_DESCALER	kWh used energy for descaling (water pumps)
EN_F1	kWh, used energy at rolling stand 1 (drives and excitation)
EN_F2	kWh, used energy at rolling stand 2 (drives and excitation)
EN_F3	kWh, used energy at rolling stand 3(drives and excitation)
EN_F4	kWh, used energy at rolling stand 4 (drives and excitation)
EN_F5	kWh, used energy at rolling stand 5 (drives and excitation)
EN_COILBOX	kWh, used energy for coilbox operation
EN_COILERDRIVE	kWh, used energy for coiling
StripID	Unique identifier for each coil
Time_WBF_IN/_OUT	Time stamps of slab heating
Time_RM/FM/Cooling	Time stamps of start of transformation or handling at rougher, finishing mill or
Slab/strip geometry and info	Thickness, width, length, weight, material, …
Temperatures	Slab in/out furnace, strip at coiling

Basic load data includes not the transformation/handling energies assigned to single coils, but those values were included into the table for direct comparison (marked by "-_TRANSFORM").

Table 2.8: Calculated basic load data for drives and devices at HRM

Variable	*Basicload electric energy of drives and devices ...*
StartTime	Begin of 8-hour intervall
EndTime	End of 8-hour interval
WBF_BL	kWh, devices and drives at WBF
EN_DESCALER_BL	kWh, … of descaler pumps and auxiliary aggregats
EN_DESCALER_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_RM_EDGER_BL	kWh, … of edger drives
EN_RM_EDGER_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_RM_DRIVES_BL	kWh, … of rougher drives
EN_RM_DRIVES_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_RM_AUXDRIVES_BL	kWh, … roller table drives roughing mill
EN_RM_SLABTRANSPORT_BL	kWh, … roller table drives roughing mill
EN_RM_ROLLERTABLE2RM_BL	kWh, … roller table drives WBF to RM
EN_RM_LOWVOLT_BL	kWh, … low voltage devices
EN_COILBOX_BL	kWh, … coilbox drive
EN_RM_COILBOX_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_COIL_FURNACE_BL	kWh, … coil furnace
EN_CROPSHEAR_BL	kWh, … cropshear drive
EN_F1_BL	kWh, … drives and excitation hot rolling stand F1
EN_F1_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_F2_BL	kWh, … drives and excitation hot rolling stand F2
EN_F2_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_F3_BL	kWh, … drives and excitation hot rolling stand F3
EN_F3_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_F4_BL	kWh, … drives and excitation hot rolling stand F4
EN_F4_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_F5_BL	kWh, … drives and excitation hot rolling stand F5
EN_F5_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_COILERDRIVE_BL	kWh, … coiler drive
EN_COILERDRIVE_TRANSFORM	kWh, … aggregated transformation/handling energy of coils
EN_COILER_TRANSPORT_BL	kWh, … coil transportation at coiler
EN_HRM_LOWVOLTAGE_BL	kWh, … low voltage devices
EN_ROLLERTABLEDELIVERY_BL	kWh, … roller table drives after coiler
EN_BLOCKA	kWh, … 30kV output transformation station A
EN_BLOCKB	kWh, … 30 kV output transformation station B
TOTAL_STRIP_WEIGHT	t, produced hot strip weight in time interval

Table 2.9: Calculated data describing furnace operation

Variable	Unit and description
DATUM_ZEIT	Start of 1-hour interval
NG_AMOUNT,	m^3, Natural gas volume injected in time interval
NG_HEATCAPAC_AVG,	kWh/m^3, heat capacity of NG
HEATING_ENERGY,	kWh, thermal energy of burnt natural gas in time interval
TOTAL_WEIGHT,	t, aggregated slab weight in WBF during time interval
SLABSHEATED_ENERGY	kWh, aggregated heating energy of slabs in time interval

2.2.4 WP 4: Semantic model for energy consumption analysis

Task 4.1: Definition of a semantic energy consumption model

Within this task the development of the semantic model for energy consumption has been performed. The aim of the semantic model was to define a common understanding of the used vocabulary and to provide a formal structure for data handling. For the generation of the ontology results from the investigations into existing energy related ontologies and experiences made in former RFCS projects have been incorporated as far as possible.
The main objective for the utilization of the ontologies inside the EnergyDB project was to create a formal interface between EIAS, the available data and models and to enrich it by semantical description. This enabled us to develop the final application in an abstract way allowing an implementation independent from specific installation.

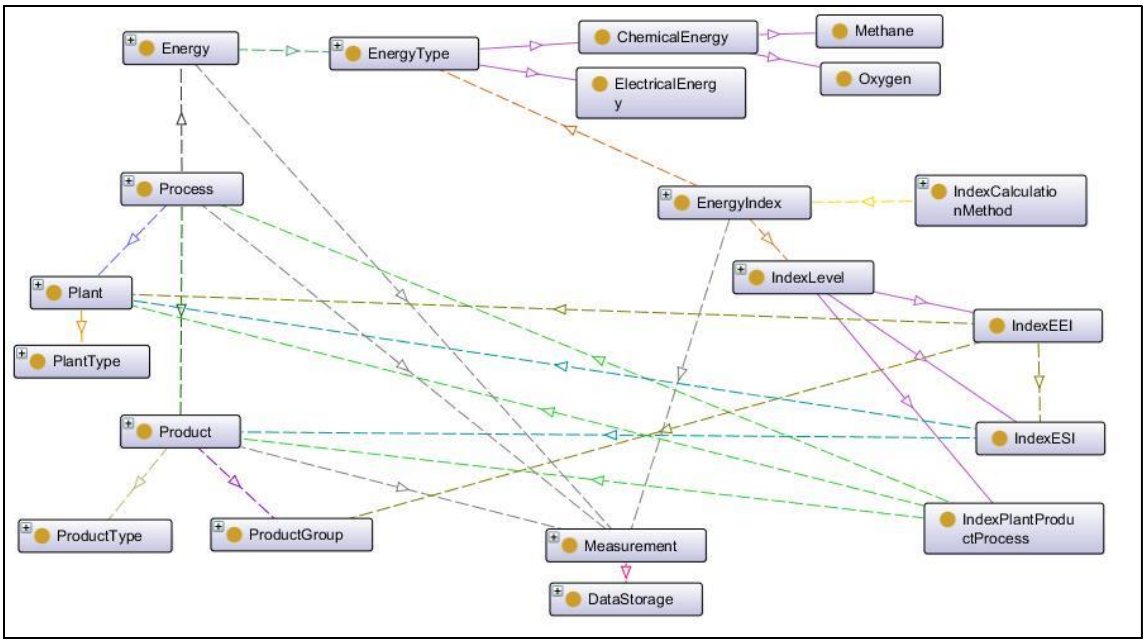


Figure 2.18: EnergyDB ontology scheme

The sketch shows the general schema of the ontological model. The schema covers the three main perspectives of the energy flow such as:

- Product perspective
- Process perspective
- Plant perspective

The mentioned perspectives allowed us to utilize the ontology in order to provide required information about the energy flow in relation to these three dimensions. That means the information stored within the ontology could be utilized for different purposes depending on the intention.

The main concepts present within the schema are:

- Energy: defines the source of the energy used in the steel plants. In general, we differentiated between chemical and electric energies which specify more exactly the type of used energy. Further additional details could be provided e.g. the composition of the chemical energy e.g. gas mixture.
- Process: defines the manufacturing process where the energy has been applied in order to produce a specific product
- Plant: represents the information about the hardware equipment which utilized the energy in order to perform a manufacturing process.
- Product: provides relation to the product which is produced within a manufacturing process utilizing the plant components.
- EnergyIndex: provides the information about the calculation and type of the index
- Measurement: provides the information about the data sources
- DataStorage: provides the information about the data repository (e.g. database, table, column etc.)

The solid and dashed lines in the figure show the relations between those entities. Some examples shall help to understand the scheme of connections in the ontology:

• **Process** *is_done_on* **Plant**	a certain process runs at a certain plant
• **Process** *produces* **Product**	a certain process produces certain products
• **Measurement** *is_stored_in* **DataStorage**	a measurement value is stored at defined place in the data storage (database)
• **EnergyIndex** *has_level* **IndexLevel**	the EnergyIndex has the numerical value IndexLevel
• **EnergyIndex** *refers_to* **EnergyType**	the EnergyIndex describes a certain EnergyType
• **IndexESI** *calculateESI_using* **Plant**	for calculation of the IndexESI parameters related to the plant under consideration must be used

Indexes were organized based on index level. Each of the specific indices foreseen was related to the entities that were used for its calculation. Index Calculation Method and Measurements and DataStorage had a special role in the ontology because they were used to store all the information which was required for retrieval of data and for the execution of the models.
In the Index Calculation Method all the information related to the calculation either the location of an external calculation library (dll) or an explicit equation could be stored identifying also all the input and output necessary for the execution. As can be seen some indexes were related to a specific product while others to product groups.

Task 4.2: Set-up of the semantic model

The aim of this task was the implementation of the semantic model developed within the Task 4.1. After the analysis of available tools and applying the results of the former RFCS project KNOWDEC ([12]) we decided to implement the ontology using Protégé software.
Protégé is a free, open-source platform, developed by Stanford University, that provides a growing user community with a suite of tools to construct domain models and knowledge-based applications with ontologies (see Figure 2.19). At its core, Protégé implements a rich set of knowledge-modelling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats. Protégé can be customized to provide domain-friendly support for creating knowledge models and entering data. Further, Protégé can be extended by way of a plug-in architecture and a Java-based Application Programming Interface (API) for building knowledge-based tools and applications.

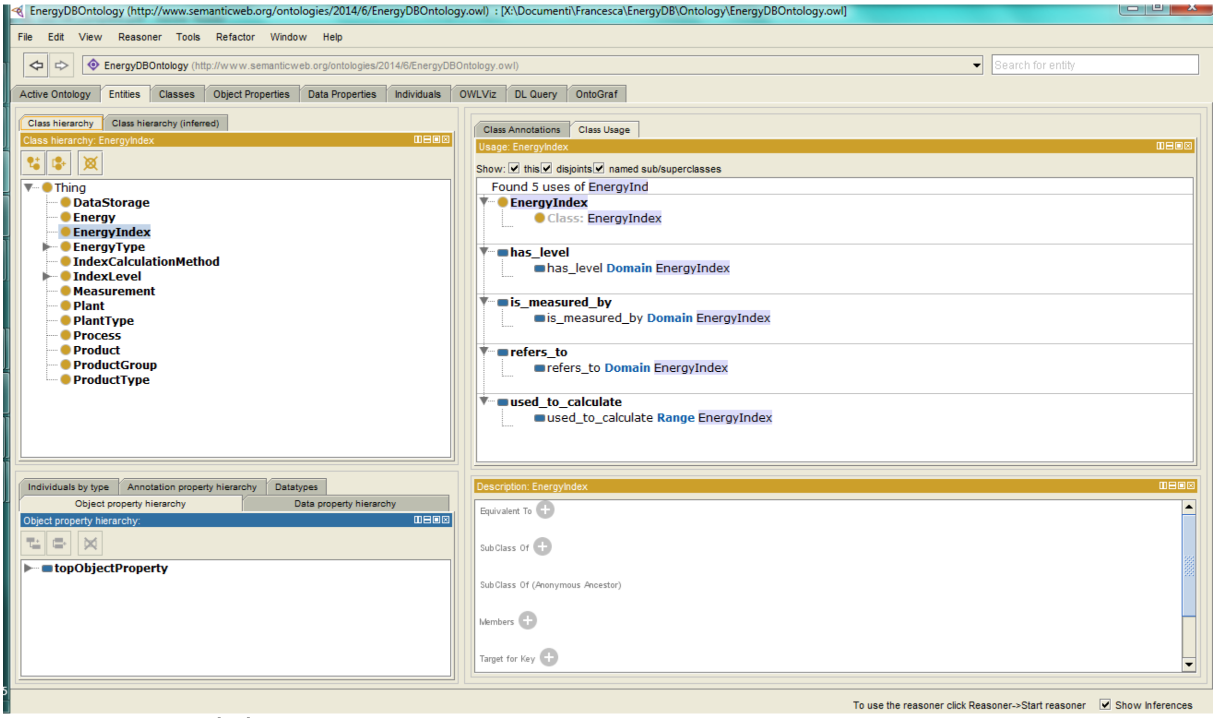


Figure 2.19: Protégé Interface with EnergyDB ontology

Task 4.3: Adaptation of the methods to different production stages (casting, hot/cold rolling, annealing …)

The aim of this task is to adapt the developed semantic model to the process stages outside the foreseen use cases. Because of the reason that the sematic model has been designed in an abstract way the extendibility to other processes can be guaranteed. In order to verify the extendibility a theoretical study of not covered process stages as casting, hot rolling, cold rolling, annealing have been performed. The results of this investigations has been incorporated into the model.

2.2.5 WP 5: Development and Implementation of the energy data base

Task 5.1: Development and implementation of a data model for the energy data

For storing the KPI, in case of DA a new database was installed, in Figure 2.20 the Entity Relationship (ER) diagram of KPI in the local EnergyDB database is reported.

It consists of two different table groups:

- Tables ESI containing specific energy usage of a particular product/semi-product;
- Tables EEI containing the energy indexes according to the concept developed.

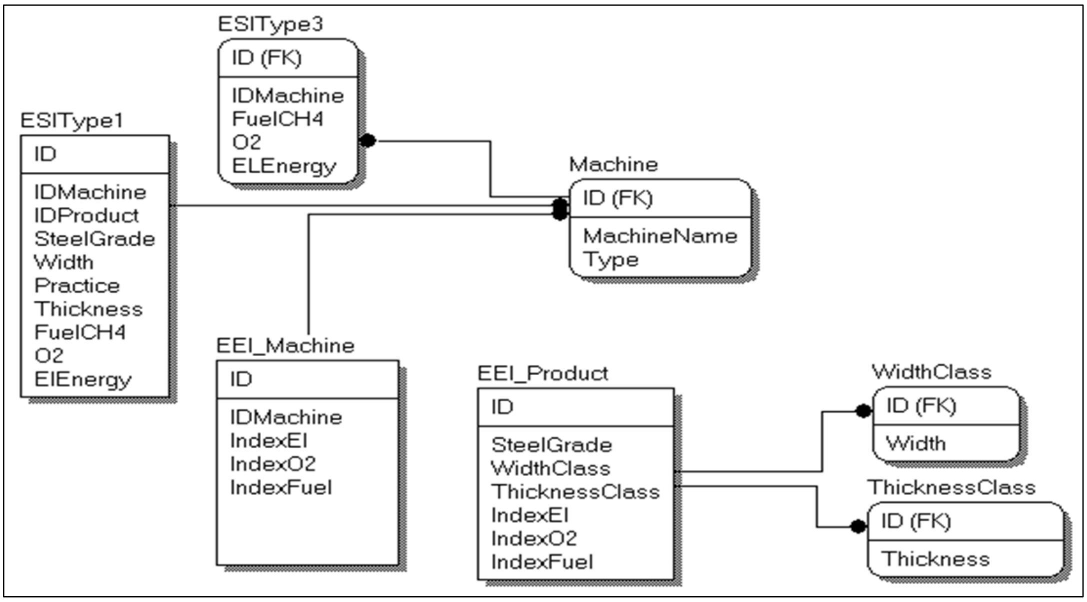


Figure 2.20: ER diagram for energy efficiency/specific indices

For the collection and analysis of energy data in the hot rolling area of AMEH, the focus was put on the piecewise assignment of energy to single coils. Process data of coils were stored in various tables in the central database system of AMEH, energy data were transferred from the external power supplier VEO in a separated energy database.

The ER diagram below shows the relations between the tables of the ZQDB, the energy data supplied by VEO, and the resulting energy tables implanted in the additional separated database.

The interconnections between the tables were realised by the identifier *STRIPID* and the time stamps found in the process data tables and the energy data table.

As described above, for the piecewise investigations there was one table including energy and process data per coil, and two tables representing the basic load in the hot rolling area and the heating operation of the furnace. Those two tables incorporate aggregated data belonging to time periods of 8 hours (basic load) and of 1 hour (heating operation).

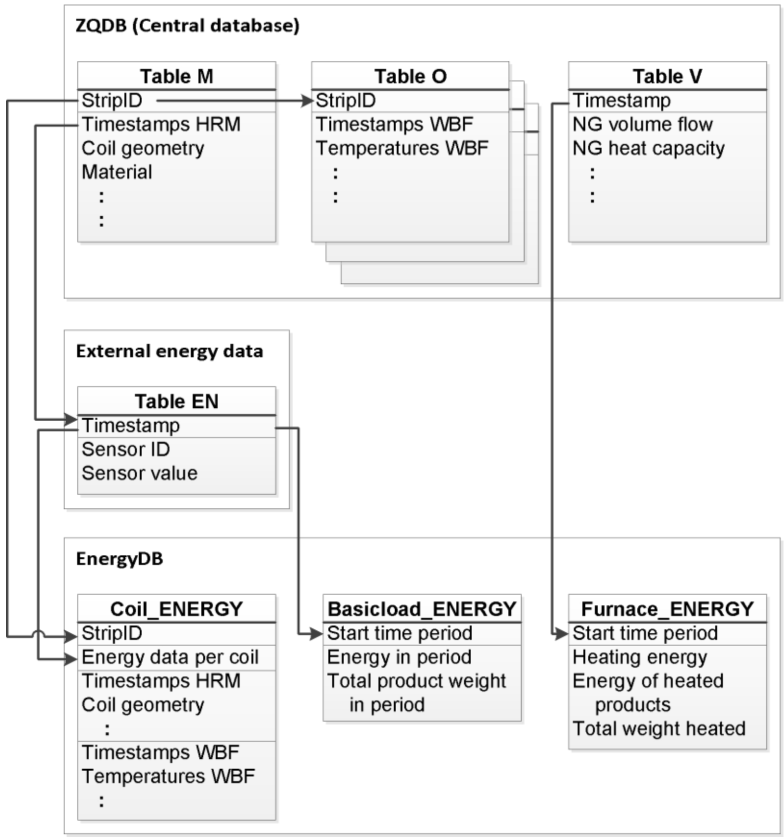


Figure 2.21: ER diagram of data table interconnections at AMEH.

Regarding Riva, the database structure has been thought and developed keeping in mind the process view: EAF, VD, LF and CC were characterized by different tables (see figure below). The basic information was represented by the casting that belongs to a steel grade group. Riva grouped its own data by five different grade groups depending on their specific chemical composition.

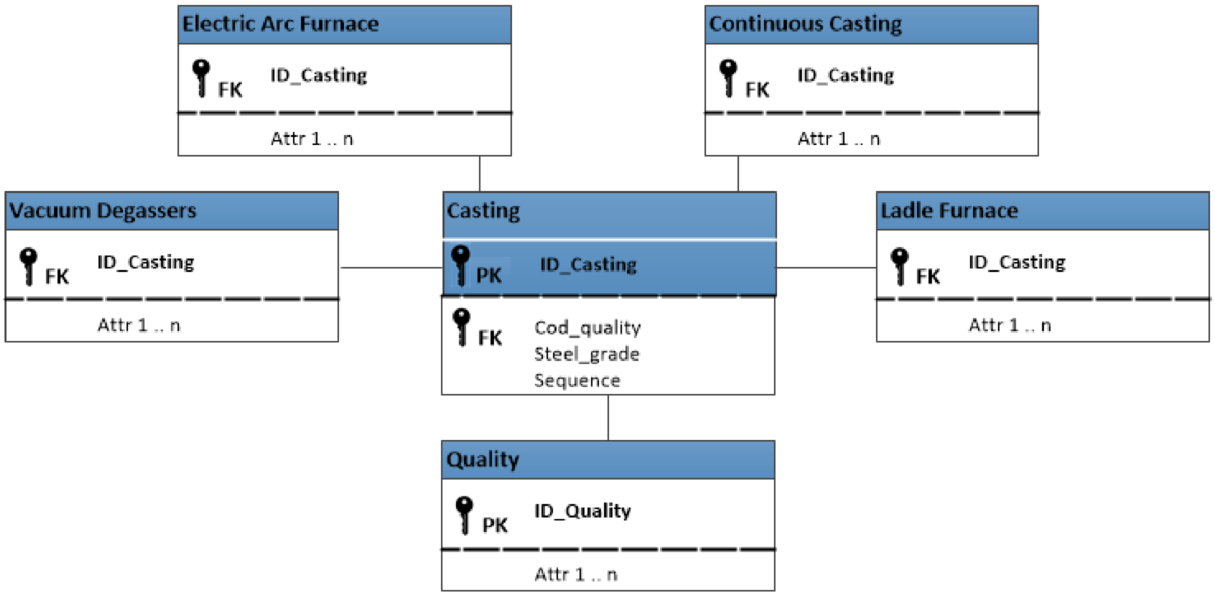


Figure 2.22: ER diagram of tables at RIVA, basing on common key ID_Casting

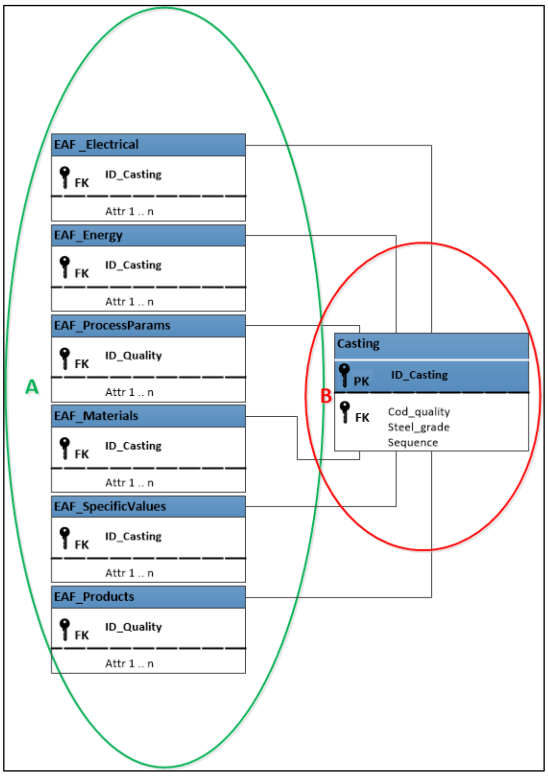


Figure 2.23: Assignment of EAF data to castings

This wealth of data has been split by their intrinsic meaning and grouped in specific elementary tables.

Regarding the EAF, the data available included materials, electric values, energy, heat specific values, process parameters and products values. All the relations between these basic tables and the casting ones were 1-1, that means for each casting there existed one and only one instance in each table (see Figure 2.23 at the left).

On the other hand, talking about the time-based sampled measurements, the amount of data was quite bigger: six hundred instances per casting per table on average.
A single casting did not represent the basic information anymore due to the time-based samples and the cardinality between the two sets of tables becomes 1-n.
As already briefly said in the task 3.3, actually there existed no automatic data transfer from the Riva IT system to the EnergyDB server, so Excel sheets and csv files were created and imported into the database by an GUI tool import module.

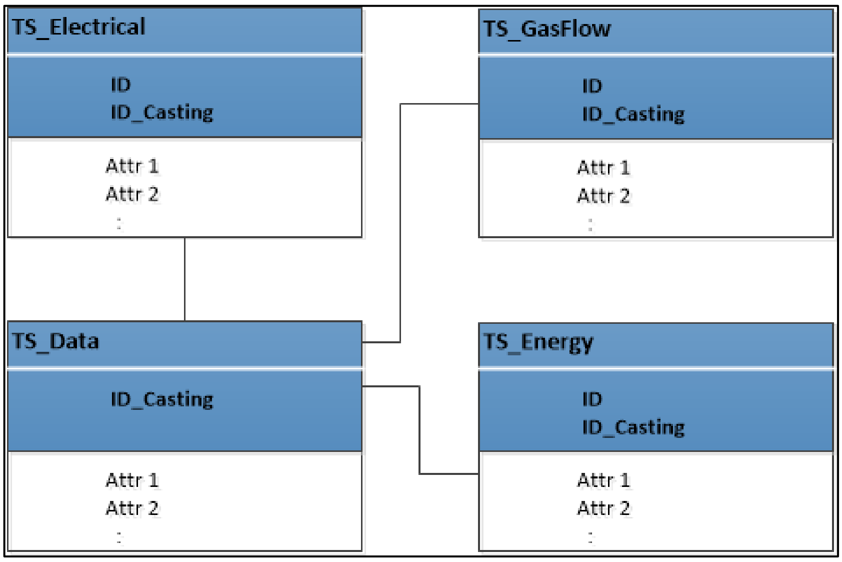


Figure 2.24: DB structure for time-sampled data

Because the internal representation of data and their interconnections differed from one application case to another, also the Entity Relationship diagrams differed slightly for the different application cases.
In general, there are the following common elements of each ER diagram:

- process data coming from sensors like temperatures, forces, speeds etc,
- product data like chemical/mechanical properties, geometry, mass etc,
- energy data measured as electrical currents and voltages, volume of used gas or mass of additions, heat capacity of products, etc.

But most important was the information that allowed the different data to be combined to investigate the relationships between the manufacturing process, the product and the energy required:

- synchronised time stamps to allocate sensor data to a certain piece/product and to bring measurements of different sensors into cover,
- unique key parameters (IDs) to identify unmistakable a product at the different processing stages and thus enables the compilation of all related data along the different production steps.

Task 5.2: Realisation of the connection between energy data and process and quality data

At AMEH an Oracle data base was installed to serve for temporary storing of the energy data transferred from the external energy acquisition and management system. This data base was also connected to the central data base of AMEH, so access to process and product data was given. By means of the synchronisation procedures those energy data were assigned to the produced coils were for the further analysis tasks. Results of synchronisation and assembling of used energy amounts were stored in this central data base. The first studies had been made using Matlab development environment.

At RIVA a MS-SQL data base was installed to collect energy and relevant process data in different tables. The synchronisation was done by specific IDs included directly in the data.

At AME an Oracle data base was installed to store and manage energy data from different sensors and transmitters.

Task 5.3: Development and implementation of a data model for the energy data

The locally data bases for energy data and the related access functions were finally established and tested. They included the data models shown by the ER diagrams (see Task 5.1 above).

The above described ER diagrams were used to design and to integrate the data models of the energy data bases into the IT systems of the different use cases. The merging of production data (process, product) and the collected energy data is realised by means of dedicated functions or by tools integrated in the data base systems.

In general, if the data model for the energy data corresponds to the structure of the data models for process data (in case of dynamic data) and for product data (in case of piece/product related data), this simplifies the use of existing tools for data merging and a combined analysis at the specific application case.

2.2.6 WP 6, Development of EIAS applications

Task 6.1 Analysis of deviations with relation to material classes, production procedures and process conditions

CSM evaluated the following example data both from L2 and EMS to assess the data sensitivity to material types and production procedures.

Table 2.10: Investigated data in the DA use case

	Consumption	Product	Time	Other	Reference Unit
EAFs	ELECTRIC_ENERGY TOT_O2_CONS TOT_C_CONS TOT_CH4_CONS	STEEL_GRADE_ID, STEEL_GROUP_ID PRACTICE_ID TAPPED_WGT	START_DATE STOP_DATE		EAF Heat
LFs	ELECTRIC_ENERGY	STEEL_GRADE_ID	START_DATE STOP_DATE		LF Heat
CCs		STEEL_GRADE_ID	START_DATE STOP_DATE LADLE_ARRIVAL_DATE LADLE_OPENING_DATE LADLE_CLOSE_DATE	TUNDISH_AT_LADLE_OPEN_WGT	CCM Heat
CCs		STEEL_GRADE_ID LENGTH WIDTH WEIGHT	CUT_DATE	STRAND_ID PROD_COUNTER AVG_CASTING_SPEED	Bloom

An analysis was carried out in order to define the filtering criteria for both process times and idle times.

EAF Process Times
The analysis showed that 90% of the heats had a duration between 45 and 75 minutes and more than 97% had a duration lower than 2 hours. Therefore this second limit was chosen to filter the data used in the Specific Index calculations.

EAFs Idle Times
The idle time was calculated as the difference between the start date and the previous heat stop date. The data showed that more than 90% of the intervals lasted less than 1 minute. As the EMS data acquisition interval was equal to 15 minutes, the indexes of the idle times could not give a useful indication regarding the actual idle energy consumptions.

UNIOVI/AME worked on the energy assignment model for the liquid steel production at the exemplary installation of the BOF in Avilés, Spain. Their work was devoted to analysing the energy consumed for several exemplary steel products including not only direct energy applied but also auxiliary charges and its contribution to non-productive time.
AME provided the UNIOVI experts with two sets of data, the last one with 7,486 heats dataset after eliminating missing values and capture errors.
Total energy consumed for each heat was calculated following the model philosophy described in tasks 2.4 and 3.2 as a function of the Oxygen consumption, Argon consumption, Nitrogen consumption, gap time (period from end of tapping to charge beginning) and other sources or sinks of energy.
Each heat included into the dataset incorporate other significant information, particularly:

- The steel composition,
- The steel quality finally obtained, characterised by a number. The larger the number, the lower the steel quality obtained.

Table 2.11 summarises the statistical description of the total energy, O_2, N_2 and Ar consumptions and production time per steel family.

Table 2.11: Dataset statistical description

	Energy consumption		O2 consumption		N2 consumption		Ar consumption		Production time	
Steel Family	Average value	σ	Average value	σ	Average value	σ	Average value	σ	Average value	σ
A	579,7	41,7	15443,7	1344,4	71,5	83,0	36,5	45,8	2229,0	564,2
B	583,0	43,1	15359,6	1486,9	72,9	54,4	45,9	48,5	2291,4	659,6
C	581,0	51,7	15128,4	1985,5	68,9	50,6	43,8	46,5	2304,9	582,3
D	581,3	47,1	15236,9	1682,3	71,7	48,3	47,4	51,0	2320,8	743,2
K	584,7	40,8	15246,6	1406,9	73,0	50,8	48,3	49,2	2266,9	566,6
N	583,5	45,9	15234,4	1495,0	78,5	57,7	46,5	52,6	2280,9	682,8
All	756,9	44,3	15310,6	1546,1	72,8	55,7	45,6	49,0	2290,4	657,1

Note that calculations were performed in MJ/t but normalised values were always shown due to confidentiality issues.

Table 2.11 shows that heats belonging to Steel Family C had the lowest energy consumption. This was due to steel family C exhibited the higher scrap use rate that had lower energy requirements as less material needed to be reduced. Thus, lower energy consumptions were achieved by using more expensive inputs.

From dataset, after different simulations, the following variables were selected for modelling (see Table 2.12):

Table 2.12: Variables used for modelling

VARIABLES	DESCRIPTION
TEMP_PIG IRON	Pig Iron temperature at charge.
CARB_CONT	Carbon content
WT_SCRAP	Scrap weight.
TIME_GAP	Time from end of tapping to charge beginning.
TIME_BLOW	Blowing time.
O2_TOTAL	Total O_2 blown.
WT_CAO	CaO Weight.
TEMP_LIQUIDUS	Líquidus temperature
TEMP_OBJ_CH	Objective temperature at charge.
TEMP_SOLID_SL1	Solidification temperature at sub-lance
WT_STEEL_OBJ	Objective Steel weight

Traditional univariate techniques were used to prepare the data.
Afterwards, a **Principal Component Analysis** (PCA) was applied in order to check the existence of anomalous cases that could be classified as outliers.
This technique is frequently used to perform dimensionality-reduction of an initial group of data by projecting the initial space into a 2-dimension space.
Consequently, elements that fall distant from the majority are considered as outliers.

As it can be seen from Figure 2.25, only a reduced number of outliers were found and the dataset was reduced to 7,344 heats.

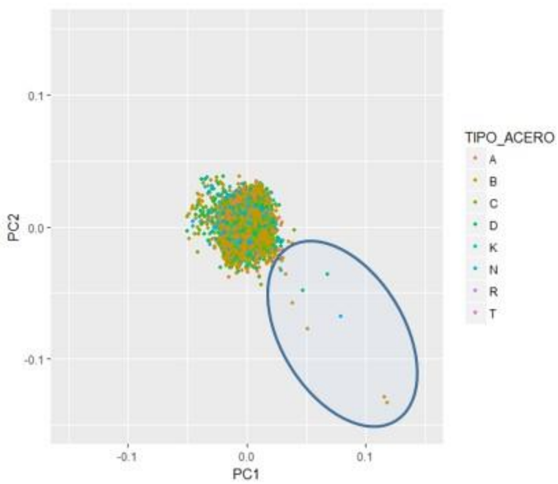


Figure 2.25: PCA results

Afterwards, data model was performed by using the **MARS algorithm**. MARS method is a nonparametric regression procedure that makes no assumption about the underlying functional relationship between the dependent and independent variables (see Annex 4.2, Description of MARS algorithm, and [13]).

Later, the dataset was divided into **two groups**:

- One containing the 80% of cases that was used for model training.
- The remain 20% of cases that were used for model validation.

Data training was performed with the **cross-validation technique** because that allows analysing model average behaviour.

Figure 2.26 shows model results and tests.

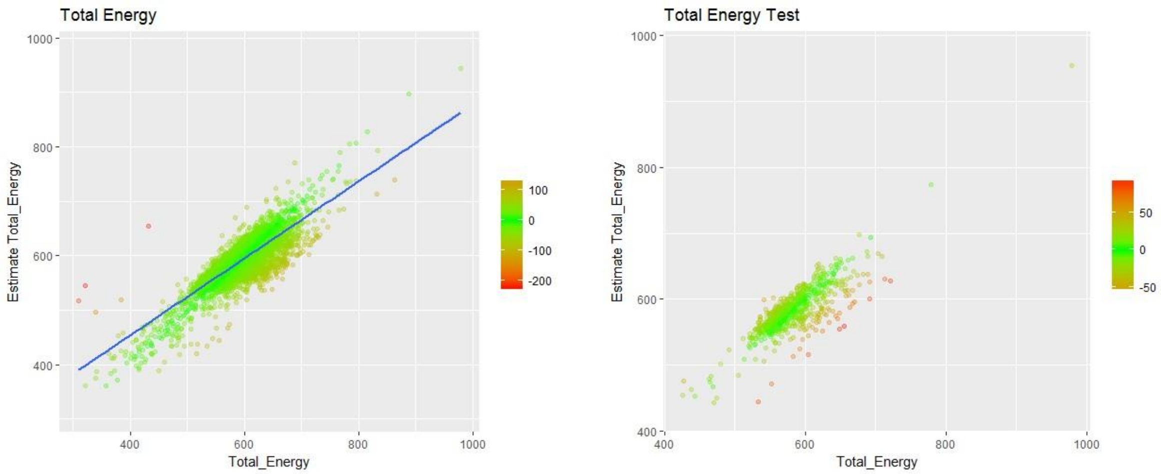


Figure 2.26: Model and test results

The achieved model´s **Root Mean Square Error** (RMSE) was 23.81. Model´s accuracy is presented in Table 2.13, showing the accuracy rate related to relative error rateed from 1 to 9% (99 to 91% confidence interval). The success rate of average values is shown as contrast.
As it can be seen the proposed model had a better behaviour than the average values.

Table 2.13: Aggregated model results

RELATIVE	ABSOLUTE	AVERAGE	MODEL
1%	6.70	13.76%	23.71%
2%	13.39	27.50%	47.07%
3%	20.09	40.99%	68.33%
4%	26.78	53.35%	82.00%
5%	33.48	64.02%	88.96%
6%	40.17	72.82%	92.51%
8%	53.56	84.76%	95.92%
9%	60.26	88.47%	97.11%

Additionally, separate models for different groups of similar steels (named from A to Z) were developed based on the hypothesis that they would provide more accurate results as each family group of data is more homogeneous.

Table 2.14 shows the accuracy rates to each separate model. As it can be seen all separated models exhibited higher success rates compared to the aggregated model (**All** model), proving that the hypothesis is correct.

Table 2.14: Model results per steel family

RELATIVE	A	B	C	D	K	N
1%	20.56%	23.25%	14.77%	21.51%	16.44%	15.58%
2%	36.29%	46.32%	29.36%	41.73%	31.2%	33.65%
3%	49.4%	67.81%	45.83%	60.58%	46.88%	50.96%
4%	65.12%	81.31%	58.9%	74.04%	61.95%	67.12%
5%	76.41%	89.29%	69.89%	84.4%	73.52%	78.27%
6%	83.67%	92.8%	79.92%	90.06%	79.91%	85.77%
8%	91.13%	96.05%	90.15%	94.86%	89.19%	92.12%
9%	93.95%	97.23%	92.61%	95.89%	91.93%	94.04%
RMSE	17.58	22.88	20.92	22.05	19.92	22.64

Global (All) model and B model showed a similar behaviour as Steel Family B was the most represented one in the dataset. Models A and K showed the best results although related to less frequent steel families.
Considering the results of the model, it was possible to affirm that the model could calculate accurately the predicted energy used to produce a given heat.

In case of the investigations for energy optimisation at RIVA, SSSA used a production database containing information for more than 10’000 heats. They were grouped into 11 different steel grade families by their chemical compositions. A further separation step has been done by splitting the heats that were degassed from the rest of the heats, due to the higher electrical energy consumption necessary to produce one heat degassed.

Table 2.15: Overview about collected data

Steel grades	Heats degassed	Total heats
1	0	26
2	0	1
3	19	1009
4	36	793
5	117	4334
6	14	33
7	244	749
8	21	89
9	168	955
10	71	126
11	642	1732

Before performing the analysis, some pre-processing steps were necessary to cleanse the data and to avoid the presence of outliers.

First, NaN values (missing values) were removed from the dataset.
Second, in order to identify and remove outliers, SSSA applied an outlier removal algorithm called "A multivariate fuzzy system applied for outliers detection" (see [14]). The structure of the algorithm is depicted below.

The analysis methods for the detection of rare events are grouped in supervised methods and unsupervised methods. The unsupervised methods for outlier detection follows different approaches based on Density (e.g. Local Outlier Factor, LOF), Clustering (e.g. Fuzzy C-means, FCM), Distribution (e.g. Grubb Test) and Distance (e.g. Mahalanobis). The input dataset is evaluated by the four different methods and the output of them became the input of a Fuzzy Inference System. It gives as output a number between zero and one, proportional to the probability that a particular input pattern is an outlier. If this number is above 0.6 (our threshold) then it is labelled as outlier and then removed from the dataset.

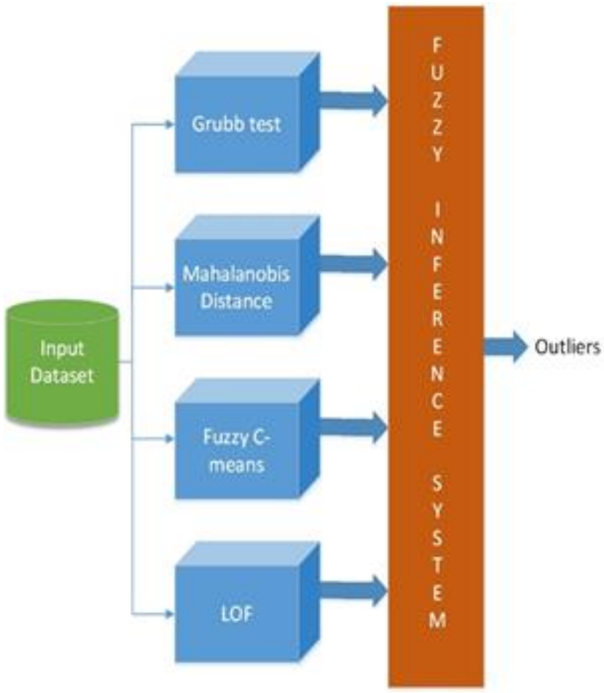


Figure 5.27: Outlier detection algorithm structure

After removing anomalous values from the dataset, a variable selection algorithm has been executed to identify from a mathematical point of view, which were the variables that have stronger influence on the specific electrical energy consumption measured in the EAF and in the LF.

See next section, Task 6.2, for details.

Task 6.2, Analysis of energy optimized production routes

Because of having such a large number of data with similar castings representing various energy consumptions, in case of AME/UniOvi it was possible to determine the optimal operating conditions that allow:

- To approach the lowest energy level possible for such material grade.
- To perform the least number of corrections in the additions, etc. during the heat itself.
- To know the real energy consumed in each heat.

In this way, an approach used the Self-organizing maps (SOM, see [15]) that determined different clusters, as shown in the figure, where the left represented the number of cases projected per neuron, in the centre the distances were represented and the left divided the clusters. On the distance matrix, five clusters were identified using k-means.

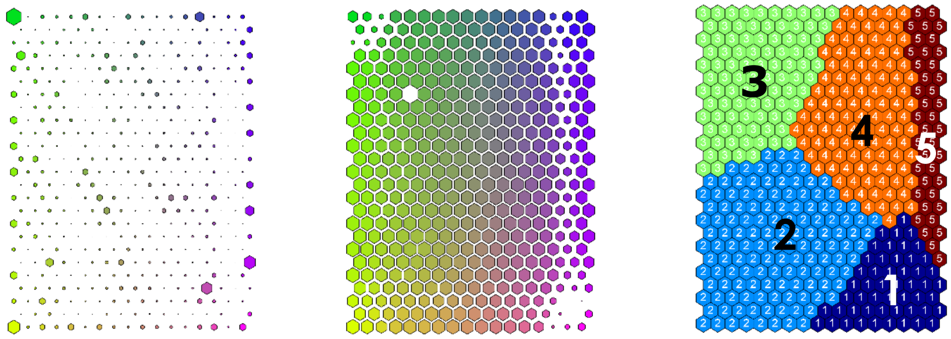


Figure 2.27: Identified clusters

The following map shows the contribution of the most significant variables to the formation of the clusters.

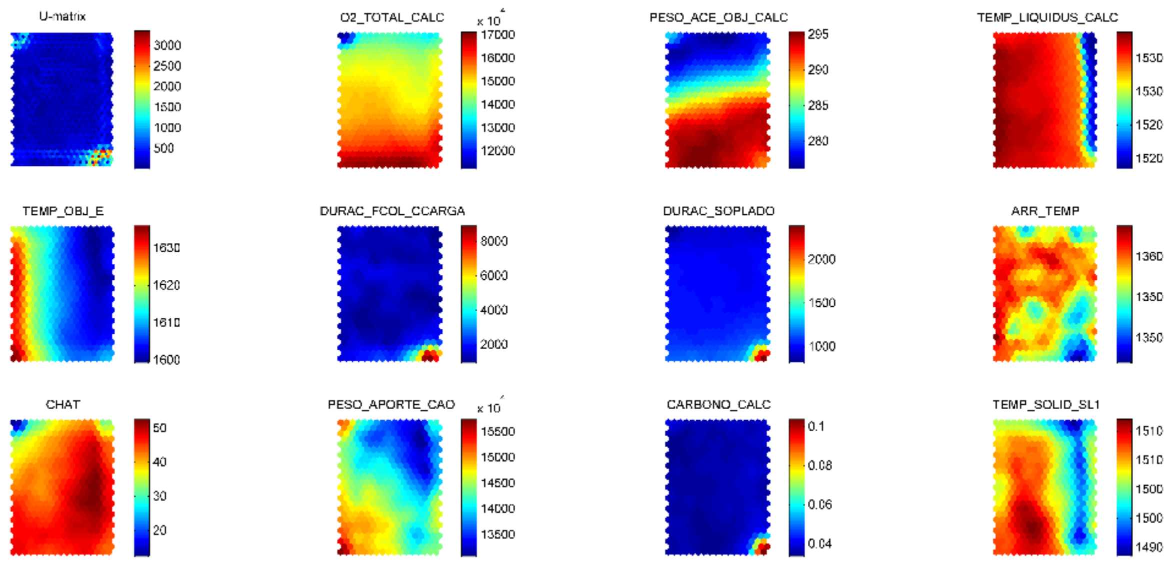


Figure 2.28: SOM components

These clusters had different energy values, as shown in the following figure, which highlights the mean values in every group.

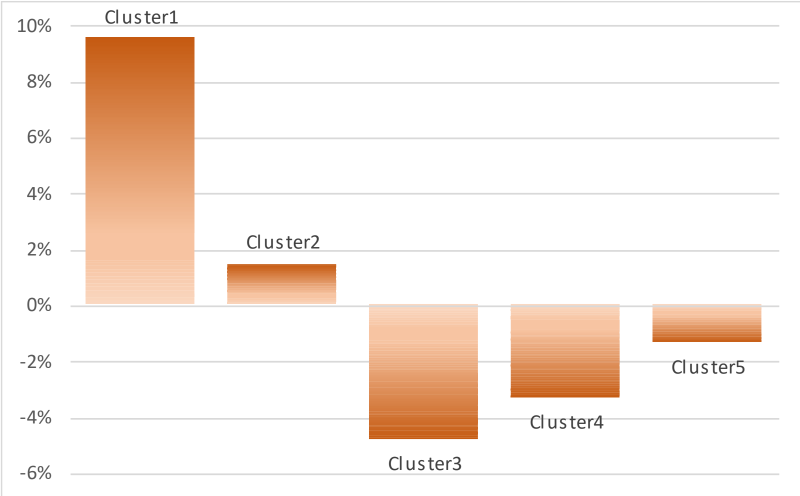


Figure 2.29: Mean energy values

Thus, when a new cast was approached, its expected behaviour was evaluated, projected into the map and associated with the most closely related cluster.
Among all the existing castings in the cluster, the best value was found according to the following characteristics:

- Similar compositions of entrance and exit.
- Less energy consumed.
- Highest level of quality achieved.

This approach allowed to optimise the actual values with which the heat will be performed from the accumulated experience.

SSSA developed an optimization tool, developed principally in Matlab, which minimized the specific electric energy consumption (EAF + LF) of the RIVA plant situated in Caronno. The fundamental ideas have been defined by SSSA and RIVA by means of a shared EXCEL sheet where all the specifics were well described and structured.

The optimization of the specific electrical energy (*SEE*) consumption for the Riva steel plant has been adapted against the investigations described in the Annual report no 4 and improved in order to obtain more reliable results.

The set of data gathered at Caronno plant (total amount of more than 10’000 heats) were split in two subsets (*ds1* and *ds2*) depending on the process routes:

- *ds1*: EAF + LF + CC
- *ds2*: EAF + LF + VD + CC

The variables involved in the analyses are listed in Table 5.16 on the next page. There the related variables were grouped in macro-categories.

Table 2.16: Initial parameter list of process data at RIVA Caronno steel works

Parameters / Plant	Description	Dataset
$Basket_{EAF}$	*Scarp type, pig iron and fluxes*	*ds1, ds2*
$TapToTap_{EAF}$	*Time needed from scrap charge to steel tapping*	*ds1, ds2*
$Delay_{EAF,LF}$	*Delays due to several process factors*	*ds1, ds2*
$Temp_{EAF,LF,VD,CC}$	*First and last temperatures*	*ds1, ds2*
$CH4_{EAF}$	*CH4 used for burners*	*ds1, ds2*
$Oxygen_{EAF}$	*User for combustion*	*ds1, ds2*
$LiquidSteel_{EAF}$	*Liquid steel tapped into ladle*	*ds1, ds2*
$Carbon_{EAF}$	*Carbon content of liquid bath*	*ds1, ds2*
$Argon_{LF,VD}$	*Argon used for bubbling*	*ds1, ds2*
$Material_{LF,VD}$	*Ferroalloys and deoxidizers added*	*ds1, ds2*
$Time_{VD}$	*Time under vacuum pressure*	*ds2*
$Pressure_{VD}$	*Pressure during the process*	*ds2*
$Steel_{VD}$	*Initial and final steel*	*ds2*
$Slag_{VD}$	*Initial and final slab*	*ds2*

Two models were defined to predict the *SEE* consumption (EAF+LF).

One model (called NN) based on a standard feed-forward neural network combined with an upstream variable selection algorithm. The number of neurons belonging to the hidden layers depended on the number of selected input variables by means of an heuristic rule and the target represented by the SEE consumption. The algorithm took as input the dataset that needed to be reduced and allowed the user to specify the variables that were necessary for the analysis by forcing their inclusion, thanks to the process knowledge provided by Riva.
For the model generation the input dataset was divided in three subsets:

- training set: 50%
- validation set: 25%
- test set: 25%

For the selection of most influencing variables a customized version of the variable selection algorithm "Give a gap" (General purpose Input Variable Extraction: A Genetic Algorithm based Procedure, see[16]) had been applied. Its result represents a variables subset V_i, i = 1,2 for each input data sample and selects the most important variables. The fitness function of the GA used to measure the goodness of each solution correspond to the average absolute prediction error of the trained network computed on the validation set. The last step was the calculation of the average absolute prediction error for the test set to confirm the goodness of the selected solution.

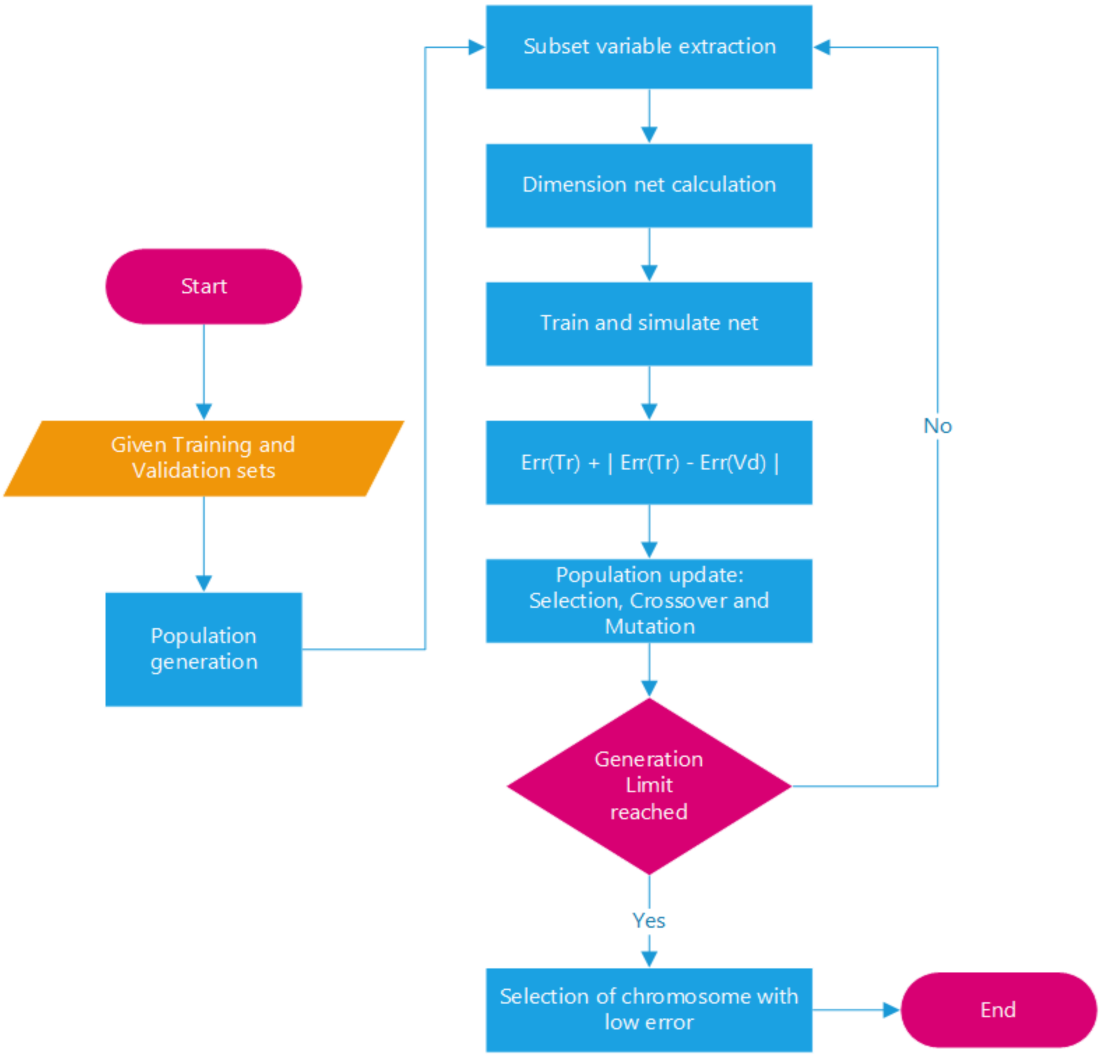


Figure 2.30: Variable selection algorithm

A simpler model (called Linear) was designed by means of linear functions (one for each input dataset) for comparison. The coefficients of such linear functions are those minimizing the mean squared error between the predicted SEE and the measured one over the training set. The following table shows an overview for both models and both datasets.

Table 2.17: Results of modelling with varying data sets and model types

Model	**Input**	**Dataset**	**Abs. Error (*kWh*)**	**Relative error**	**MSQE**
Linear	*V1*	*ds1*	4.13	0.9	12.25
NN	*V1*	*ds1*	0.39	0.08	0.57
Linear	*V2*	*ds2*	0.88	0.15	3.97
NN	*V2*	*ds2*	0.42	0.08	0.55
Linear	All variables	*ds1*	0.71	0.15	1.99
NN	All variables	*ds1*	0.24	0.05	0.53
Linear	All variables	*ds2*	0.78	0.13	3.95
NN	All variables	*ds2*	1.23	0.18	10.36

The developed SEE prediction models have been used as the objective function to be minimized. During the processing of each single heat, the steel plant technician can select the value of some process parameters while other variables can be optimized, although they must be located in a specific range that is determined by the specific production process.

Thanks to the process knowledge, RIVA and SSSA also defined relations among variables; two examples:

$$28° \leq LastLFTemperature - FirstCCTemperature \leq 51°$$

$$49min \leq TapToTap - Delay \leq 52°$$

and another example for the degassed steel class:

$$5° \leq LastLFTemperature - FirstVDTemperature \leq 12°$$

$$44min \leq TapToTap - Delay \leq 47°$$

The first two equations of the two classes constraint the temperature loss of a heat when it is transferred from the ladle furnace to the subsequent process phase.
The other two involve the *TapToTap*, the time elapsed from charging the scrap into the EAF until steel liquid tapping into ladle which is affected by the *Delay* as a consequence of several process factors.
The lower and upper bounds together with these constraints are part of a constrained optimization problem.

Results of tests on real data gathered from the RIVA plant IT system have been performed. The optimisations exploited on the one side a Matlab function called *fmincon* for the neural network predictor and on the other side a LP-solver for the linear predictor. The optimal set of variables has been used as a input to the neural network predictor to calculate the optimized SEE.
The results are shown in the following table:

Table 2.18: Performance of optimising tool

	NN on *ds1*	**Linear on *ds1***	**NN on *ds2***	**Linear on *ds2***
# of heats	7000	7000	2019	2019
Running time	62542 s	499 s	13138 s	51 s
Average time/heat	9.1 s	0.05 s	6.5	0.03
Energy saving	14.42 kWh/t	14.20 kWh/t	3.58 kWh/t	2.21 kWh/t
Rel. saving	3.24%	3.2%	0.6%	0.32%

The table shows that for the degassed steel the difference in terms of SEE savings was more remarkable even though the global saving was smaller than the one related to the non-degassed steels. The overall savings were limited in relative terms.

Figure 2.31 and Figure 2.32 compare the optimized SEE (NN model) of 100 heats with the historical data. The blue function represents the historical data, while the red one is the optimized SEE.

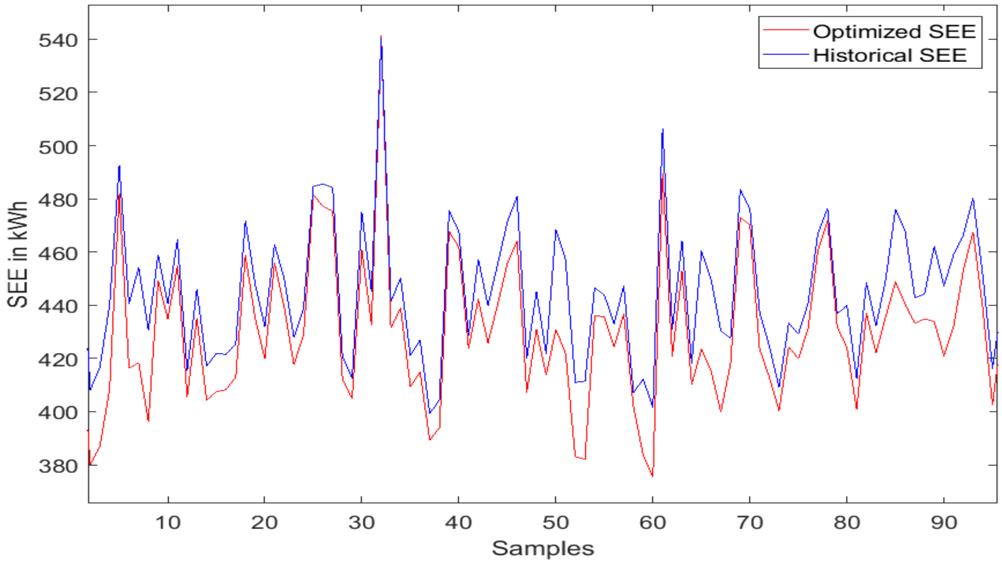


Figure 2.31: Optimized vs Sampled SEE, line plot

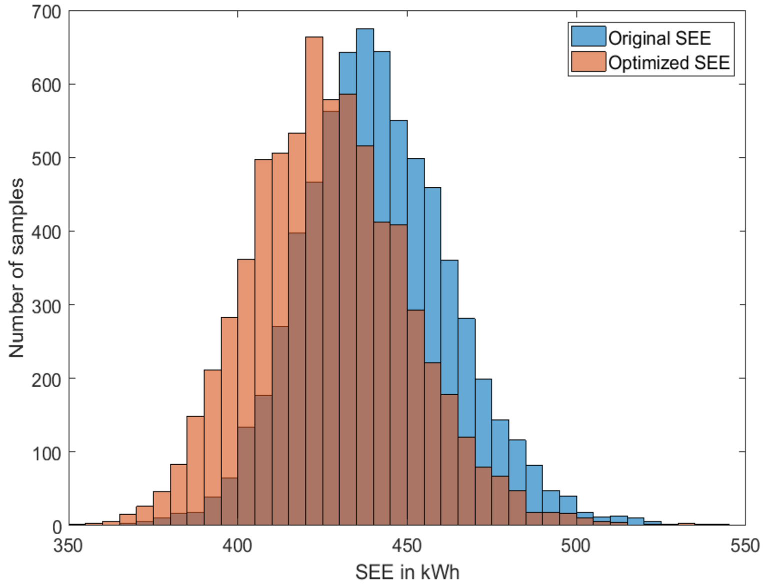


Figure 2.32: Optimized vs Sampled SEE, histogram

The optimization algorithm has been integrated in a common web environment. It can be used by steel making technician to guide themselves to how to set and combine some touchable process variables in order to consume less electrical energy for each heat.

Task 6.3, Application of EIAS for internal and external Benchmarking

Application case BOF steel production

Benchmarking is defined as the process of assessing business performance by comparing certain metrics either internally or externally. Over this task UNIOVI-AME has compiled reference values for several processes that can be used for external benchmarking.

The objective was to find the energy for BOF process compiled for three concepts:

- Theoretical Minimum energy consumption represents the minimum energy required to produce a steel product using thermodynamic calculations in ideal conditions. This consumption level is impossible to be reached but allows establishing a bottom line under which all readings must be considered as errors.
- Practical minimum energy consumption represents the minimum energy required in practical terms, that obviously is higher than the theoretical one. This is also a theoretical calculation and includes yield losses and the interactions of components during processing.
- Actual energy consumption obtainable using the Best Available Techniques (BAT).

The most completed sources worldwide were consulted for data compilation, focusing in steel trade associations and Life Cycle Inventory sources, including:

- WorldSteel
- American Iron and Steel Institute
- PE-International (GaBi)
- EcoInvent 3.0 and 4.0
- Reference Document on the Production of Iron and Steel (BREF)
- International Energy Agency
- U.S. Department of Energy
- Institute for Environment and Sustainability (ILCD database)

But the creation of reference levels for benchmarking in steel making is a very complex task due mainly to some factors:

- Oxygen steelmaking does not in itself consume energy but instead generates it. All the oxidation reactions of the elements dissolved in the pig iron during the steelmaking are strongly exothermic. The energy produced is higher than that required to raise the temperature of the cast iron (1350-1400C) to around 1650 but it implies the use of all the exhaust gas for combustion, recuperation of latent heat of slag and steel, and zero thermal losses.

- There are several inputs and outputs implied. In the process, the carbon, silicon, and other elements in the hot metal are oxidized, producing energy primarily used to melt scrap. The energy can also be used to melt and smelt (reduce) waste oxide briquettes or smelt ore. The amounts of these oxide-containing materials that can be used are significantly less than scrap because of the energy required to reduce the iron oxides. In BOF steelmaking, the energy to produce steel is less than the energy to produce iron because scrap is melted in the process. Electric energy is needed, mainly for the pumps, coolers, activation and complementary equipment.

- The different energy sources used in different factories makes the problem more complex. This diversity is remarkable in the BREF report. The energy reported by 21 existing basic oxygen steelmaking plants in different EU Member States, shows that big differences due to their different management systems.

  Table 2.19: Variations in the energy content of different energy sources

Source	**Unit**	**Input**
Natural Gas	MJ/t LS	44-730
Electricity	MJ/t LS	35-216
COG	MJ/t LS	0-800
BF Gas	M3/t LS	1.84-17.6
Steam	MJ/t LS	13-150
Compressed Air	Nm3/t LS	8-26

- Finally, as it is an intermediate process, it is not easy to find databased data, specially from LCA, generally product-oriented. The information of Life cycle data bases does not provide directly values for the BOF stage as they are based in final products but from the value of the slab, we can extract a maximum value in all the stages as they include from ore to slab, recovering all the possible energy. The most well-known value comes from Ecoinvent v4.0 the most updated and extended data base which gives 117.75MJ/t Steel coming from 80.00 kJ/t due to electricity, 0,25kJ/t from coke, 37,5 kJ/t gas and 0,07145kg of oxygen.

As the project uses BOF as the reference process, some assumptions are done:

- Energy from the pig iron is not considered as it is not possible to act on it. The liquid cast iron which reaches the converter at an approximate temperature of 1370C. Steel additions (ore, scrap, solid cast iron, etc.) are introduced at ambient temperature, intended to adjust the thermal balance, in order to obtain the target steel temperature.
- Expected energy consumption including heat losses are studied.
- Recovery of heat from steel and slag is not considered as it is different in every factory.
- Use of off-gas is not warrantied so it is not considered as a reduction of energy needs.
- The desired temperature for the steel is 1650C.

In these conditions, the absolute theoretical minimum to produce liquid steel at 1600C from Pig iron at 1450C is 487 MJ/t LS. It could increase with yield losses, heat of solution, ore reduction, scrap melting, etc. Yield losses in both oxygen steelmaking and EAF steelmaking can be significant (Fruehan 00). The highest yield loss is FeO to the slag, which can be 5% to 10%. This yield loss releases energy, but more iron must be charged and there is no energy charge for the increased scrap usage. Other yield losses can be vaporization of iron (which is oxidized to the dust), other iron losses to the dust (iron is also lost to the dust by simple metal ejection) and losses during tapping and handling. Vaporization of iron consumes a considerable amount of energy in steelmaking. The energy is not recovered when the vaporized iron is oxidized in the off gas. For 1.0% iron vaporizing in the BOF without energy recovery, the energy loss is the energy invested in the steel (80 MJ) and the heat of vaporization (64 MJ), or a total of 144 MJ/t of steel. Typical losses by vaporization are about 0.5% to 1.0%. The energy loss will result in less scrap melting, which will cause a shift from scrap to hot metal. Since hot metal requires considerably more energy than melting scrap, the resulting increase in energy could be as high as 500 MJ/t.

A more accurate decomposition of the main energy elements is shown in the following table (see[17]).

Table 2.20: Energy inputs for BOF processes

Input	**Energy (MJ/t)**
Pig Iron	1045
Oxidation of C to CO	491
Oxidation of Fe	40
Oxidation other elements (Mn, P, Si,…)	102
Combustion (CO to CO2)	94
Oxide reduction	-17
Total	**1755**

According to this table and considering the pig iron enthalpy as an external energy not linked to this process, the consumption of energy at BOF is 710MJ/t for a heat with high level of scrap. In a similar way for a heat with more ore to deoxidize, the energy is around 646MJ/t. This will be the limits fixed for the maximum consumption with mature technology steelmaking.

For the application to AME works, a big set of 4,000 heats from selected steel grades were selected with a mean value of energy 586MJ/t LS, under the value of 646MJ/t determined as BAT. Each heat was characterized by an energy value considering:

- The total oxygen used during the heat.
- A proportion of the additions.
- The direct measure of heat losses in the mobile and fixed parts.
- Electricity consumption related to the global time from charge to discharge.

The results achieved by the EIAS can be used to establish reference values to compare with other standard values to assess processes' efficiency. Also, external benchmarking can be used for anomalous energy consumption detection. The following figure shows for some sample heats the actual energy consumption values of several heats against the expected values provided by the model and the target values (under BAT conditions):

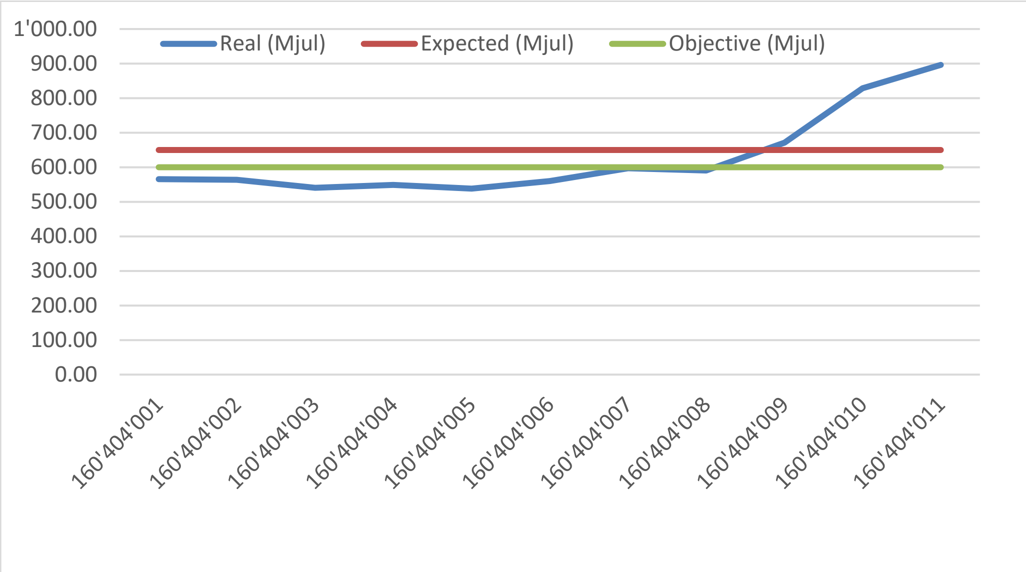


Figure 2.33: Energy use for heats (comparing real vs. model vs.BAT use)

As it can be seen, although energy values were usually correct, some anomalies were detected as real energy consumptions fall initially under the objective values and then rocket even under the same production conditions.
Further analysis has shown that differences were due to energy recovered in form of steam and LD gas that was not properly considered, so it became necessary to provide a compensation factor to correct the deviations.

Application case Hot Rolling Mill

In the studies at the hot rolling use case, internal benchmarking concerning the energy use coil processing was available by the above described structure of the resulting energy tables. With these data every selection of interesting energy value, grouped by e.g. a thickness interval or the material ID became possible. Exemplarily here a table of a comparison of different strip thickness groups is shown, where one steel grade family was selected.

Table 2.21: Used energy at different production steps for one steel family and 5 thickness ranges

Group of STRIP_THICKNESS	BISRA group	EN_SLAB HEATING	EN_RM_ DRIVES	EN_RM_ EDGER	EN_DESCA-LER	en_F1	EN_F2	EN_F3	EN_F4	EN_F5	EN_COIL-BOX	EN_ COILER DRIVE
>1.75 Und <=2.25	1	48.981	4.537	0.156	2.983	2.820	3.533	2.824	2.951	2.055	0.033	0.214
>2.25 Und <=2.75	1	75.692	4.431	0.173	3.147	2.655	2.831	2.307	2.556	1.781	0.037	0.238
>2.75 und <=3.25	1	79.023	4.379	0.192	2.954	2.475	2.419	2.096	2.148	1.631	0.040	0.189
>3.25 und <=3.75	1	75.140	4.121	0.186	2.763	2.334	2.404	2.063	2.143	1.910	0.035	0.174
>3.75 und <=4.25	1	78.278	3.998	0.153	2.507	2.132	2.300	1.965	2.030	1.876	0.028	0.169

Values are normalised to a reference strip (ΣEN=100) because of confidentiality reasons.

These compilations allowed the definition of tolerance bands regarding the energy use during the processing of a strip. At current state such calculations could only be done offline, because some of the necessary tables were actualised with a delay of some hours.

Further investigations corresponding to the energetic costs became possible by summarising the energy total energy input for the hot rolling of a certain product. By summing-up the coil-wise energy values together with basic load energy values and the heating energy (after calculation of the portion used for the specific coil by its weight) the energy costs for a specific coil or a mean value for one steel family or steel grade could be assessed in more detail.

Besides the initial analyses executed in the project, the technological experts at AMEH investigate the now accessible data in more detail by application of data analysis environments like R. This allows a data compilation and analysis tailored to the technological knowledge.

Task 6.4, Application of process monitoring and fault prevention

At AME, results from energy assignment model allowed to determine the most significant variables influencing the steel product´s energetic charge.
As explained on the previous task, data models were developed following two supplementary approaches:

1. Separate models per each steel family. This approach provided more accurate results.
2. A unique model valid to all steel families.

The next table shows all variables in decreasing order of significance.

Table 2.22: Variable importance to model

	A	**B**	**C**	**D**	**K**	**N**	**All**	
TIME_BLOW	100.0	100.0	37.2	100.0	100.0	66.7	100.0	100
O2_TOTAL	56.6	55.1	100.0	48.5	58.3	100.0	50.9	78
TEMP_SOLID_SL1	30.1	44.8	37.2	27.0	32.3	38.8	40.3	41
TEMP_OBJ_CH	24.0	49.2	19.8	17.8	46.6		33.7	32
TEMP_PIG IRON	19.7		21.8	30.5	23.1	59.5	32.4	31
WT_STEEL_OBJ	19.7	30.0		34.2	32.3	34.7	32.4	30
CARB_CONT	10.2	14.2	21.8	37.8	32.3	25.4	32.4	29
TIME_GAP		32.7	27.4	24.2	32.3	24.0	30.1	28
WT_CAO	14.3		11.2	17.8	7.8	59.5	10.0	20
WT_SCRAP	25.5	21.9		37.8			31.0	19
TEMP_LIQUIDUS	11.6	26.2			46.6			14

Where columns **A**, **B**, **C**, **D**, **K** and **N** represent the individual models per different steel families and the **All** column relates to the overall model. The column on the right-hand side shows the significance of the most significant variables weighting all models. Weighting is calculated by adding the importance of each column and dividing it by the maximum value (and multiplying by 100).

As it can be seen from the table, TIME_BLOW, followed by O2_TOTAL, are the most influential variables to all steel families (including the overall model) but steel families **C** and **N**, where the order is inverted.
On the opposite side, TEMP_LIQUIDUS is the less significant variable to most cases, and even for some models, the **All** one and the ones developed for steel families **C**, **D** and **N**, is not even included into the analysis.
Also, the weighted results show that most variables have a similar influence, as it can be seen for TEMP_OBJ_CH, TEMP_PIG IRON, WT_STEEL_OBJ, CARB_CONT and TIME_GAP.

Apart of evaluating the model, the importance of the variables can be used to determine changes in the process or in the equipment. A change in the contribution of the variables to the final value can indicate a change in the procedure, the equipment or even an unknown problem.

The EIAS also can be used for **predictive maintenance** (PdM) purposes. PdM techniques are designed to help determine the condition of in-service equipment in order to predict when maintenance should be performed; resulting in significant cost savings as tasks are only performed when warranted.

Therefore, the EIAS has incorporated a system that compares offline the total energy consumed for a heat with the expected correct value in order to detect deviations. It must be noted that production conditions are highly changeable so deviations do not necessarily entail malfunctioning or maintenance needs, so the system should not set an alarm to every deviation event.
A philosophy inspired by "**The Rule of 7**" from quality control systems has been implemented. The Rule of 7 states that when a controlled process produces 7 consecutive dots on one side of the mean there is a high chance of malfunction. Such rule is based on probabilistic theory stating an occurrence probability of 0.78%, so the process is labelled as possibly out of control.

For the BOF production, a trigger function has been included into the EIAS that sets an alarm to the plant technicians when 3 consecutive values of energy consumption deviates from the expected value on the same side. The probability of occurrence was significantly higher than for the rule of 7 (12.5%) but it must be noticed that tapping time is approximately 30 minutes, so waiting for 7 deviated heats could risk on 3.5h of process out of control and high expenditure risks.
This approach allows an efficient monitoring and minimises false alarms occurrence.

Task 6.5: Development of energy consumption efficiency indexes to be used as KPIs within Planning and Scheduling modules to compare different planning/scheduling scenarios

Based on the concepts developed in WP2, CSM and DA implemented the indices ESI and the EEI. The main calculation procedure was based on two different modules.

- The first calculates the Energy Specific Index (ESI) associated to each product, both the total and the specific energy demand. This procedure was implemented as a C# .dll that can be then integrated in the EIAS.
- The second module calculates the Energy Efficiency Index to be integrated in the EMS for the energy evaluation of a production plan.

The Energy Specific Index describes the energy demand of a specific product considering the EMS data, acquired around every 15 minutes, and the Level 2 and product data. Two different types of product/process can be considered the one where the production time of a specific product is longer than 15 min and the others.
In first case (production processes longer than 15 min) the ESI calculation for EAF, LF and VD is based on the integration of EMS energy data considering the duration of the processes according to the L2 data. As the EMS acquisition time is not always of precisely 15 minutes, the ESI calculation was done considering a variable integration step. Moreover, to accurately evaluate the specific energy demand of a product along the production chain, the use of a common produced quantity was necessary in steel shop area especially when an EAF heat can be treated in more than one LF heat. Specifically, ESI for both EAF and LF are based on the EAF tapped weight to be able to attribute the energy demand to the each LF processes.
In second case (production processes shorter than 15 min) pre-elaboration of available data from L2 and product data is necessary to individuate the specific products in each EMS interval.
In particular, for the CCM the available data (see Table 2.4) are related to heat at the beginning of the process and to the product at the end. Therefore, is necessary to calculate both the starting date of each product and the number of products simultaneously processed by the caster in each EMS interval.

The ESI calculation for EAF, LF and VD based on the integration of EMS energy data considering the duration of the processes according to the L2 data. As the EMS acquisition time is not always of precisely 15 minutes, the EIS calculation was done considering a variable integration step. Moreover, in order to accurately evaluate the specific energy demand, the ESI for both EAF and LF are based on the EAF tapped weight, as an EAF heat can be treated in more than one LF heat.
The ESI calculation for the CCM needs a pre-elaboration in order to define the starting date of each product and the number of products simultaneously processed by the caster.

Some assumption based on a statistical analysis were necessary to evaluate missing data. Moreover, the EMS only stored data when they were over a consumption threshold and therefore it was necessary to redistribute the energy demand over the duration of a CCM sequence.

Table 2.23 shows, for each EMS interval, the number of products simultaneously processed the redistribution of energy and the comparison with the recorded consumptions.

Table 2.23: Example of number of products for each EMS interval and redistributed energy compared to the recorded one

DATE_START	DATE_STOP	EE EMS	distributed EE	# products
09:15	09:30	0	0.104375	6.781211111
09:30	09:45	0	0.104375	10.62659556
09:45	10:00	0.1	0.104375	18.93490667
10:00	10:15	0	0.104375	24.69384333
10:15	10:30	0	0.104375	25.64350778
10:30	10:45	0	0.104375	35.98491333
10:45	11:00	0	0.104375	31.69659556
11:00	11:15	0	0.104375	35.54221889
11:15	11:30	0	0.104375	34.59069111
11:30	11:45	0	0.104375	35.22306222
11:45	12:00	0	0.104375	27.26777778
12:00	12:15	0	0.104375	24.33777778
12:15	12:30	0.67	0.104375	18.94888889
12:30	12:45	0	0.104375	13.26666667
12:45	13:00	0	0.104375	7.022222222

The second module calculated the EEI. It was developed using OLAP (Online Analytical Processing) cubes due to the intrinsic multidimensional nature of the data. Such an approach offered the possibility to easily set up the clustering criteria.

The cube was organised in measures where the ESI were stored and dimensions that were used to cluster the data. Four dimensions were implemented: Time, Steel Grade, Operative practice and Machine. For each ESI type mean value, standard deviation, maximum, minimum and sum were available. The mean value and the standard deviation were specifically developed because the native MS function only calculate a temporal mean value and standard deviation.

The test of the system has been performed using the native Excel interface as shown in Figure 2.34. The final user could easily select the variables to analyse, choosing any of the original or derivate measures. The dimensions could then be selected as a filter (field "Machine" =EAF in) or to define the desired granularity for the indexes calculation (field "Practice Type").

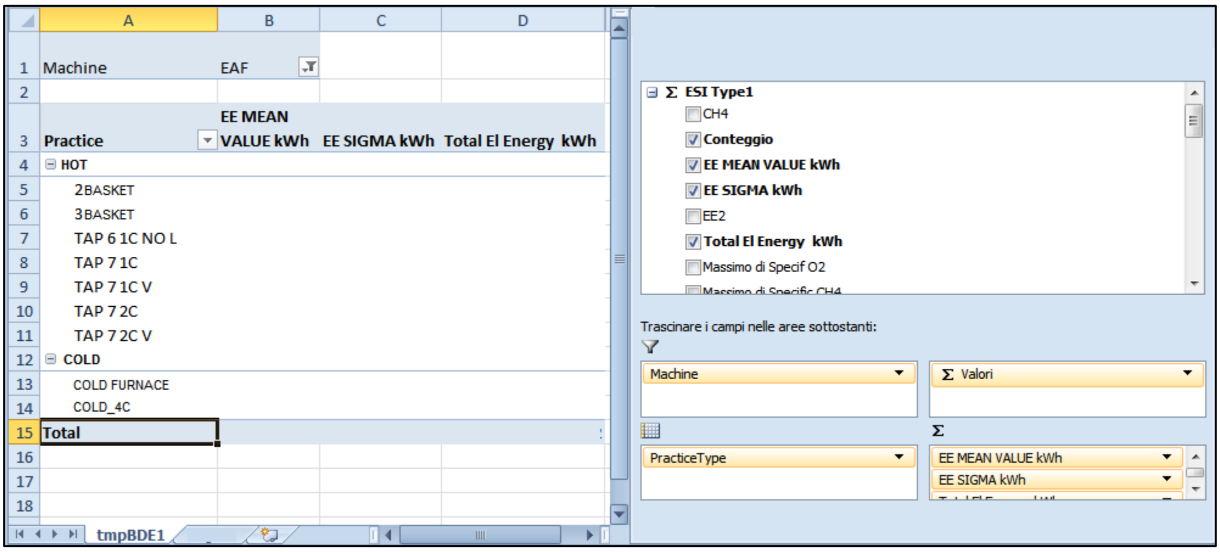


Figure 2.34: Excel interface for EEI calculation

Task 6.6: Discussion of the results with production experts

In order to discuss the results with the process experts DA, the Energy Specific Indexes calculated by the application were compared to the L2 energy data.
In particular, the total amount of energy calculated during process times by the application was compared with the total amount of energy according to EMS. In Table 2.24 the results of the comparison are shown. The DELTA column indicates the percentage of energy measured by EMS not allocated to any product. This value is due to the energy needs during idle time and approximation in the procedure.
It can be seen that both for EAF and LF, where the idle time are not considered as described in Task 6.5, the difference is quite good. On the opposite, for the CCM, the idle time has a consistent relevance in the evaluation of energy demand. In any case the total amount is two orders of magnitude less than the EAF and one less than the LF. Considering that the Index is used for the evaluation of the energy demand associated to a specific production plan, a fixed value can be considered.

Table 2.24: Comparison of EnergyDB EEI and EMS

	EE MEAN VALUE kWh	EE SIGMA kWh	Total El Energy kWh	EMS kWh	DELTA
EAF	35584	2941	58002362	61573930	6%
LF	3966	1807	6793131	7090880	4%
CCM	33	21	692015	1710610	60%

For the use cast at AME, a roundtable discussion was set after final results from the model were achieved with production experts with 3 main objectives:

1. Make them aware of the EIAS capabilities
2. Model validation
3. Future improvements

Cluster philosophy and results were discussed with the experts, coming from the plant, R&D and quality. All of them agreed on the usefulness of the tool and highlighted its potential for expel for preventive maintenance purposes, to be used for refractory walls wearing monitoring. Some other case studies were thought to continue the study of the applicability of the system. An evaluation of the best route to produce a specific grade of tinplate using two routes (an alloyed steel and a standard steel) was tested.

2.2.7 WP 7: System integration

Task 7.1: Integration of the components into an information and analysis system

All SW modules were required to be integrated in a common environment. However, due to the significant differences on the IT environments of the industrial partners, individual solutions were necessary for the user interfaces to the EIAS.

As every company had its own IT configuration, the integration of the system could not be done in a single traditional software tool but in a decentralized software environment, accessible from any partner independently of the tools they use. The advantages of this technique include:

- It allows the execution of different platforms installed in remote locations in a coordinated way.
- It is a standard technique, perfectly defined and well-known.
- Free, no licence fee has to be paid.
- Accessible through HTTP which avoids problems due to firewalls or other usual protocols like FTP or SMTP.
- Independent from platform (e.g. Windows, Linux), programming language (e.g. JAVA, C#, C++) and protocols (e.g. HTTP/HTTPS).
- Fast adaptation to the individual preconditions given at the industrial partners IT environment as well as a fast implementation.
- Possibility to integrate new modules, remote or locally.

This also ensure the update and maintenance of the system as every partner develops, runs and stores it in its own environment and server.

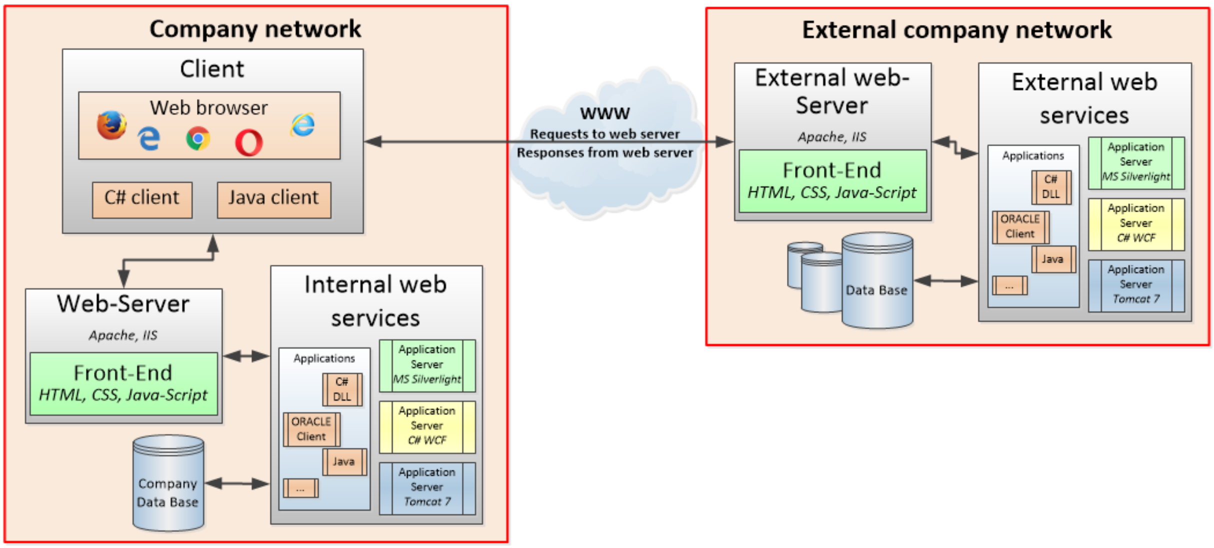


Figure 2.35: Sketch of the web system of EIAS

AME/Uniovi models were implemented using software modules hosted in a server of AME R&D accessible from other factories of the company. This kind of web services, well-known techniques, were selected because they are usable whatever configuration the plants have. This will ensure its use internally as its immediate transferability to the other members of the consortium.

UNIOVI-AME fit-to-purpose tool EnergyDB developed for this RFCS project was stored in AME´s premises and graphically configured as shown on Task 6.2. The software package for AME was based on a previous framework, capable to generate software by graphical programming. Final code was implemented using the Microsoft.NET version 4.5, fully compatible with Microsoft Windows Operative Systems 7 or newer. However, the graphic capabilities cannot be used for thin-client use, so a direct access route to kernel has been developed allowing the optimisation tool execution for the web services, although changes on the configuration could only be done locally.

SW included three main functionalities:

- Determination of the expected energy consumed for a given heat.
- Evaluation of its energetic efficiency according to internal and external standards.
- Proposal of a new configuration for the heat optimising the energy consumption.

And other Non-functional features as:

- Export/Import data from Excel files.
- Administrative tools to manage and update the system.

The solution was able to handle data in different formats:

- EXCEL xlsx file
- CSV file (comma separated value)
- XML file (extended mark-up language)
- ASCII file (American Standard Code for Information Interchange)

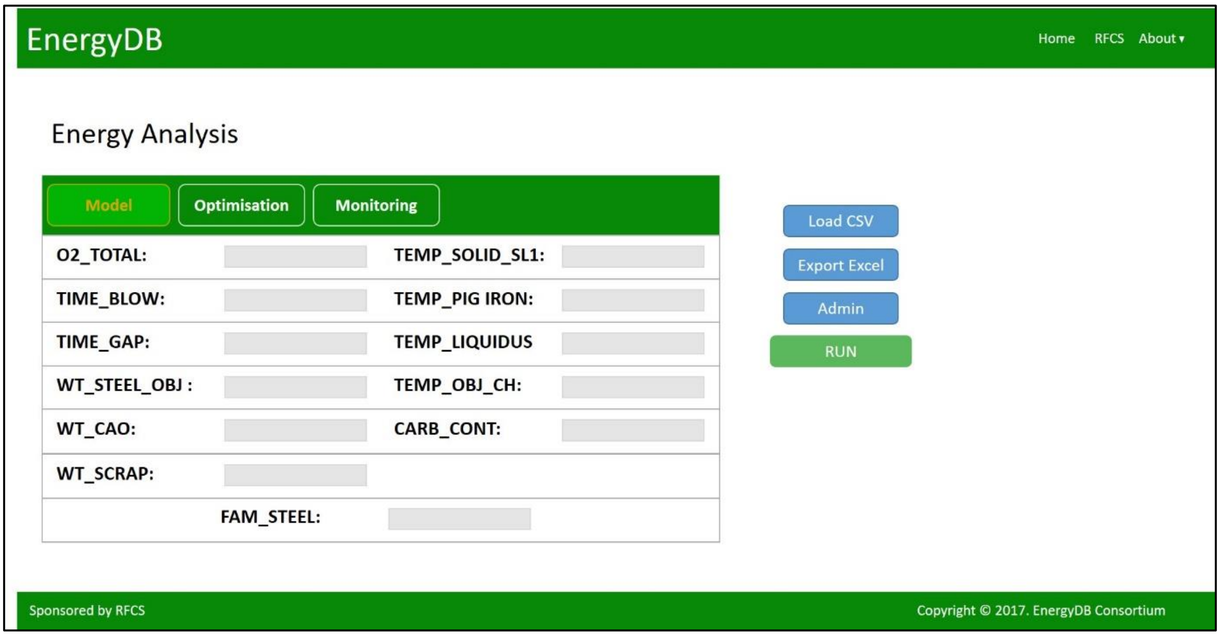


Figure 2.36: Example of HMI developed for AME/UniOvi tool

In case of the use case of DA, the calculation of Specific Index was realised by a dll to be executed off-line each day. A specific dll could be integrated in the MES system for extemporary calculation or integrated in a console application to run each day on the new acquired data. In the EIAS both the visualization of the Specific Indices and the calculation and visualization of the Efficiency Indexes were inserted.
See the figures below for examples of related menues.

Figure 2.37: Web Interface for ESI selection and visualization

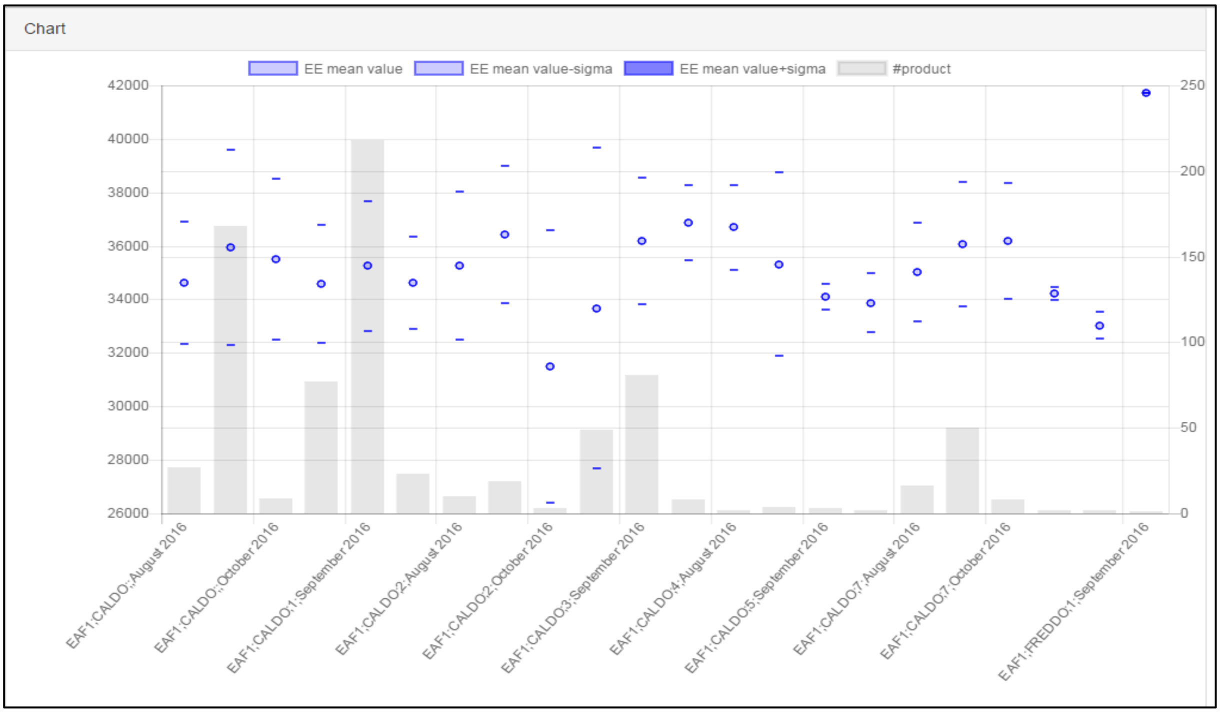


Figure 2.38: Web Interface for EEI visualization

In Figure 2.37 the web interface integrated in the EIAS is shown where the user can select plant, time interval, steel group and practice.

In Figure 2.38 an example of the visualization of EEI for one EAF with operative practices a selected month is shown. For each of the identified group mean and +- sigma values together with number of considered samples is reported.

In Figure 2.39 below, an example of the use of EEI in the MES is shown. According to the production plan shown in the lower part of the figure, the energy profile based on the EEI was calculated and shown. Moreover, the total energy needed for the whole plan was calculated. In such a way different plans could be compared from an energetic point of view. The continuous caster was not reported in the plan because it accounted for a fixed contribution.

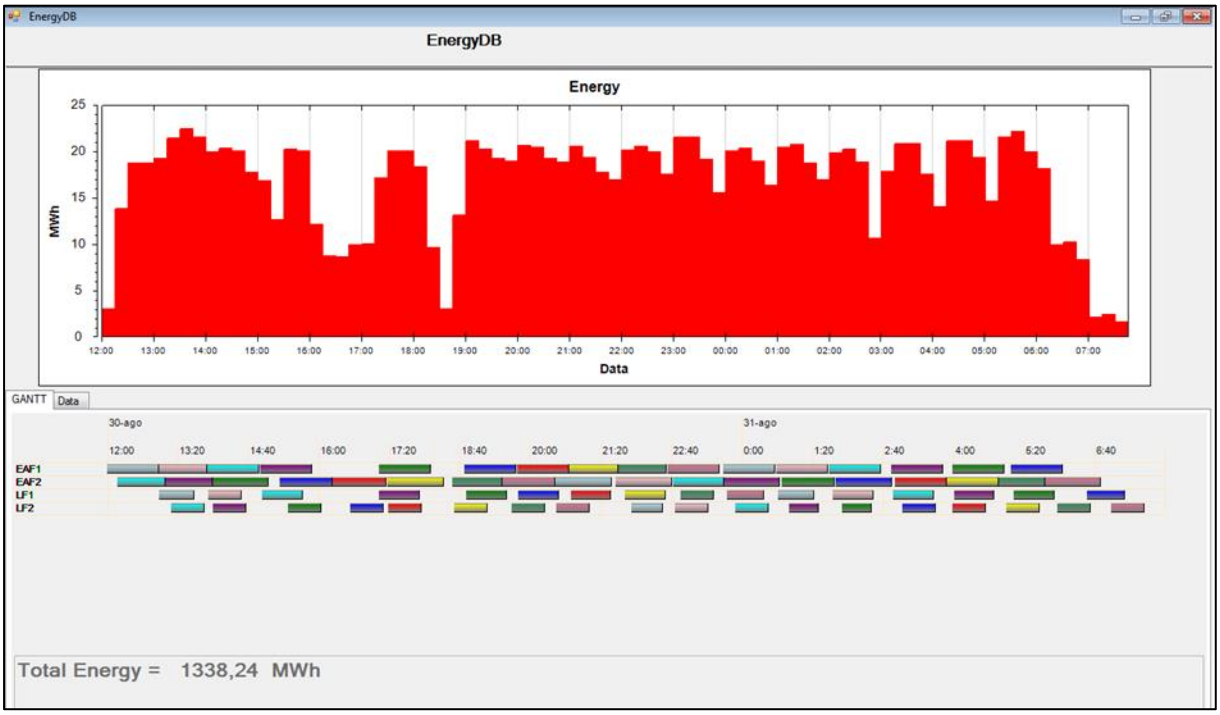


Figure 2.39: Example of EnergyProfile

The RIVA and SSSA optimization tool can be executed for the degassed heats or for the non-degassed heats. Several settings can be specified by the user, such as which are the touchable variables (see Figure 2.40), which is the model the user prefers to use (linear or NN or both), which optimization function (e.g non-linear programming solver) and the ranges of acceptable values for each variable.

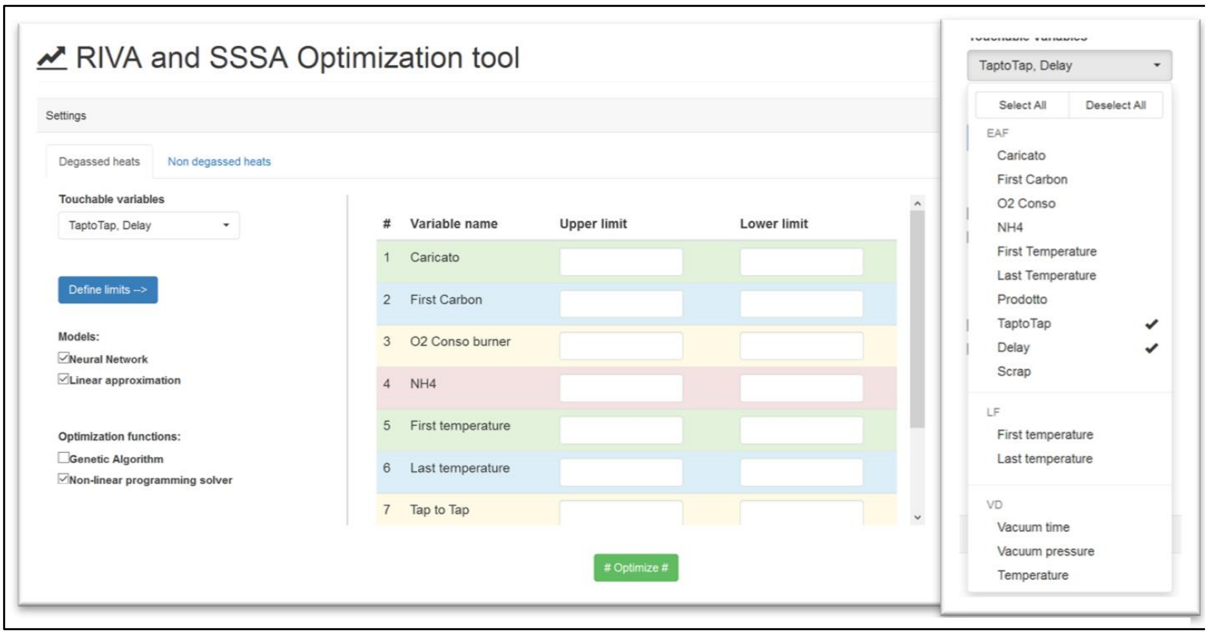


Figure 2.40: SSSA optimization tool

If this last field is left empty, the algorithm takes both limits from the historical data.
An example of the execution of the algorithm is shown in Figure 2.41, where the interface gives as output a comparison of the two different optimization functions and even how the alterable variables have been modified in order to obtain the following results.

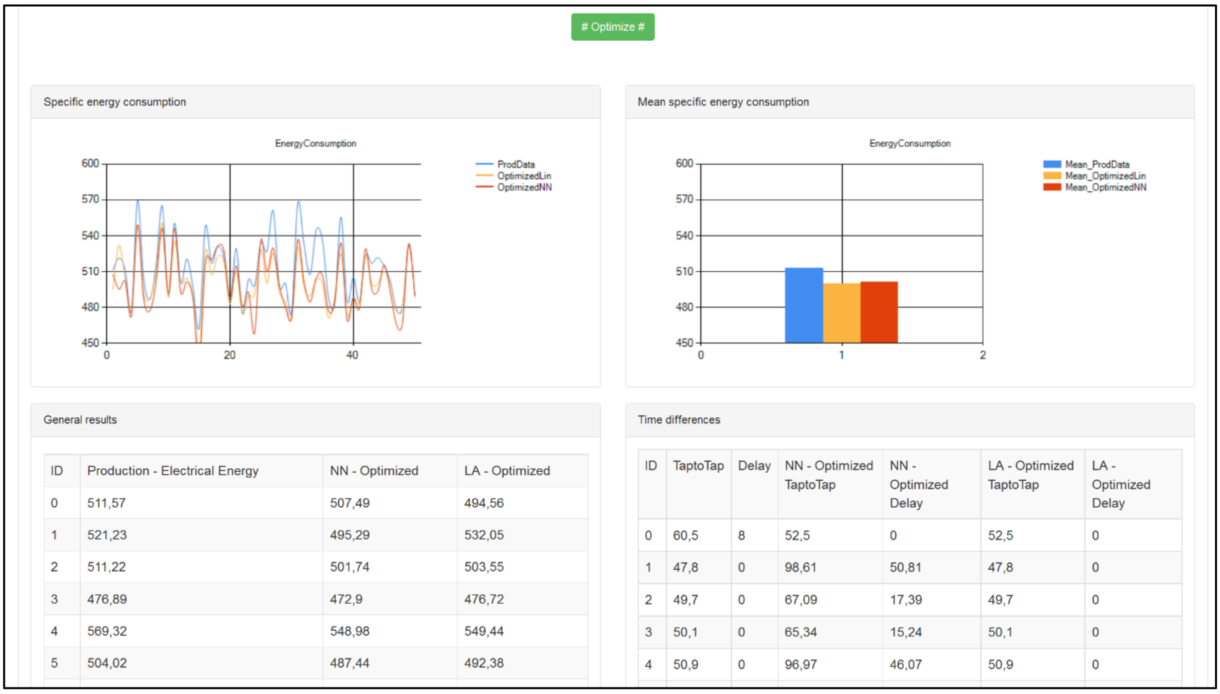


Figure 2.41: Example result

Task 7.2: Realization of an offline test environment

The offline simulation environment was implemented in a dedicated server, equipped with a SQLServer database hosting the same DB structure of the L2 and EMS data.

The DBs were configured accordingly to DA specification for both L2 and EMS data and were populated with a selected set of data coming from specific acquisition campaigns. The server also hosts a selected set of MES and EIAS modules relevant to the scenario analysis.

The test of the EIAS applications, for the DA and CSM parts, were performed using this offline environment.

Task 7.3: Realisation of the automatic storage of the energy consumption information into the data base

The automatic storage of the energy consumption information into the data base was solved locally. Both AME´s production DB and UNIOVI simulation & research BD were integrated and operational and using the same system could be integrated with the other partners. Original sources were the process database and the business (Level3) database, both on Oracle. Although during the modelling stage a non-SQL DB was used, the final DB installed for the common framework was developed on MySQL in order to ensure accessibility and compatibility with the DB of the rest of the partners (SQLServer, Oracle and MySQL). All partners use ANSI standard statements, avoiding system specific SQL statements to facilitate the integration.

At AMEH the derived energy data per product/process step were stored in an Oracle database running at AMEH's site. Additionally, results of analyses were stored into dedicated data tables for documentation and further examinations.

Data of Level 2 system and EMS were stored in a MS SQLServer database at DA. There was also the local EnergyDB incorporated for storage of ESI and EEI KPIs.

Task 7.4: Implementation and installation of the EIAS

As stated over the previous tasks, AME´s and UNIOVI´s databases were fully integrated and operational. Also, as stated on Task 7.1, AMEs contribution to the final EIAS runs through by web service so it does not require local installation and therefore establishing local links was not necessary and it was accessible from everywhere.
Consequently, the EIAS will not be installed straight into the production PCs but will run from the specific process server just with a click on a link. Then it will support experts to assess the correct production operation and optimize the production planning processes.

Task 7.5: Guidance of the target user and activation of the developed system

During the project the production and quality experts of the industrial partners, the final users of the systems, were involved from the very beginning. That was the case of AME were technicians participate on the models developed by Uniovi so they were familiar with the concept development and implementation.
UNIOVI had profit from its teaching experience to develop a specific training course for AME target users. The training material was composed by a set of exemplary tutorials and a practice exercise to be performed by the trainee with the assistance of UNIOVI staff.

Over this task UNIOVI has provided a training session to AME target users. Software user manual, attached as an annex to this document, was delivered to the relevant AME staff members. During the training session held in AME´s premises users were guided through the application's interface following some exemplary cases and all questions were answered.

All other partners executed training sessions to instruct the staff in the basics and the handling of the implemented tools. Also documents for internal use with detailed descriptions of data interconnections were handed out.

2.2.8 WP 8: Test and evaluation

Task 8.1: Test of the system

The EIAS module developed by UNIOVI is running by web service means and so is accessible to AME´s production experts.
New data has been incorporated to the database and system remains with a correct behaviour keeping the required precision.
The new buttons developed over Task 7.1 have been tested with successful results.

The ESI and EEI calculations at DA have been tested on the offline test environment with industrial sample data.

In case of the procedures implemented at AMEH, the continuous operation by means of time triggered calls of the procedures to fetch the necessary data and to store derived figures was tested concerning

- the robust operation of the procedures, also in case of uncomplete filled source tables and related computation problems
- the correctness of calculations also in case of missing values. In case of important measurements like temperatures of which several sensors exist, a graduated approach is looking for the most reliable measurement. In cases of missing values, the derived calculations will deliver no value (NULL) to avoid confusion with values equal "0" which are correctly calculated, albeit it is mostly an uncommon value.

Task 8.2: Evaluation of the reached results

AME/UNIOVI has prepared their evaluation following the SWOT analysis format shown in Table 17:

Table 2.25: SWOT analysis performed by AME/UNIOVI

	STRENGTHS 1. Clear results 2. User friendly 3. Coexist with existent system	**WEAKNESSES** 1. Not very flexible 2. Future modifications of the plant have to be integrated by a third part
OPPORTUNITIES 1. Optimization 2. Synergies 3. Detailed information	Optimization and new opportunities regarding energy saving are possible both in case of improved routing and comparison of energy efficiency for single products. Priority of actions became more clear.	EIAS should be modified if any change on the plant configuration/layout/revamping is done. This could help to design future more efficient process. EIAS should be modified when significant productive changes on the plant configuration/layout/revamping is done. This could help to design in future more efficient process.
THREATS 1. Possible mistakes due to DB lack of maintenance or wrong signal values	Some warning rules should be implemented in terms of bad data insertion. The user interface should be adapted to this field.	Any change or modification cannot be done by internal resources of the plant. It is dependable in a third part. Maintenance may be a problem

Task 8.3, Tuning of the system, if necessary

The system is already completed and no significant tuning is expected to be necessary. However, all steel manufacturers, including AME, are continuously developing new products to fulfil the market needs so new steel products are arising at BOF. Therefore, some maintenance and tuning , e..g. for re-training of cluster representation, is expected to accommodate the evolution of the BOF´s product mix.
During this task, new steel products and grades produced at Avilés´ BOF were being assessed in order to incorporate them into the EIAS keeping the same philosophy presented over the previous tasks. Because the reliability of this analysis dependents on reaching a minimum amount of heats to each assessed product, so new products will not be included into the EIAS until reaching a minimum number 500 heats. Moreover, UNIOVI and AME have been working coordinately to find new ways to ease the tuning process when changes in production processes and/or the product mix occur, so AME production experts are nowadays able to perform the EIAS maintenance without UNIOVI experts' intervention.

For the installation at the hot rolling use case a tuning of the implemented approach was necessary because of slow processing speed. Here the creation and use of temporary tables which serve as intermediate storages and which include an indexing of often requested columns accelerated the data access massively.

Task 8.4: Evaluation of the transferability

The ESI and EEI calculation has been developed in such a way that it is very easy to insert them in new Danieli Automation industrial systems if the final customer is interested in the developed functionality. Some tuning up may be necessary depending on the specificity of the customer plant layout and available processes. Especially in such cases the developed semantic model clarifies and simplifies a structured documentation of changing plant layouts and processes and the implementation of the procedures and tools for the energy efficiency analysis.

The module developed by UNIOVI is addressed to Avilés BOF conditions. Transferability of the system to other processes/installations is possible but as a service because its introduction into industrial environments other than this one is subjected to several physical and logical constrains. However, even though a direct transfer of the whole system in its actual condition is not possible, the concept, methodology and techniques used are transferable. A new rollout would require some consulting work in order to adapt the system to the new specific purpose as well as it would require certain period of training for the new project team. This could be done by either any of the research partners of the EnergyDB consortium or an external consulting firm instead. It is important to mention that this procedure is frequent into the IT sector like the way other well-known tools or systems, like SAP for instance, operate.
The internal transferability from the exemplary processes to other facilities inside the consortium partners is simpler due to the decentralised implementation approach. Corporate IT services could host the web servers managing the services developed over this project and its different plants could use the applications without new requirements for local installation. This centralised approach would facilitate maintenance and further developments of the tool, easing the scalability still allowing access from any side of the world.

The accumulate delays kept pushing forward the initial intention to present the EIAS and its results in a workshop. For that reason, workshop´s date had to be postponed after the RFCS project´s end and UNIOVI will assume its full cost.

The implementation of a coil-wise assignment of energy values at selected aggregates in the hot rolling area has shown that the used approach of the synchronisation of energy data with process data is successful. Occurring problems or difficulties are related to the structure of the underlying database system and the structure of source data tables. Here massive efforts had been necessary to achieve the aimed gapless data assignment. And such efforts will be necessary also when transferring the implemented approach to another plant.
In Annex 4.1, Guidelines for structure of energy databases, the authors try to explain the problems occurred during the project's work and give some hints and suggestions how to proceed in future applications.

Task 8.5: Final report and presentation

The draft final report was prepared with a delay and presented at the TGS9 meeting in May, 2019 in Duisburg, Germany.

2.3 Conclusions

Assessing energy use and efficiency is a promising subject to achieve improvements and optimisations in the manufacturing of steel.
If one leaves the way of using energy information only for cost estimations but sees this information on the same level as process and product data, the common investigation of both information sources can lead to new insights and opportunities of improving processes and optimising production plans and process guidance.
But the work in this project shows that the way to a beneficial use of energy data is a difficult and laborious. Starting from the access on energy data which are existent on internal or external sources, the structure and the resolution of this data in time and "space" (single aggregates or complete areas of production) influences the necessary efforts for the energy assignment and assessment as well as the level of detailing.
Furthermore, the IT environments at the different industrial sites have been grown over years, so a wide variety of heterogeneous and specialised database and automation systems was found. This fact enhances the efforts in the synchronisation and assignment of energy and process data. Especially for the assignment of energy to the processes and furthermore to intermediate or final products the energy sources and the energy "drains" had to be identified and formal descriptions must be defined.
For the preparation and processing of data besides traditional univariate techniques also sophisticated methods like PCA, LOF or Fuzzy technology were applied.

The ambiguous goal to develop one system incorporating the different examined application cases was not possible because of different reasons.
One reason for that failure could be found in the security guidelines of the companies. So in some cases, external access was strictly prohibited, and this prohibition was technically implemented. For example, so-called VPN connections (Virtual Private Network) were permitted for external access, but at the same time the access via a web browser was suppressed, also in case of an established VPN access. Therefore, the original idea that each partner could access the functionalities of the other partners via a web-based application could not be implemented.
In addition, certain forms of data processing and aggregation were carried out within existing database extensions, which were not accessible from the outside under no circumstances. A web-based application could only be used in the company's intranet. Therefore, the transfer of this promising concept was done locally at the industrial premises at AME and DA. For the future development of systems basing on internet connections, it is essential to find other ways to secure the communication between different application sites.

But the realised EIAS systems showed the applicability of the designed concepts:

- The development of the different tools to assess the energy efficiency at the production route of AME's integrated steel production at Aviles allows an optimisation of the production planning related to energy efficiency aspects.
- In a similar way at RIVA the implemented system focussing on the steel route via EAF and secondary metallurgy treatment supplies information to improve the processes to minimise the used energy, especially for steel grads being degassed.
- For DA the developments offer opportunities to valuate and compare products and product families by a formalised generation of energy indices which supports the comparison of different processing routes. DA's application case is located on a more abstract level than the other application cases because as a supplier of steel making technology they focus more on general concepts and approaches to fulfil the requirements of different customers. Therefore the results achieved here are those with the estimated lowest transfer efforts to a single specific plant, but have the required high intrinsic portability to be applied across different mills.
- The assignment of energy use to the production of single products in the hot rolling area of AMEH for single process steps like roughing or rolling at a single stand, delivers a detailed energy information about the different processing steps at hot rolling. The availability of such detailed energy information supports the analysis of energy use to detect irregularities at one process step when producing similar products and to find reasons for such irregularities, or just to assess the amount of total energy used for one single product or steel grade.

In all cases one occurring difficulty was related to the brown-field implementation, because the existing IT systems especially for the acquisition and supply of energy information have not been designed in the past to be detailed and accessible like "conventional" process data. The resolution in time of electric energy is often limited to several minutes (e.g. the well-known 15 min-values for electric parameters), but also the acquisition of other energy sources and carriers like gases or steam is mostly not very detailed and it is difficult to access the data. Additionally the incorporation of external companies like power suppliers or others increases the complexity of data acquisition, synchronisation and access.
Just for the latter aspect, the growing interconnections between the members of a production chain following the Industry 4.0 schemes may support future developments in the field of energy information and energy efficiency.

2.4 Exploitation and impact of the research results

2.4.1 Actual applications

At AMEH hot rolling area the following applications are the result of the presented project:

- The system of energy assignment to single products on a per-process-step resolution delivers detailed information about the energy use at single aggregates per coil, about the basic load at the same level of differentiation and an estimation of the efficiency of the furnace operation.
- With the new applications deeper analyse are possible to define reference values for different product families (related to steel grade, coil geometry, transformation in the preceding process step, …) to detect deviations in the energy use from those reference values.
- Irregularities in the used energy of single products can be detected and analysed to uncover reasons for that behaviour using a Matlab based analysis tool and R programming.
- Energetic costs for producing coils can be estimated more accurate to improve the production planning with regard to changing energy costs during in advance.
- A tool for pre-defined analysis and assessment of energy and product data is implemented for automatic reporting.

For the optimisation of AME's production route and planning following applications were developed and implemented

- a route simulation using UNIOVI's proprietary modelling & simulation framework ATOS
- a modelling approach using MARS algorithm for energy estimation
- a clustering tool based on Self Organising Maps which groups the data sets of most important heat parameters into a map of sub-clusters. Related to these clusters is the energy use derived from the historical data. The assignment of an approaching heat to one of these clusters and a further detail search for a similar heat that fulfils the constraint of less energy used.
- outlier detection by the application of a PCA

SSSA's developments and their application at RIVA includes

- the modelling and estimation of the energy demand of single heats in the secondary metallurgy using a neural network approach and a LP-Solver for the linear predictor
- a multi-variate outlier detection methodology incorporating different approaches to identify anomalous heats

At DA, the investigations done on energy assignment according to well-defined and generalized KPIs were extremely useful to define the system dealing with such a vast domain. The key aspect here was the definition of an efficient way to translate historical information to expected energy use.
Additionally, the data analysis results proved the validity of such an approach, but also defined how to display energy information to the user in a concise and efficient way. This aspect in particular was already applied outside this project scope to improve the usability of dedicated plant performances monitoring tools.

2.4.2 Technical and economic potential for the use of the results

The results in finding improved production routing and process guidance will reduce the energy use for the production of steel. Just in the production of liquid steel with its high energy demands such reductions will lead to economic and ecologic benefits.

The developments applied at AME supports the company to analyse similar heats in detail with the main target of improving energy consumption of the steel shop. From that, diverse strategies were taken into consideration by the technical team of the steel shop implementing new rules to the operators and automation of the plant. Apart from that, it is possible to optimize different process variables depending on the different nature of the heats (time, composition, temperature requirements…). Another advantage is the possibility of allocation and comparison of different heats, especially those with worse GJ/hot metal Tn to optimize and save energy.
System's operation into ArcelorMittal Spain premises is resulting in substantial energy savings due to routing optimisation. Due to confidentiality issues details cannot be disclosed.

Because the information retrieval of energy use and energy flows will increase in the future, the generation of energy related KPIs will become more detailed, more accurate and thus more beneficial for the steel produces. An example is the planned revamping of the automation systems at AMEH, where the new system includes energy monitoring for the drives so more information will be available in the future. Also the wider application of Smart Meters with their integrated connectivity via networks and their implemented capabilities in data processing will increase the amount of information and thus will improve its exploitation.

The detection of deviations from reference values in a detailed manner applied at the different use cases will increase the awareness of necessary countermeasures including maintenance actions or deeper cause analyses.

2.5 Any possible patent filing

There are no patents pending.

2.5.1 Publications / conference presentations resulting from the project

Mocci C., Maddaloni A., Vannucci M., Cateni S., Colla V. (2018)
A Dive into the Specific Electric Energy Consumption in Steelworks. In: Rocha Á., Adeli H., Reis L., Costanzo S. (eds)
Trends and Advances in Information Systems and Technologies. WorldCIST'18 2018.
Advances in Intelligent Systems and Computing, vol 746. Springer, Cham

2.5.2 Any other aspects concerning the dissemination of results

A workshop was not executed.

2.6 ***List of Figures***

2.7 ***List of Tables***

3 REFERENCES AND LIST OF ACRONYMS/ABBREVIATIONS

Reference List

[1] The British Iron and Steel Research Association: Physical constants of some commercial steels at elevated temperatures, Butterworths Scientific Publications, 1953

[2] Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control

[3 Best Available Techniques (BAT) Reference Document for Iron and Steel Production, European Comission, 2013

[4] Best Available Techniques (BAT) Reference Document for Ferrous Metals Processing Industry, European Comission, December 2001

[5] Best Available Techniques (BAT) ReferenceDocument for Energy Efficiency, European Commission, February 2009

[6] Theoretical minimum energies to produce steel for selected conditions, U.S. Department of Energy, March 2000

[7] Holzknecht, N.; Cananas Corrales, M.; Heckenthaler, T.; Nastasi, G.; Ortega, F.: Intelligent control station for improved quality management in flat steel production by a next generation decision support system (ICONSYS), RFSR-CT-2012-00037, Jun 2012-Dec 2015

[8] Linnenberg, T.; Müller A. W.; Christansen, L.; (2013) ONTOENERGY – A LIGHTWEIGHT ONTOLOGY FOR SUPPORTING ENERGY-EFFICIENCY TASKS Enabling generic evaluation of energy efficiency in the engineering phase of automated manufacturing plants, Conference: KEOD 2013 – International Conference on Knowledge Engineering and Ontology Development

[9] NASA, Jet Propulsion Laboratory at California Institute of Technology: SWEET – Semantic Web for Earth and Environmental Terminology, 2012; http://sweet.jpl.nasa.gov

[10] e-SAVE - Energy Efficiency in the Supply Chain through Collaboration, Advanced Decision Support and Automatic Sensing, FP7 project 288585, 2012-01-01 to 2014-06-30

[11] Wang, Xin; Wang, Chuan; Grip, Carl-Erik; Dahl, Jan; Implementation of energy audit in the Chinese steel industry - case studies of integrated steel plants, Scanmet III, 3rd International Conference on Process Development in Iron and Steelmaking, Proceedings, Vol. 1, Lulea, SE, 8-11 June 2008

[12] Ebel, A., Marchiori, F., Lonzi, G., Diego Diaz F.: Knowledge management and decision support with special focus to process and quality optimisation at flat steel production, (RFSR-CT-2009-00031)

[13] Friedman, J. H. (1991). "Multivariate Adaptive Regression Splines". The Annals of Statistics. 1991

[14] "A multivariate fuzzy system applied for outliers detection." Cateni Silvia, Valentina Colla, and Gianluca Nastasi. Journal of Intelligent & Fuzzy Systems 24.4 (2013): 889-903

[15] Kohonen, Teuvo. " Self-Organized Formation of Topologically Correct Feature Maps", Biol. Cybernetics 43, 59-69 (1982)

[16] "General purpose input variables extraction: A genetic algorithm based procedure give a gap." Cateni Silvia, Valentina Colla, and Marco Vannucci. Intelligent Systems Design and Ap-plications, 2009. ISDA'09. Ninth International Conference on. IEEE, 2009.

[17] Béranger, G., G. Henry, and G. Sanz. "Le livre de l'acier. 1994."Paris: Lavoisier-Technique et documentation

List of acronyms and abbreviations

Acronym	Definition
AME	ArcelorMittal Spain
AMEH	ArcelorMittal Eisenhuettenstadt GmbH
BF	Blast Furnace
BFI	VDEh-Betriebsforschungsinstitut GmbH
CC, CCM	Continuous Casting (Machine)
CSM	Centro Sviluppo Materiali
DA	Danieli Automation
EAF	Electric Arc Furnace
EEI	Energy Efficiency Index
EIAS	Energy Information and Analysis System
EMS	Energy Monitoring System
ESI	Energy Specific Index
FTP	Fumes Treatment Plant
HSM	Hot Strip Mill
LF	Ladle Furnace
LRF	Ladle Refining Furnace
MES	Manufacturing Execution System
PSA	Pressure Swing Adsorption technology for Oxygene production
RHF	ReHeating Furnace
RM	Rolling Mill
SSSA	Scuola Superiore di Santa Anna
SY	Scrap Yard
VD	Vacuum Degasser
VEO	Vulkan Energiewirtschaft Oderbrücke GmbH
WTP	Water Treatment Plant

4 ANNEXES

4.1 Guidelines for structure of energy databases

Concerning the evaluation of energy use for single pieces like slabs or coils, the project shows that the existing system at AMEH could be improved, especially from the data analysts view.

The investigated energy data acquisition system at AMEH's hot rolling plant delivers the energy data – mostly currents of the related electric devices and systems – in the form of "change telegrams". That means, the related table has one row for each measurement consisting of the timestamp, the identifier of the device/system, and the measurement value itself. The timestamps are not equidistant, a new row for one device/system is generated if the current value exceeds a tolerance band around the previously acquired value. This reduces the number of rows during periods without significant variation, whereas in times of high "activity" measurements are documented at sample rates up to 2 or 3 measurements per second.
This is a common approach in steel industry not only for energy related data but for all kinds of measurement data of processes and plants.

This approach produces much more smaller tables, e.g. per hour, than tables with values measured at equidistant sample times of according high frequency.

Table 4.1: Real "Change telegram" table vs. table of fixed sample rate

	Time period hours	**#rows**	**#columns**	**size**
Change telegram	9	230000	3 (date, number, number)	7168 kB
Fixed sample rate (5Hz)	9	160000	52 (date, 51 x number)	~50000 kB

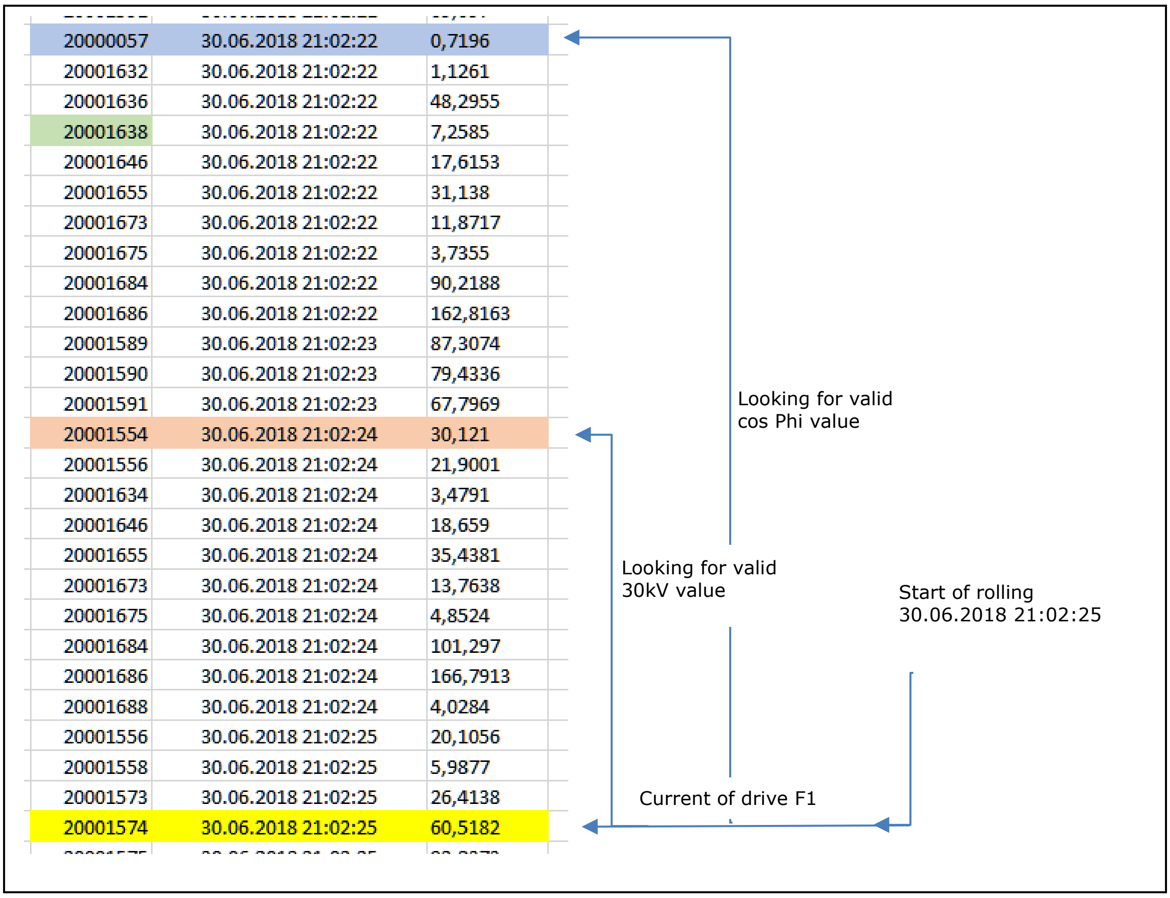
The scheme of change telegrams was necessary some years ago when storage capacity was expensive and an essential part of investigations into IT technology. But nowadays storage is cheap and concepts of acquiring and storing sensor data at high and constant sample rates fail no more because of processor and storage capacity.
From an analyst's view the simplest solution is to store data at fixed sample rates when they should be mathematically combined like in the calculation of electric energy out of the data for current, voltage and cos Phi. Having these data measured at the same time stamps, calculation of energy needs no complex search for those values of voltage which are related to a current measurement at a certain time.

The sketch on the next page will clarify the difficulties and the corresponding higher efforts in programming and processing time for the assignment of these values
For the calculation of electric energy used for a drive one needs the motor current, the related voltage and the cos Phi value. I.e., in case of a given time stamp for the start of rolling a certain coil

1) the drive current value has to be identified when the rolling start by process timestamp
2) the last measured voltage value just before this timestamp has to be identified, and
3) the last measured cos Phi value right before this timestamp.

Additionally for the integration of the energy for a time period, e.g. the duration of a rolling operation at one rolling stand, the varying different time distances between two measurements have to be considered by increased programming efforts.

The following figure shows this procedure.



20000057	30.06.2018 21:02:22	0,7196
20001632	30.06.2018 21:02:22	1,1261
20001636	30.06.2018 21:02:22	48,2955
20001638	30.06.2018 21:02:22	7,2585
20001646	30.06.2018 21:02:22	17,6153
20001655	30.06.2018 21:02:22	31,138
20001673	30.06.2018 21:02:22	11,8717
20001675	30.06.2018 21:02:22	3,7355
20001684	30.06.2018 21:02:22	90,2188
20001686	30.06.2018 21:02:22	162,8163
20001589	30.06.2018 21:02:23	87,3074
20001590	30.06.2018 21:02:23	79,4336
20001591	30.06.2018 21:02:23	67,7969
20001554	30.06.2018 21:02:24	30,121
20001556	30.06.2018 21:02:24	21,9001
20001634	30.06.2018 21:02:24	3,4791
20001646	30.06.2018 21:02:24	18,659
20001655	30.06.2018 21:02:24	35,4381
20001673	30.06.2018 21:02:24	13,7638
20001675	30.06.2018 21:02:24	4,8524
20001684	30.06.2018 21:02:24	101,297
20001686	30.06.2018 21:02:24	166,7913
20001688	30.06.2018 21:02:24	4,0284
20001556	30.06.2018 21:02:25	20,1056
20001558	30.06.2018 21:02:25	5,9877
20001573	30.06.2018 21:02:25	26,4138
20001574	30.06.2018 21:02:25	60,5182

Figure 4.1: Procedure to assign data in the calculation of single energy values

This sketch shall show the difficulties in the search of the valid figures used to calculate the energy used for one single measurement.

Therefore it is suggested

- to use sensor equipment able to acquire and transfer data at high sample rates to not lose necessary resolution of information
- to apply concepts in the databases enabling the storage of such data together with equidistant time stamps (fixed sample rates)

Such a concept supports also the near-online evaluation of data for immediate use of results.

After exploitation, the data can be compressed by suitable mechanisms to reduce the memory capacity, so the long-term storage will not exceed in comparison to the former approach.

4.2 Description of MARS algorithm

MARS method is a nonparametric regression procedure that makes no assumption about the underlying functional relationship between the dependent and independent variables. Instead, MARS constructs this relation from a set of coefficients and basis functions that are entirely "driven" from the regression data. In a sense, the method is based on the "divide and conquer" strategy, which partitions the input space into regions, each with its own regression equation. Mathematically expressed the model is given by:

$$\hat{f}(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{M} a_i B_i(x)$$

where:

$x \in D$

$a_i, i = 1, \ldots, M$ are the coefficients of the basis function B_i

M à is the number of basis function within the model.

The type of the basis functions used by MARS:

$$B_i(x) = \begin{cases} 1, & i = 1 \\ \prod_{j=1}^{J_i} \left[s_{ji} \cdot (x_{v(j,i)} - t_{ji}) \right]_+ & i = 2,3,\ldots \end{cases}$$

where:

$(\cdot)_+ = max(0,\cdot)$ that is, positive part inside parenthesis.

J_i is the interaction degree of the basis functions B_i

$s_{ji} = \pm 1$ is the sign indicator

$v(j,i)$ is the index of the independent variable which is being divided, constrained to $v(j,\cdot), j = 1, J$ must be different, that is, each independent variable appears only once on each interaction term.

t_{ji} gives the position of the division and is called *knot*.

To illustrate the notation an example will be shown. Suppose a MARS model containing the basis function B_i given by:

$$B_i = (x_2 - 1.3)_+ \left[-(x_5 + 33.7) \right]_+$$

It is shown immediately that two factors exist in the term interaction, so $J_i=2$. The sign indicators are $s_{1,I}=1, s_{2,I}=-1$ and knots are given by $t_{1,I}=1.3, t_{2,I}=-33.7$. For last, the labels for variables are given by $v(1,I)=2, v(2,I)=5$.

The MARS model is continuous on D and can be extended to a model with continuous first order derivative, replacing the linear splines with cubic ones in the basis functions.

Built of the MARS model is carried out in two steps: forward stepwise and backward stepwise.

Forward stepwise: The basis function is initialised to 1. On each step, the division that minimises any convergence criterion between all possible divisions is selected, allowing only as possible division points the data introduced during training. If the division selected for base B_i corresponds to variable x_* in the knot t_*, then two new basis functions will exist and will be given by:

$$B_i \left[\pm (x_* - t_*) \right]_+$$

This process continues until the model achieves a predetermined number of functions.

Backward stepwise: The basis functions are eliminated one by one in this step, until the convergence criterion gets a minimum. On each step, the basis function which improves the adjustment degree or causes a lower information lose on its elimination, is then eliminated, that is, a penalizing criterion is used based in the number of basis functions and the convergence degree. The error estimation used is the generalized criterion validation (GCV).

4.3 Application of BISRA table for calculation of the heat capacities of steel

The book "Physical constants of some commercial steels at elevated temperatures" of the British Iron and Steel Research Association offers a collection of physical constants and values for 22 steel grades. For the calculation of the thermal energy of heated slabs the table 2, *Total Heats - Heat required to raise steel from 50°C to given temperatures*, was used and adapted.
The original temperature range of the examined steel samples is between 50°C and 1300°C, but for its application in the project it must be extended to a range starting at 0°C up to 1400°C.
The values at 0°C were derived by extrapolation (2nd degree polynomial) of the first 10 values, the values at 1350°C and 1400°C were extrapolated by linear function using the last 5 values of the table for each material group.
Additionally the unit of the thermal energy was changed from cal/g to kWh/t to simplify the comparison of other calculated energy values with the thermal energy included in the heated slabs.

For calculation of the slab specific thermal energy for the heating from temperature Temp_WBF_IN (slab temperature at entry in walking beam furnace) to temperature TEMP_WBF_OUT (at drop-off from the furnace) the following equation was implemented

$E_{Th,slab} = E_{Th,slab}\left(TEMP_{WBF_{OUT}}\right) - E_{Th,slab}\left(TEMP_{WBF_{IN}}\right)$ using

$$E_{Th,slab}(\mathrm{Temp_x}) = (\mathrm{e_{upper}}\,(TEMP_X) - \mathrm{e_{lower}}(TEMP_X) * \frac{50}{\left(Temp_{upper} - Temp_X\right)} + \mathrm{e\_lower}(TEMP_X)$$

with

$Temp_{upper}$, $Temp_{lower}$	the upper and lower temperature in between the slab temperature is located
e_{upper}, e_{lower}	energy per ton from the table at the upper and lower temperature in between the slab temperature is located
50°K	Constant temperature step in the table

The second equation realises an interpolation of the specific energy value between the boundary values of a temperature interval,
the first equation represents the specific energy at a certain temperature basing on the interpolations for the in and out temperatures.

The following table shows the chemical composition of the 22 listed steel grades, the other table listed the used specific energy values for these 22 steel grades at the elevated temperature.

Table 4.2: Composition of investigated steel grades in the BISRA study

Group no	C	Si	Mn	S	P	Cr	Ni	W	Mo	V	Cu	Al	As
Carbon Steels													
1	0.06	0.01	0.38	0.035	0.017	0.022	0.055		0.03		0.08	0.001	0.039
2	0.08	0.08	0.31	0.05	0.029	0.045	0.07		0.02			0.002	0.032
3	0.23	0.11	0.635	0.034	0.034		0.074				0.13	0.01	0.036
4	0.415	0.11	0.643	0.029	0.031		0.063				0.12	0.006	0.033
5	0.435	0.2	0.69	0.038	0.037	0.03	0.04		0.01		0.06	0.006	0.024
6	0.8	0.13	0.32	0.009	0.008	0.11	0.13		0.01		0.07	0.004	0.021
7	0.84	0.13	0.24	0.014	0.014						0.02	0.004	0.009
8	1.22	0.16	0.35	0.015	0.009	0.11	0.13		0.01		0.077	0.006	0.025
Low Alloy Steels													
9	0.23	0.12	1.51	0.038	0.037	0.06	0.04		0.025		0.105	0.015	0.033
10	0.325	0.18	0.55	0.034	0.032	0.17	3.47		0.04	0.01	0.086	0.006	0.023
11	0.33	0.17	0.53	0.033	0.031	0.8	3.38		0.07	0.01	0.053	0.006	0.028
12	0.325	0.25	0.55	0.025	0.018	0.71	3.41		0.06	0.01	0.12	0.008	0.023
13	0.34	0.27	0.55	0.003	0.024	0.78	3.53		0.39		0.05	0.007	0.037
14	0.315	0.2	0.69	0.036	0.039	1.09	0.073		0.012		0.066	0.005	0.028
15	0.35	0.21	0.59	0.031	0.028	0.88	0.26		0.2		0.12	0.004	0.039
16	0.485	1.98	0.9	0.047	0.044	0.04	0.156				0.086	0.007	0.029
High Alloy Steels													
17	1.22	0.22	13	0.01	0.038	0.03	0.07				0.07	0.004	0.038
18	0.28	0.15	0.89	0.003	0.009		28.37				0.03	0.012	0.027
19	0.08	0.68	0.37	0.011	0.022	19.11	8.14	0.6			0.03	0.004	0.025
20	0.13	0.17	0.25	0.024	0.018	12.95	0.14			0.012	0.06	0.034	0.015
21	0.27	0.18	0.28	0.022	0.022	13.69	0.2	0.25	0.01	0.022	0.074	0.031	0.0031
22	0.715	0.3	0.25	0.028	0.018	4.26	0.067	18.45		1.075	0.064	0.004	0.035

Table 4.3: Table of specific energy at elevated temperature

TEMP	1	2	3	4	5	6	7	8	9	10	11
0	0	0	0	0	0	0	0	0	0	0	0
50	**5.562**	**5.598**	**5.53**	5.502	**5.579**	**5.539**	**5.821**	**5.873**	**5.425**	**5.6**	**5.6**
100	12.307	12.343	12.275	12.247	12.208	12.284	12.799	12.618	12.054	12.345	12.462
150	19.285	19.321	19.253	19.225	19.302	19.495	20.010	19.829	18.916	19.323	19.556
200	26.496	26.532	26.464	26.320	26.513	26.938	27.569	27.388	26.010	26.534	26.767
250	33.939	34.091	33.907	33.647	33.956	34.498	35.129	34.948	33.337	33.977	34.210
300	41.615	41.767	41.583	41.322	41.632	42.406	43.037	42.740	40.896	41.653	42.118
350	49.523	49.676	49.608	49.231	49.657	50.547	51.062	50.765	48.689	49.561	50.143
400	57.781	57.933	57.865	57.372	57.914	58.921	59.552	59.022	56.946	57.702	58.400
450	66.503	66.655	66.587	65.862	66.404	67.643	68.274	67.628	65.436	66.309	67.239
500	75.691	75.843	75.775	74.933	75.359	76.947	77.578	76.467	74.507	75.496	76.543
550	85.460	85.496	85.544	84.470	84.663	86.600	87.347	85.655	84.160	85.265	86.545
600	95.927	95.847	95.895	94.355	94.665	96.486	97.814	95.308	94.511	95.616	97.361
650	107.092	106.779	106.827	104.473	105.248	106.604	108.630	105.658	105.210	106.665	108.642
700	119.071	118.642	118.574	115.173	117.111	117.303	120.260	117.056	116.840	129.343	126.785
750	134.422	134.458	138.461	137.154	142.580	146.146	150.614	146.014	137.077	142.601	143.067
800	146.518	147.833	151.719	145.760	154.559	154.636	159.337	155.086	148.474	150.975	150.859
850	157.682	159.812	161.953	152.854	163.049	163.823	167.943	164.157	156.150	159.697	158.767
900	169.312	171.093	170.909	160.414	171.190	172.429	176.549	172.763	163.593	168.653	166.792
950	178.500	180.164	179.980	169.136	179.913	181.036	185.156	181.486	171.734	177.608	175.631
1000	187.804	189.236	188.935	177.742	188.635	189.874	193.645	190.092	180.108	186.563	184.469
1050	197.108	198.423	198.006	186.581	197.358	198.713	202.368	199.047	188.481	195.518	193.308
1100	206.412	207.611	206.962	195.304	206.080	207.785	211.207	207.886	197.087	204.473	202.147
1150	215.716	216.799	216.149	204.259	215.035	216.972	220.278	216.957	205.694	213.312	211.218
1200	225.020	225.986	225.337	213.330	224.107	226.276	229.582	226.029	214.532	222.383	220.290
1250	234.324	235.174	234.757	222.634	233.411	235.697	239.002	235.333	223.371	231.455	229.361
1300	243.628	244.478	244.294	232.171	242.831	245.117	248.655	244.637	232.326	240.642	238.433
1350	252.932	253.666	253.598	241.358	252.019	254.479	258.018	253.825	241.165	249.714	247.504
1400	262.236	262.888	262.983	250.662	261.288	263.865	267.473	263.059	250.039	258.820	256.575

TEMP	12	13	14	15	16	17	18	19	20	21	22
0	0	0	0	0	0	0	0	0	0	0	0
50	**5.684**	**5.559**	**5.604**	**5.455**	**5.616**	**6.202**	**5.977**	**6.084**	**5.432**	**5.416**	**4.673**
100	12.429	12.304	12.466	12.084	12.594	13.413	12.955	13.178	11.945	11.929	10.372
150	19.640	19.282	19.560	18.946	19.572	20.856	20.049	20.505	18.923	18.790	16.303
200	26.851	26.609	26.771	26.156	26.899	28.764	27.260	27.948	26.133	25.885	22.351
250	34.294	34.169	34.214	33.483	34.458	36.789	34.703	35.392	33.460	33.328	28.631
300	41.970	41.845	41.890	41.043	42.134	45.046	42.263	43.067	41.136	40.887	35.144
350	49.878	49.986	49.914	48.951	50.159	53.536	49.938	50.743	49.161	48.796	41.889
400	58.135	58.359	58.172	57.208	58.532	61.910	57.382	58.652	57.534	57.053	48.867
450	66.858	67.198	66.778	65.698	67.255	70.516	64.941	66.793	66.373	65.892	56.078
500	76.045	76.502	75.965	74.770	76.559	79.006	72.849	75.050	75.910	75.312	63.753
550	85.931	86.504	85.618	84.423	86.328	88.659	80.874	83.772	85.912	85.430	71.894
600	96.514	97.203	95.853	94.657	96.795	98.428	89.015	92.844	96.844	96.130	80.152
650	107.679	108.601	106.669	105.357	107.611	107.383	97.272	101.566	108.125	107.876	88.642
700	123.612	123.255	118.299	116.870	119.125	116.338	105.413	110.289	120.336	120.786	97.480
750	142.802	146.282	139.116	139.200	131.685	125.293	113.554	118.895	132.897	134.509	107.482
800	150.710	155.121	152.142	151.528	150.642	134.365	121.695	127.850	142.433	145.441	117.484
850	158.618	163.960	159.934	159.436	159.132	143.436	129.836	136.805	153.598	158.699	126.904
900	166.643	172.798	167.959	167.577	167.854	152.740	138.094	145.760	162.902	167.887	137.139
950	175.249	181.753	176.449	175.834	176.577	161.928	146.351	154.715	171.974	176.842	145.163
1000	184.088	190.476	185.171	184.208	185.416	171.348	154.608	163.787	180.929	185.914	153.421
1050	193.160	199.315	193.894	192.698	194.371	180.768	162.982	172.858	190.000	194.752	161.911
1100	202.115	208.154	202.616	201.188	203.442	190.305	171.356	182.046	199.071	203.824	170.517
1150	211.302	216.992	211.106	209.910	212.630	199.958	179.845	191.350	208.143	212.779	178.890
1200	220.374	225.947	219.829	218.749	221.934	209.611	188.452	200.654	217.098	221.967	187.497
1250	229.678	234.903	228.551	227.588	231.354	219.380	197.407	210.074	226.169	231.154	195.870
1300	238.865	243.974	237.506	236.543	240.891	229.149	206.594	219.494	235.241	240.575	204.360
1350	248.053	252.929	246.229	245.382	250.253	238.860	215.375	228.857	244.254	249.762	212.850
1400	257.253	261.919	255.021	254.256	259.673	248.594	224.295	238.242	253.291	259.020	221.328

4.4 User guide for ENERGYDB – Implementation at AME and UniOvi

PROJECT ENGINEERING RESEARCH GROUP-UNIVERSITY OF OVIEDO/ARCELORMITTAL

User guide - EnergyDB

ArcelorMittal

Universidad de Oviedo

TABLE OF CONTENTS

FIGURE INDEX

1 INTRODUCTION

This document contains the User Guide of the web application resulting from the implementation of the project "*Application of a factory wide and product related energy database for energy reduction*" (hereinafter EnergyDB), that is, a reference manual addressed to the end user where the parts of the application are presented, what can be done in each one of them and how to respond to the messages that may appear.

All the **pages** follow the same structure or **template** that is discussed in the second section of this document.

In the third section, a **screen organization chart** is included to facilitate the understanding and placement of the reader in the manual.

The fourth section describes the **public access** pages of EnergyDB, that is, the only pages that a user of the network can consult without being authenticated in the system.

The fifth point is dedicated to authentication in the system, which includes resetting the password by forgetting without the intervention of the administrator.

In the sixth, the main tasks have been included, the tasks that a user can perform without administrator permission: search, data query and calculation of the optimization. In addition, an authenticated user can modify some of his/her profile data and password.

The seventh section is devoted to the work of **administrators**, which include the handling of user data and the loading and deletion of heats from the database.

2 PAGE GENERAL LAYOUT

All ENERGYDB interface pages consist of three sections:

1. Header: With the menu items which vary depending on whether the user has been authenticated or not.
2. Body: With the specific content of the page.
3. Footer: It is always the same in all pages (see image below).

Figure 1: Page layout.

3 SCREEN ORGANIZATION CHART

This chart summarizes the pages that make up the ENERGYDB interface. As you can see, three colours are displayed: green, blue and violet. The pages in green are the ones accessible to the user before authentication; the rest, in blue and violet, are the pages the users have access to after authentication. Only administrators can access the *data loading*, *data deletion* and *manage* pages, that is, the pages in violet.

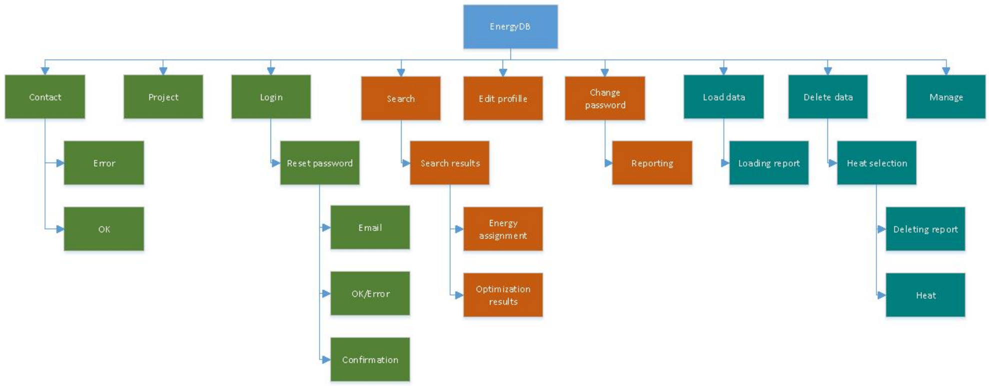


Figure 2: Screen organization chart

4 ENERGYDB HOMEPAGE

The first step is accessing the ENERGYDB webpage and authenticate yourself, since you must be registered to gain access to information on heats (the registration is made by the administrator).

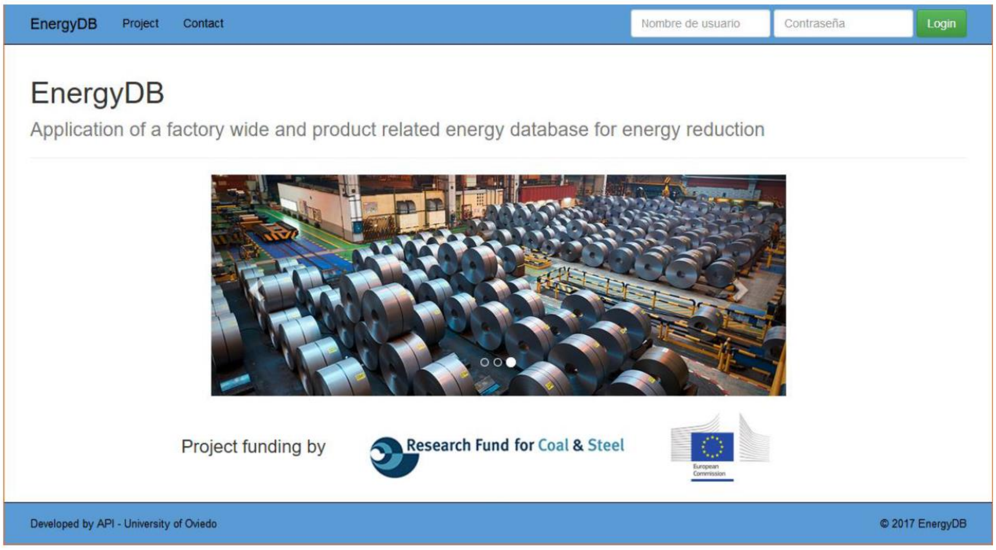


Figure 3: Homepage

However, there are several open access pages which are described in the following subsections.

4.1 Project

As shown in the figure below, you can see a page with a short description of the project.

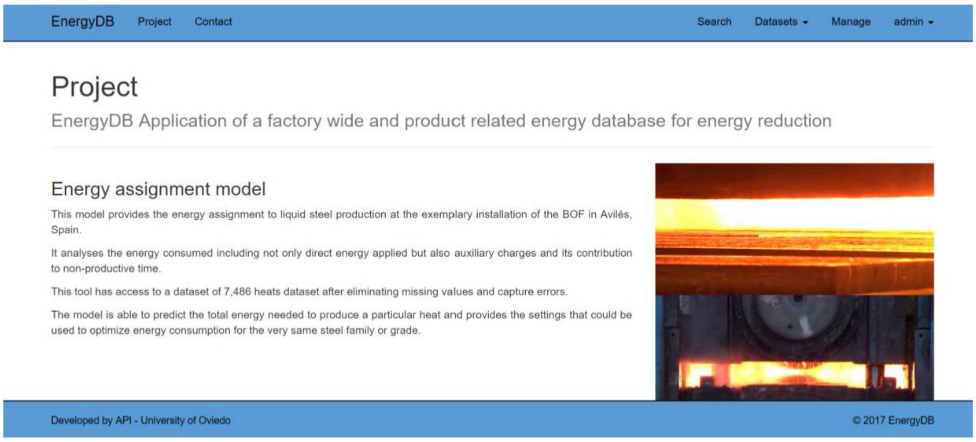


Figure 4: Project Page

4.2 Contact

If you click on the **Contact** link on the upper menu, you access to a form similar to the figure below:

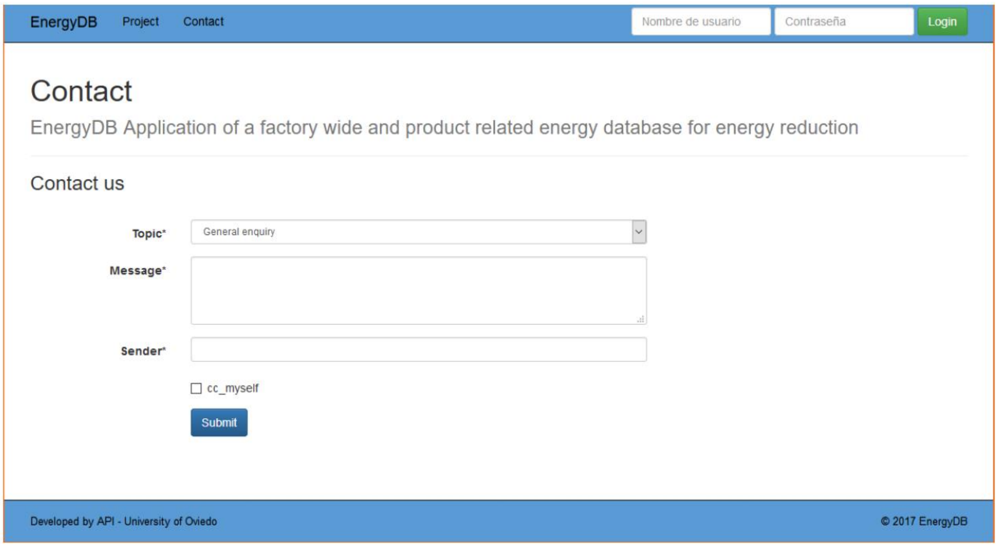


Figure 1: Contact Page.

The fields marked with * are compulsory, that is, you must choose a topic, write a text and provide an email in the *sender* field. By clicking the ***Submit*** button, an email is sent. You can click the checkbox **copy** if you wish to receive a copy of this email.

5 ACCESS TO ENERGYDB

5.1 Login

The easiest way to identify yourself is through the fields on the upper menu.

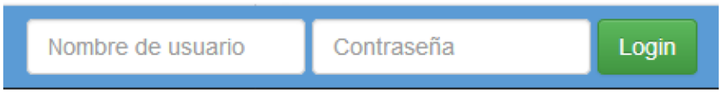


Figure 2: Login on the upper menu.

If the user name and password are correct, the upper menu does not change and it shows another set of options apart from our user name.

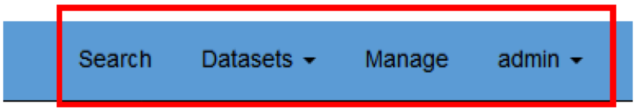


Figure 3: Correct Login.

6 AUTHENTICATED USERS' TASKS

The main tasks a user with no administration rights can perform are search, data query, calculation of energy assignment and optimization. An authenticated user is allowed to modify some of his/her profile data and password.

6.1 Search

Once logged-in the system, if the user clicks on the **Search** link in the upper menu; a page as the one below will appear.

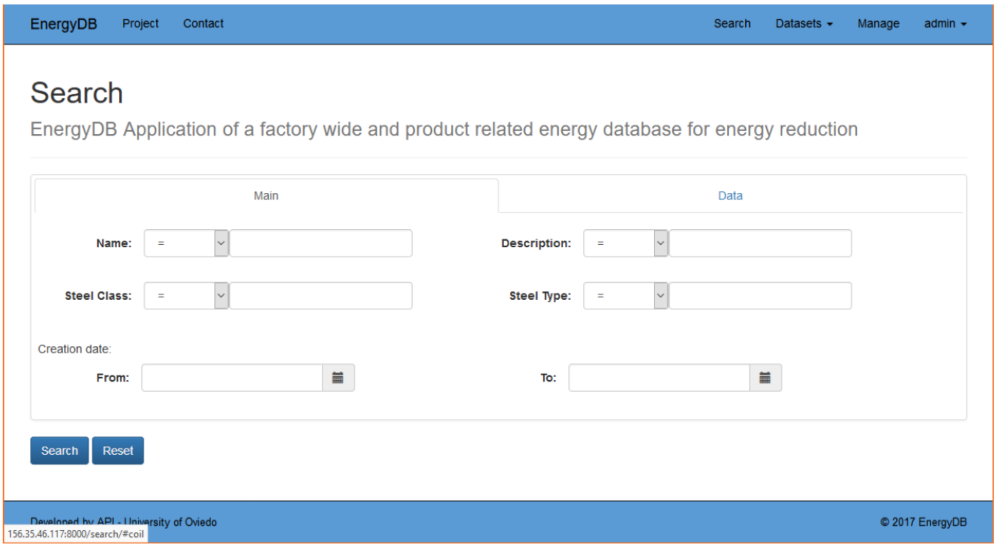


Figure 4: Search - heat.

There are a set of tabs in the body of the page to choose the search parameters. Each tab has the values to establish the search parameters depending on the origin of the data. In order to access a tab you must click on its name.

The following images display the contents of each tab:

Data

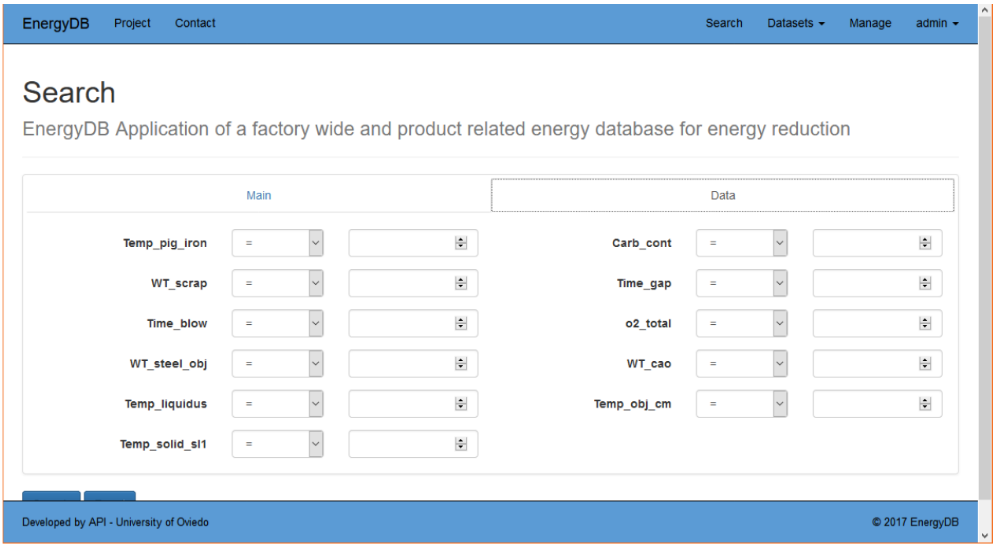


Figure 5: Search - Data.

When possible, a pop-up list will allow you to choose the exact value, lower, lower or equal, high, higher or equal or the same as the value introduced in the field. When there is text, the **like** means it contains the text**.**

The following figure shows how to select the heats created between April 16th at 1:00 PM and April 26th at 7:00 PM. If we introduce an initial date, the final date gets conditioned, in the calendar of "until" the dates prior to the initial date are disabled

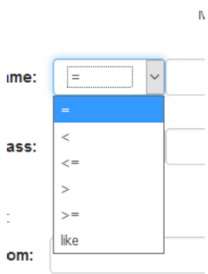


Figura 6: Search - Operators.

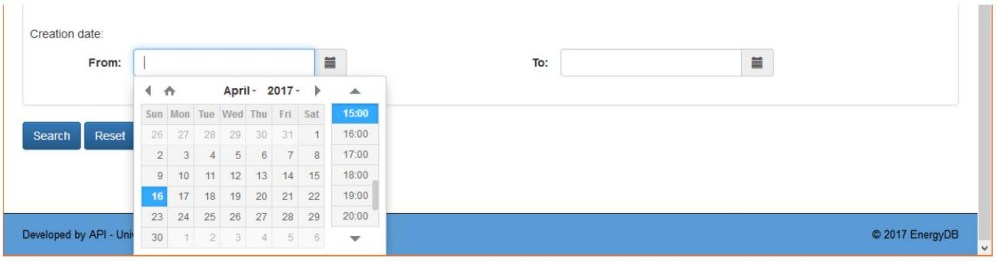


Figure 7: Search – heat - Date.

To add the rest of parameters you have to use the data tab. For each field the pop-up list is modified and the value introduced.

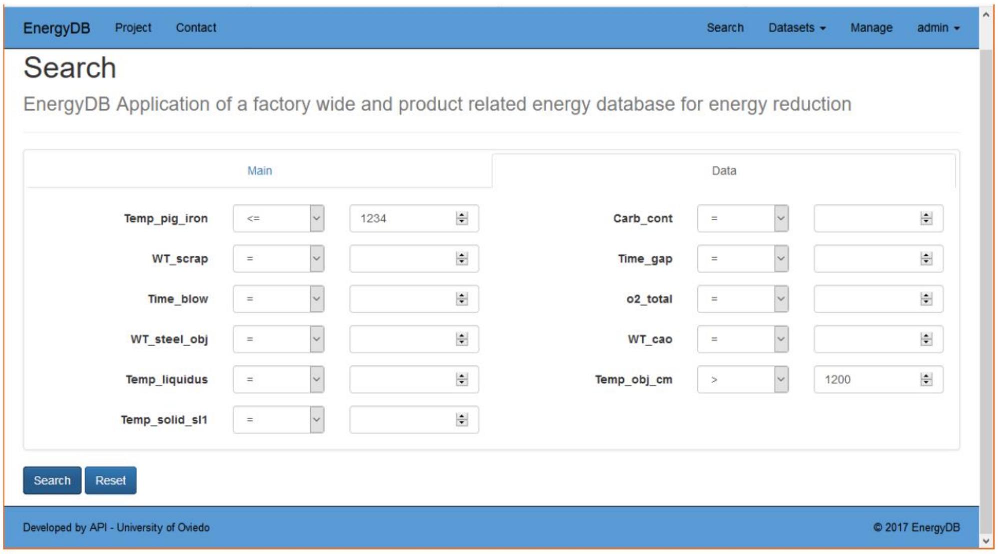


Figure 8: Search – Combined.

6.2 Search results

If the database has heats corresponding to the introduced criteria, the results will be a page like the following.

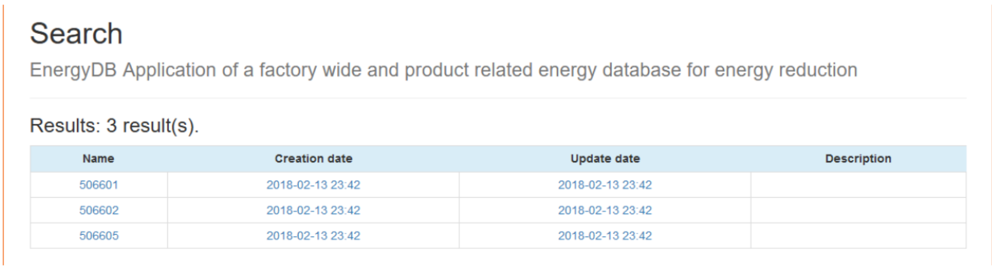


Figure 9: Search – Positive result.

It has the number of heats that meet the established criteria and a table with some of the values of the heats. If you click on the arrow of the column title, you can sort the table from highest to lowest or from lowest to highest.

Figure 10: Search results - Sorted.

On the other hand, if the database does not contain heats with the entered criteria, the result will be a page like the following, where it says there is no heat that matches the selected criteria.

6.3 Total Energy

Starting from the result of a search with positive results, if we click on the links we are redirected to the *total energy* page.

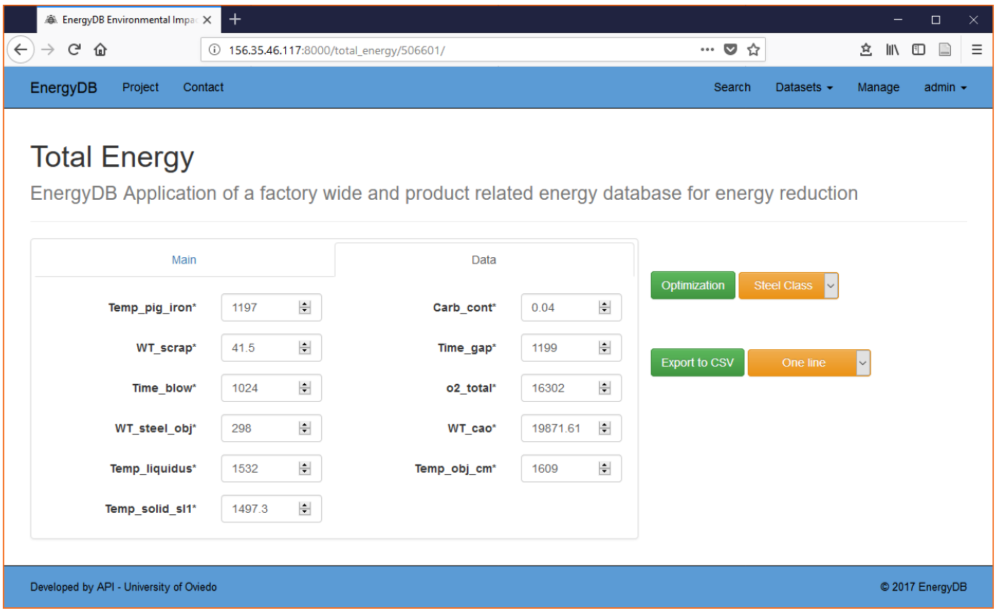


Figure 11: Total energy.

You can check the values of the variables grouped in tabs according to their origin.

In this page we can choose between:

- **Optimization**: The optimization of energy by grouping techniques can be done by steel class or steel type
- **Export to**: Generate a CSV file with the heat values.

6.4 Optimization

If you click on the **Optimization** button, a call to the web service in charge of the process is made and it returns the following page as results.

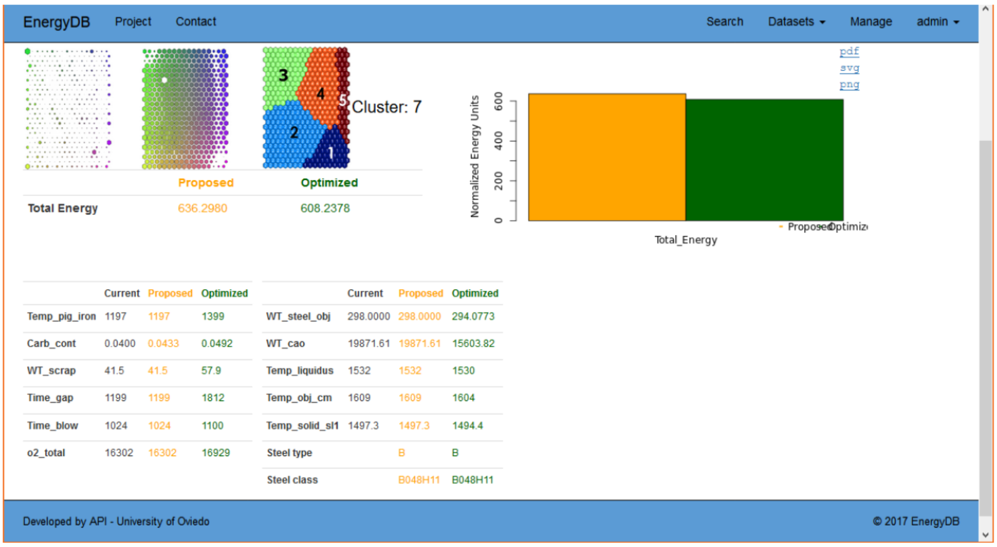


Figure 12: Optimization result.

The process classifies the heat into one of the 5 clusters and provides:

- The energy proposed for this case the optimal.
- A graphic representation of the energy, which can be zoomed in by clicking on the links on the top corner of the histogram and be saved as pdf or image file (svg or png formats).
- At the bottom, under the graph, we can see the initial configuration of the heat and the configuration proposed by optimization.

To return to the energy page just click on **Back to main page** button.

6.5 Export to CSV

It is possible to modify the values and make the optimization again or calculate the energy assigned to observe how the results obtained vary according to the changes introduced. These changes are not stored in the database, so the option **Export to CSV** allows us to save the data of the modified heat in the file.

First, we should choose between one of the CSV formats proposed by the page in the drop-down list attached to the button. When clicking on the **Export to CSV** button we will see the dialog box *Opening somefilename.csv*, from which we can save the file or open it.

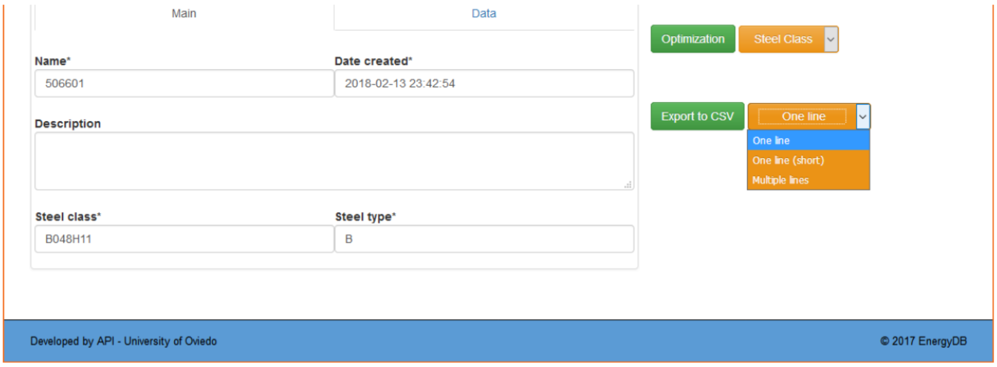


Figure 13: Export to CSV.

6.6 Change password

Once you are authenticated and logged in, you can change the password by clicking on your user name in the upper menu and choosing the option **Change password**.

The system will show the Change password page, where first you have to enter your current password (later old password) and next the new password, that must be entered twice for security reasons.

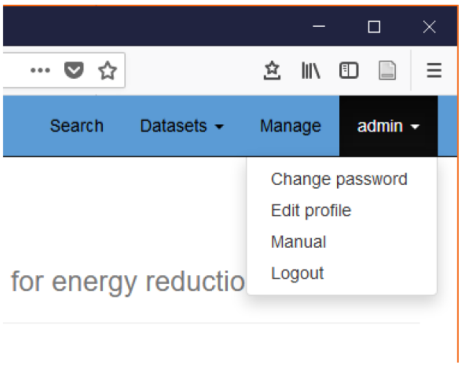


Figure 14: Change password.

This process is different from password reset. In this case, you know your password and you want to change it for a new one. In the case of a reset, you do not know your password, so you ask for a new one.

6.7 Edit profile

In the same submenu, you can choose the **Edit profile** option to be able to modify our data by changing the field values and clicking the **Save** button.

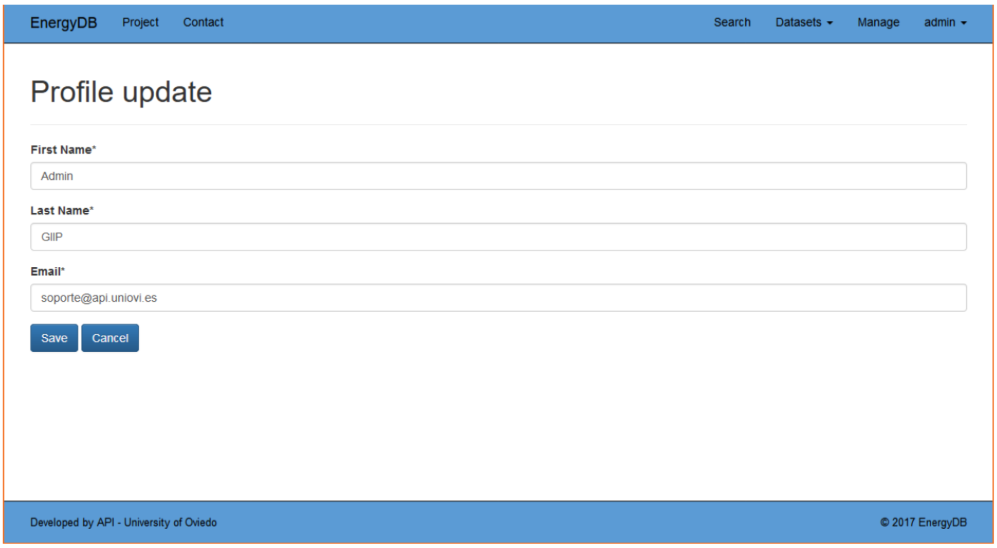


Figure 15: Edit profile.

7 ADMINISTRATION TASKS

This section describes the tasks that only the users with administration role can manage.

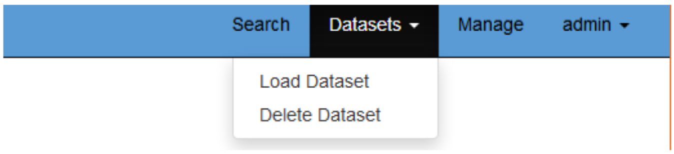


Figure 16: Data loading and deletion.

If we do not have the proper permissions when choosing the upper menu options, it will ask us to log in again.

7.1 Data loading

To be able to load new data to ENERGYDB, the administrator must have a CSV file with the heats data in a specific format. In the first line there are the names of the 62 variables and in the remaining lines the heats data.

The loading process is simple; you must select the file on your computer and click on the **Load** button. You can see an example file in the **example** link.

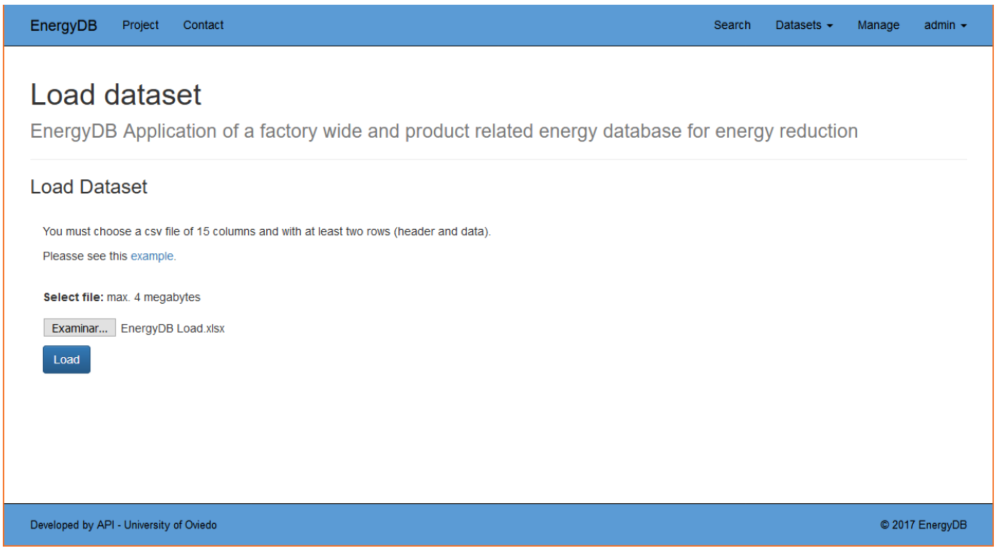


Figure 17: Selection of SCV file for loading.

By clicking on **Examine** it opens a dialog box to choose the file with de heats data. Once it is chosen, the page shows the name of the file and you must click on the **Load** button to start the process.

After a few seconds (the duration of the process obviously depends on the size of the file) the system shows us a report screen.

7.2 Delete data

First, you must provide the system with some search criteria of the heats you wish to delete. Then the search is done and the system returns the heats that meet the requirements. The heats are selected and finally deleted.

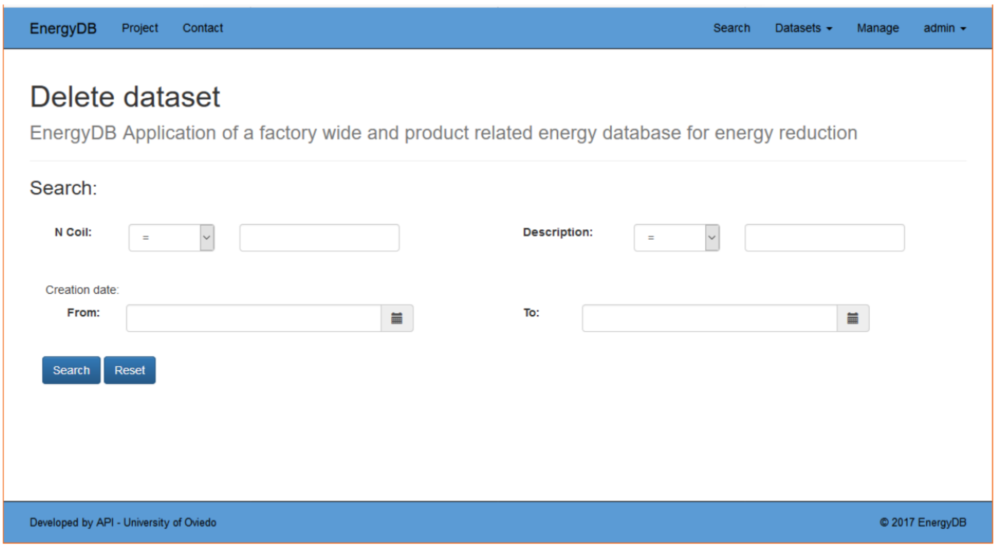


Figure 18: Search heats for deletion.

7.3 Manage

The option menu **Manage** gives access to the administration of ENERGYDB, which allows you to manage users and modify directly the ENERGYDB database tables. By clicking on the Users link, the administration has access to user management.

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The EU Open Data Portal (https://data.europa.eu/euodp/en/home) provides access to datasets from the EU. Data can be downloaded and reused for free, for both commercial and non-commercial purposes.

The EnergyDB project aimed at using energy data in the steelworks in the same way as process or quality data in order to identify correlations between energy required and process behaviour or product properties. For this, suitable methods and tools for the analysis of these relationships were developed, based on a tailored compilation of available energy data and recorded process and product data. In the project, necessary data models for the combination of all necessary data were developed on different process routes and production steps, functions and tools for the processing of those data and for the calculation of product-related energy amounts were implemented and a web-based user application was created and tested.

As application examples, this work was carried out in a steel mill with BOF production route (AM Espana), a steel work with EAF and VD plant (RIVA), and in a hot rolling mill (AM Eisenhüttenstadt). In addition, a supplier of steel mill plants and automation technology was developing a general procedure for the energetic valuation of products, plants and processes (Danieli Automation).

In the project concepts and methods were developed for

- the design of energy data bases,
- the assembling and assignment of energy data to products and process data,
- the assessment of used energy for products and process steps,
- the use of this data for analysis and optimisation,
- the specifications for an Energy Information and Analysis System

concerning the topics of process routing optimisation, KPI definition and benchmarking, semantic representation of energy flows and the extended analysis together with process data.

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