FRONT PAGE

PROJECT FINAL REPORT

Grant Agreement number: 614140

Project acronym: TOP-REF

Project title: Innovative tools, methods and indicators for optimizing the resource efficiency in process industry

Funding Scheme: Collaborative Project (CP) - Large-scale integrating project (IP)

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1. Final publishable summary report.

1.1. Executive summary

TOP-REF developed and demonstrated a **robust, cross-sectorial and resource efficiency focused methodology**. In a second step, this methodology was validated by the development and testing of **non-invasive, on-line monitoring and optimization tool** adapted to three specific resource intensive sectors represented by three industrial demonstrators: Fertilizer (MKP), Refining (Crude Fractionation) and Chemical (Ethylene Cracker).

The TOP-REF methodology path is the following:

1. Definition of the system boundaries, the main Key Performance Attributes (KPAs), as limits of operation and the Key Resource Indicators (KRIs) as a measure of the resource efficiency to be optimized.
2. Initial assessment of the main irreversibilities in the utility process for Chemical and Petrochemical sectors and in the overall process in the Fertilizer sector by a thermoeconomic analysis.
3. **Modeling** of the **productive** processes and the **utilities**. Development of complex models based on Matlab, Aspen Hysys and Aspen Plus.
4. Development of **surrogate models** **when** is **required** (petrochemical and chemical plants have hundreds of streams and running the models in real time is not possible) to obtain the **relation** between the **KPAs** and **KRIs** and by means of the global **sensitivity analysis**, the Critical Process Parameters (**CPPs**) to be optimized.
5. In parallel, the development of softsensors as an online real-time application.
6. **Optimization** of the **CPPs** by means of the tool in order to **increase** the **resource** efficiency by optimizing in a single and a multi objective modes.

Results in Fertilizer industry

After a demo period of 200 hours, where different trials were performed, in the fertilizer industry, the impacts achieved when all the plant was studied are the following:

- Reduction of exergy cost of 30 %
- Reduction energy costs of 80.000 € / year (natural gas and electric consumption). This is for a production plant of 8.000 Ton/ year
    - Gas consumption per Kg of fertilizer reduced in 21,82 %
    - Electricity consumption per Kg of fertilizer reduced in 14,83 %
- Increase of 14% of production without any cost

Results in chemical industry (Ethylene cracker)

The TOP-REF scope in the ethylene cracker included the steam network and the cracker. At the end of the project the impact highlighted are:

- A simulation validated and capable to simulate a feedstock scenario of 100% naphtha and an ethylene production at nameplate capacity with an accuracy of ±10%
- The thermoeconomic and subsequent analysis from an energetic and economic point of view showed that venting low-pressure steam was the most inefficient spot in the steam network (45% of the total economic losses and 55% of the total energetic losses). The annual savings in case all the low pressure steam was used in the facilities instead of being were estimated by Dow Chemical Iberica in 2M € per year.

- The development of two different softsensors are of high interest in terms of replicability.

1.2. Summary of project context and objectives.

TOP-REF aimed to develop and validate specific indicators, methodologies and non-invasive Monitoring and Optimization Tools (M&OT) devoted to the improvement of resource efficiency in energy intensive industrial sectors. In general terms TOP-REF final impacts was expected to be:

- To **improve energy and resources efficiency by 20%** compared with the initial levels.
- To pave the way for **achieving the SPIRE2030** objective of **reducing non-renewable, primary raw material intensity up to 20% and fossil energy intensity up to 30%**, both compared with initial levels.
- To **increase the reusability and recycling of materials between 30%,** depending on the sector.
- **Reduce production costs up to 15 %** compared with the initial levels.
- A significant **reduction of the environmental impacts** (CO_2 emissions, water footprint, pollutants, hazardous emissions, etc.).

To achieve these goals, TOP-REF wanted to develop and demonstrate a **robust, resource-efficiency-focused and cross-sectorial methodology (see Figure 1)**. This methodology will be supported by means of a **specific, non-invasive, real time and on-line monitoring and control tool** adapted to three specific energy and resource intensive processes: Fertilizer, Refining and Chemical. The tools would be validated through demonstration under real conditions in three pilots, one per sector.

In order to ensure TOP-REF impacts, specific **Key Resources Indicators (KRI)** will be developed and standardized to foster the greening and the competiveness of the European process industry. The indicators, based among others on resource consumption and life cycle indicators will help to measure the decoupling of environmental impacts and resource use, from economic growth. Furthermore, a method and standard for providing environmental performance information based on the Key Resources Indicators (KRI) will be developed in TOP-REF.

A multi-sectorial methodology will be constructed by performing the following steps:

1. The methodology will start by developing specific **Key Resources Indicators (KRI)**. These KRI will guide the complete execution of the methodology.
2. Definition of **Key Performance Attributes (KPA)** for the final product addressing:
    a. Quality,
    b. Safety
    c. Costs

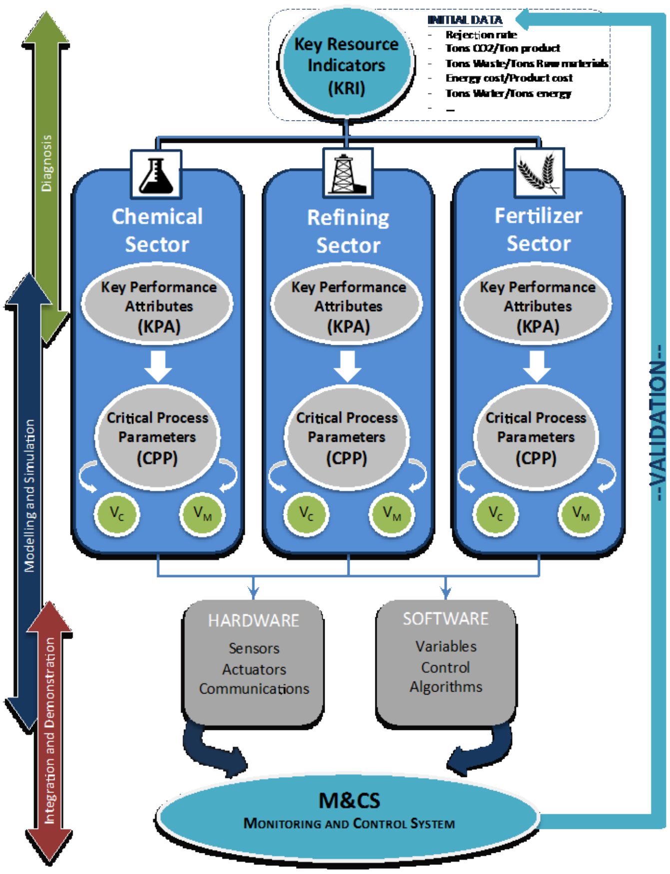


Figure 1: TOP-REF methodology schema

3. Evaluation of the **resource efficiency potential** of the global process by performing audits and diagnosis over the different sub-processes and related equipment: the aspects with the highest resource-efficiency improvement potential points will be identified in order provide a focused framework to the following actions.
4. Modelling and simulation of the identified highest resource-efficiency improvement points to establish the **Critical Process Parameters (CPP)**, like residence time, temperature of the raw materials, cooling water flow rate, etc. and understand their relation with the Key Attributes (**KPA = f (CPP)).** This step will allow the:
    a. Characterization of the Critical Process Parameters
    b. Identification of the **variables for monitoring (V_M) and optimization (V_o) of the CPP**
5. Development of the **monitoring and optimization strategies** attending to different prioritization schemes of the targeted KPAs.
6. Design and implementation of the **monitoring and optimization tools** attending to the previously established strategies, defining the required hardware (SCADA, sensors, actuators) and software.
7. Integration of the results, **pilot's deployment plan**, **proofs of concept** demonstration and final optimization of the methodology and the monitoring and control tools.
8. Finally, a methodology for developing environmental product declarations will be established based on these KRI.

In the Figure 2 is shown the approach of TOP-REF to the industrial processes directly involved in TOP-REF.

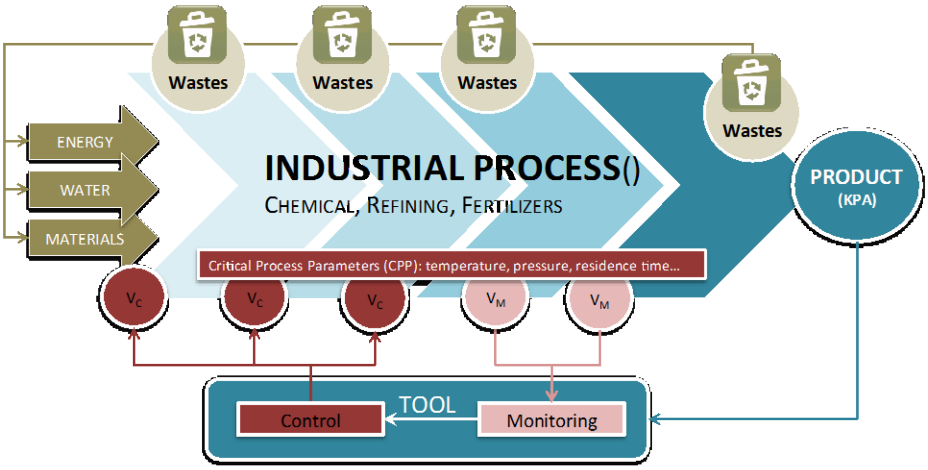


Figure 1*:* **TOP-REF approach to the industrial process**

Motivation and rationale

The European Union is facing major challenges such us the economic crisis, sustainability and the competition with emerging economies. In this context, the TOP-REF project is willing to contribute to a smart and sustainable growth while promoting a more efficient, greener and competitive economy based on knowledge and innovation. The activities and the implementation of the results of TOP-REF will improve the resource efficiency within the EU intensive industry. Specifically, it is expected a rise in the **efficiency in the use of energy, water and raw materials by up to 20%,** while reducing production costs by up to 15%. Furthermore, it will contribute towards achieving the targets set by the European industry association **SPIRE**, which aims to reduce the use of non-renewable raw materials by 20% and of fossil fuels by 30%.

Moreover, one of the initiative's key goals consists in considerably reducing the environmental impact linked to these processes, which takes the form of **CO_2 emissions**, harmful substances and waste generation, among others.

Ultimately, the final goal is to contribute to **drive Europe to a leadership position** in energy efficiency in industries by means of the promotion of a more efficient, greener and competitive economy based on knowledge and innovation.

As considered in the "Europe 2020 Strategy", the European Union is facing major challenges such us the economic crisis, sustainability and the competition with emerging economies. In this context, TOP-REF contributes to a smart and sustainable growth while promoting a more efficient, greener and competitive economy based on knowledge and innovation. In addition, the improvement of resource efficiency in process industries is a key action to accomplish three main EU concerns:

1. The productivity and competitiveness of European Industry for securing growth and jobs.
2. The efficient use of resources to deal with the climate change and other environmental issues.
3. The improvement of resource efficiency to secure Europe's supply of raw materials for making the EU economy more resilient to future increases of global energy and commodity prices.

TOP-REF is committed to increase the competitiveness and efficiency of the EU resource-intensive process industry, as well as to assure a long-term greener economy. All this by the innovation focused on an optimized monitoring and control of the processes, providing a deeper knowledge of the processes.

The specific indicators and environmental declaration guidelines to be developed in TOP-REF contribute to assess the decoupling of environmental impacts from economic growth as established in the Sustainable Consumption and Production (SCP) Action Plan.

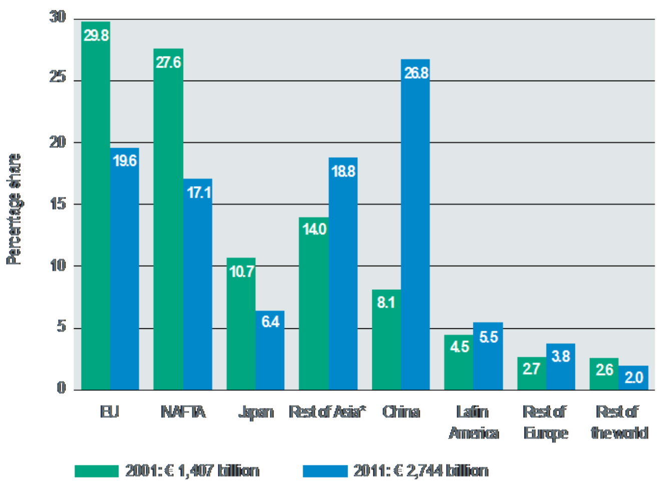
Furthermore, one of the aims of TOP-REF is to facilitate the **future implementation of cross-sectorial solutions**. According to this, it does exist a huge commitment of the consortium with the improvement of the sustainability and resources efficiency in the industry. This is reflected in the fact that several members of the consortium belong to the SPIRE initiative, moreover, the coordinator of TOP-REF (CIRCE) is the leader of the SPIRE Task Force for Processes: "Solutions for more efficient processing and energy systems for the process industry, including industrial symbiosis. The high resource intensive sectors included in SPIRE *(Sustainable Process Industry through Resource and Energy efficiency),* represent 450,000 individual enterprises, with 6.8 million employees and 1,600 billion € turnover.

A brief overview of the potential of the sectors tackled in TOP-REF is presented below:

On a general basis, the energy intensive industry is facing the introduction of **auctioning under EU ETS from 2013**. This could place EU industry at a competitive disadvantage. The TOP-REF results implementation in the EU industry will bring a reduction of the industry emissions.

The EU **chemical industry** comprises about 27.000 enterprises, 98% of which are considered SMEs, employing a total staff of about 1.9 million employees. In addition, the chemical industry contribution to the EU gross domestic product amounts 1.3%, with €178.5 billion of value added. In addition, the chemical sector accounts for 12 percent of total EU energy demand and for one third of EU industrial energy use.

Furthermore, the chemical industry features prominently among Europe's exports: its 28%



share of global production makes the EU the world's biggest chemical-producing area. Nevertheless, since the year 2001 has lost gradually the ground to the emerging economies, 10.2 percentage points of sales rate as may be seen in the Figure 3.

Figure 2 world chemical sales by region

One of the key challenges of the chemical and refining industry is the increasing of the energy costs. In 2009, the European chemicals industry, including Refining used 50.4 million tonnes of oil equivalent (TOE) of gas consumption, with 147.4 million tonnes of CO_2 equivalent.

The refining industry in EU-27 holds a capacity of 767 million tonnes per year, about an 18% of the global capacity. The overall cost for refining one barrel is between 1.0 and 2.5 €/ton depending on refining complexity. CO2 emissions correlate strongly with refinery capacity and the typical emissions are 15.0 tons of CO2 per 1000 barrels of crude oil in direct emissions and 1.4 tons of CO2 per 1,000 barrels in indirect emissions. This means 88 million tonnes of CO_2.

Fertilizer imports into Europe (EU-27) in 2010/2011 from countries outside the EU were 0.9 million tonnes more than the previous year. These accounted for 25% of total European fertilizer consumption compared to 20% the year earlier.

The fertilizer industry is EU´s single industrial use of natural gas. It is a primary raw material for fertilizers production and represents a 50%-70% of its total production costs. The industry depends on a freely available supply at a competitive Price. But the European gas market is dominated by a small number of key suppliers including Russia, Algeria and Egypt. Prices have increased by over 230% in the past 10 years. In the Figure 4 it is shown the EU dependences from external sources of Gas.

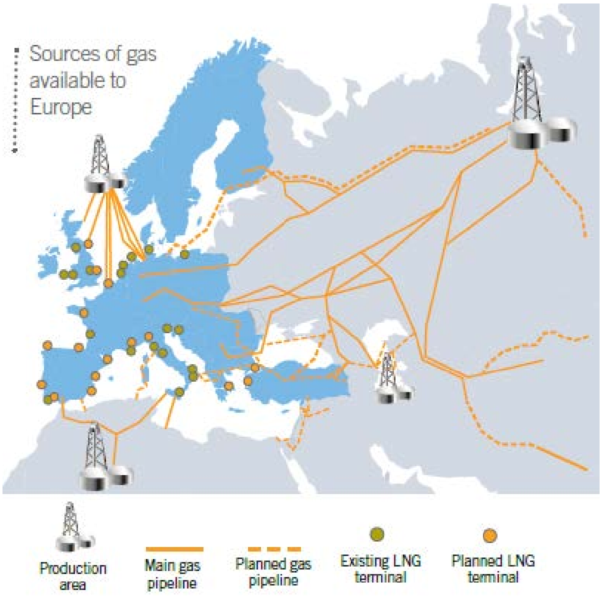


Figure 4 Sources of gas available to Europe for fertilizers production

1.3. S&T results/ foreground

To achieve the results above a huge involvement of the whole consortium to apply the methodology developed in the project was needed. This methodology wanted to be implemented in very complex industrial process without affecting to the production daily work.

Regarding the WP distribution, the following tasks were performed along the project:

- Definition of the system boundaries, the main Key Performance Attributes (KPAs), as limits of operation and the Key Resource Indicators (KRIs) as a measure of the resource efficiency to be optimized **(WP2)**.
- Initial assessment of the main irreversibilities in the utility process for Chemical and Petrochemical sectors and in the overall process in the Fertilizer sector by a thermoeconomic analysis **(WP3)**.
- Modeling of the productive processes and the utilities. Development of complex models based on Matlab, Aspen Hysys and Aspen Plus **(WP4)**.
- Development of surrogate models (petrochemical and chemical plants have hundreds of streams and running the models in real time is not possible) to obtain the relation between the KPAs and KRIs and by means of the global sensitivity analysis, the Critical Process Parameters (CPPs) to be optimized **(WP4)**.
- Development of softsensors as an online real-time application **(WP5)**.
- Optimization of the CPPs by means of the tool in order to increase the resource efficiency by optimizing in a single and a multi objective modes **(WP5)**.
- Testing in the demo site the optimized CPPs and evaluating the new values of the KRIs. Identification of environmental footprint under optimized conditions **(WP6)**.
- Evaluation of the new exergy unit costs in terms of calculating the exergy and economic effects of the new CPPs in the final market product **(WP3)**.
- Evaluation of the KRIs at the same and different sectors **(WP7)**.
- Replication and validation of the KRIs and the methodology **(WP7)**.

The conceptual optimization process can be identified in the following picture. In this process, the Critical Process Parameters are changed within the limits set by the Key Performance Attributes in order to obtain the best possible values for the set of the Key Resources Indicators.

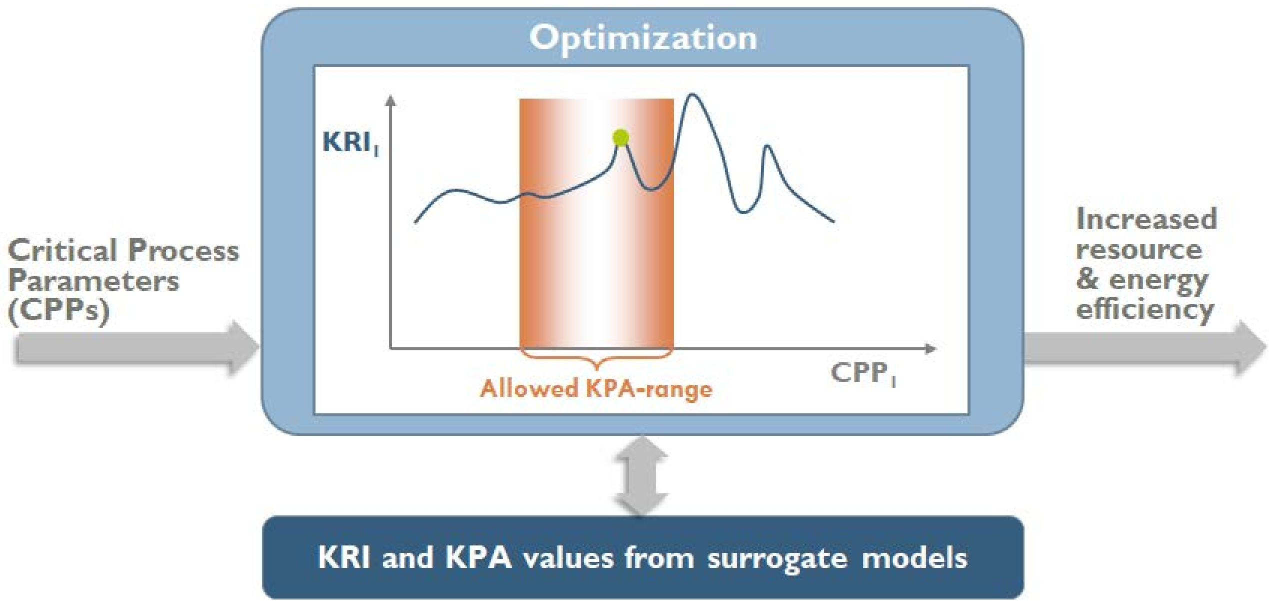


Figure 5: Monitoring and Optimization tool sketch

Following a summary of the main results generated in the project are presented

2.1.1 Set of KRIs, including an innovative exergy indicator.

The headline KRIs are: Unit Material Cost (kg/OU), Direct Primary Energy Consumption (kJ/OU), Gross Water Use (m^3/OU), Net Water Use (m^3/OU) and the Resource Exergy Indicator (resources: materials, energy and water) (kJ/OU).

The Key Resource Indicators (KRIs) developed during the project have been tested with the aim to be replicated and used in the same industrial sectors for different facilities and in other SPIRE industrial sectors. In this sense, the replication of the KRIs has been analyzed in the cement, pig iron and ceramics sectors.

One of the main results obtained from the KRIs application is their capability of being a benchmarking tool, mainly in sectors where no any standardized mode to compare between companies are found. Additionally, the application of the Resource Exergy Indicator has been proved as a good objective for optimization. All of the resources can be accounted in the same unit, it is universal as exergy is a physical property, it is absolute as it does not depend on market fluctuation or local availability, it can be aggregated or disaggregated, and it allows assigning costs in a rigorous way based on the exergy (and not on the price) based on thermoeconomics.

2.1.2 Implementation of an audit and diagnosis methodology in alternative industrial sectors.

This methodology, which is based on Thermoeconomics, has been already tested as it is found in bibliography to thermal power systems. In TOP-REF project, it has been applied to Fertilizer and Chemical sectors, providing the information to support a better decision-making process to tackle the implementation of more efficient systems and equipment.

2.1.3 Global methodology for the optimization of the processes by means of modeling and simulation activities

A general methodology for optimization of the process by modelling and simulation has been developed.

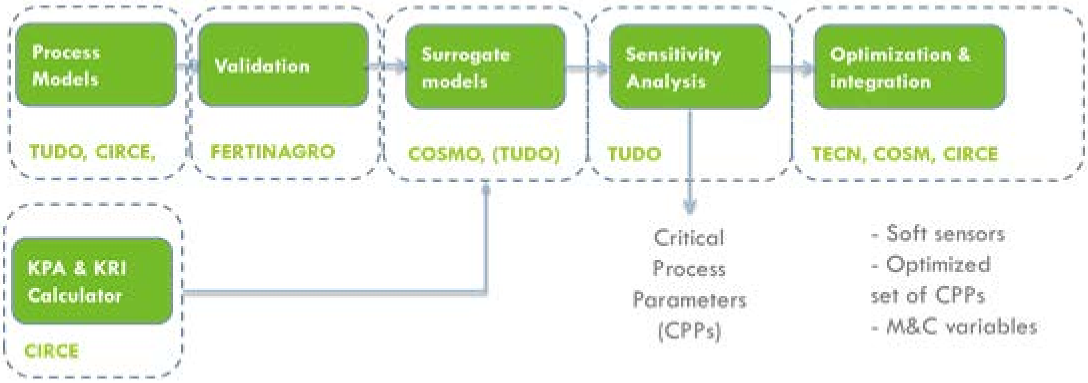


Figure: 6: Overview of the TOP-REF methodology by partner (Fertilizer case study)

Firstly, the ***Key Resource Indicators (KRIs)***, parameters to represent resource efficiency indexes, were developed. They were designed to be universally applicable to industrial sectors or plants, have been reviewed, updated and applied to the industrial sites. In addition, a set of ***Key Performance Attributes (KPAs)*** was specifically defined for each plant to ensure a proper investigation space in terms of product quality, operability, safety and environmental issues. Next to these indicators, ***Process Models*** of the different use cases were set up by using commercially available process simulation software.

Process models, KRIs and KPAs were the basis of the TOP-REF methodology approach. The final objective was to detect the influential Process Parameters that decrease resource efficiency (minimize the KRIs) using the KPAs as constraints. However, due to the large number of real plant operating parameters, the ***Critical Process Parameters (CPPs)***, had to be identified by a ***Global Sensitivity Analysis***. The use of detailed process models, such as those used under TOP-REF, adds reliability but makes the sensitivity analysis and optimization algorithms highly computationally-intensive. In consequence, prior to the global sensitivity analysis, surrogate models are used. ***Surrogate models*** are sampling-based approximations of detailed process models which require less computational time, which enables the application of the global sensitivity analysis and the optimization tool. Thus, based on the detailed process models, surrogate models were developed and used for obtaining the global sensitivity analysis and for feeding the M&OT. The global sensitivity analysis identifies the CPPs of all the operating parameters. In a last step, this set of CPPs is used to optimize the surrogate models by using ***Single- and Multi-objective optimization*** techniques.

1.3.1. Ad-hoc plant models integrating Key Resource Indicators (KRIs) and Key Process Attributes (KPA)

Within TOP-REF framework, five modelling tools have been mainly used:

1. Chemical process simulators with advanced kinetic models (CPS)
2. Advanced Steam Network Modelling (ASNM)
3. Solid Handling Simulations (SHS)
4. Multi-scale Balance Population models in rotary drum for Solids (BPMS)
5. Surrogate Modelling (SM)

The models were properly validated according to historical data from process plants. To ensure a proper operating space, the KPA and KRI list were updated and a list of Process Parameters were built for the three industrial cases.

Detailed process plant models of the different use cases (representing examples of the Agrochemical, Chemical and Petrochemical sectors) were built by using commercially available process simulation softwares. The developed simulation tools describe in detail the components of the process units and utilities. In the case of the Fertilizer plant, the main process units were simulated by default Aspen Plus® models, although for the rotary drum granulator-dryer and cooler, specific models based in population balance equations were done in MATLAB® and connected with the Aspen Plus® model.

The ethylene plant use-case is the representative case for the chemical industry, which consists of a steam cracker and the associated compressors train plant and the corresponding utility plant. They were separately modelled and validated using Aspen Plus® software. Then the models were integrated in order to generate data for building up a surrogate model.

As a third use-case, the Petrogal plant is the example of the *petrochemical sector*. It was a complex plant where the main energy-intensive process sections corresponding to the 25% of the overall energy consumption were modelled in detail: the crude distillation unit, the fractionation section and the utility section. In this case, in order to obtain a more reliable model for the crude distillation unit, Aspen Hysys® were adopted as the simulation software, instead of Aspen Plus®, which has been used only for the utility section. In a similar way to DCI case, both models were linked in order to obtain needed data for the surrogate model.

1.3.2. Monitoring and Optimization Tool

During the project a monitoring and optimization tool has been developed and tested for each of the processes included in the project. The tool has proved to be robust in several conditions, as well as easy to control and to adapt to the different trials.

In the figure 7, the evolution of the main resource for the Fertilizer demo plant before and after the implementation of the optimized set of CPPs in the facilities is shown. As per figure, it can be seen that working under specific scenarios after the implementation of the optimized CPPs, the real conditions (in terms of consumption) is even better that the expected values.

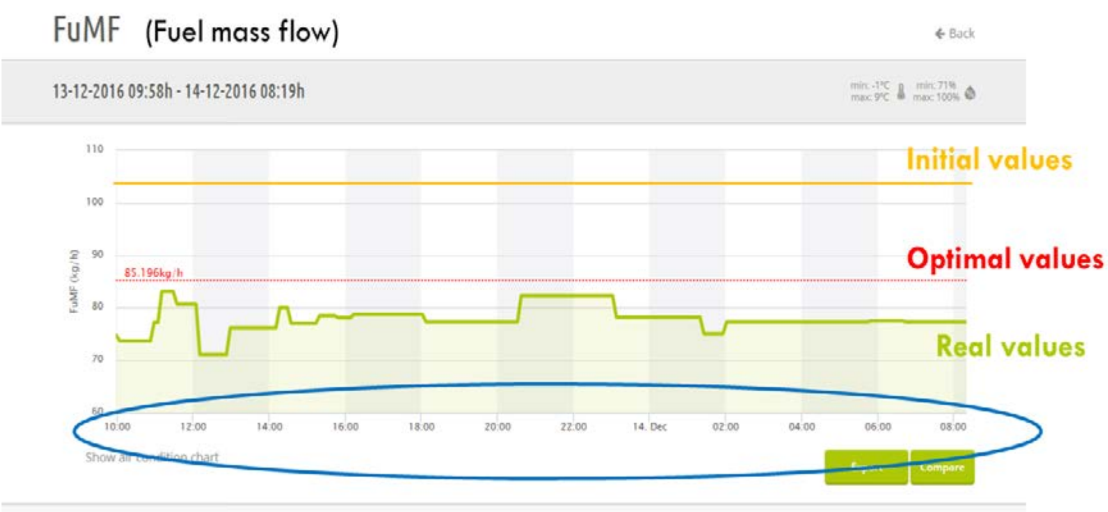


Figure 7: Screenshot of the M&O tool for Fertinagro.

Another important indicator of the success of the project in the implementation of the tool in the Fertilizer demo plant is the fact that six months after the demo the operators still use the conditions provided by the M&O tool even though at the beginning of the demo activities they refused to change the typical operational parameters.

In the figure 8 is shown how the conditions suggested by the M&OT led to an improvement of the KRIs in the demonstration.

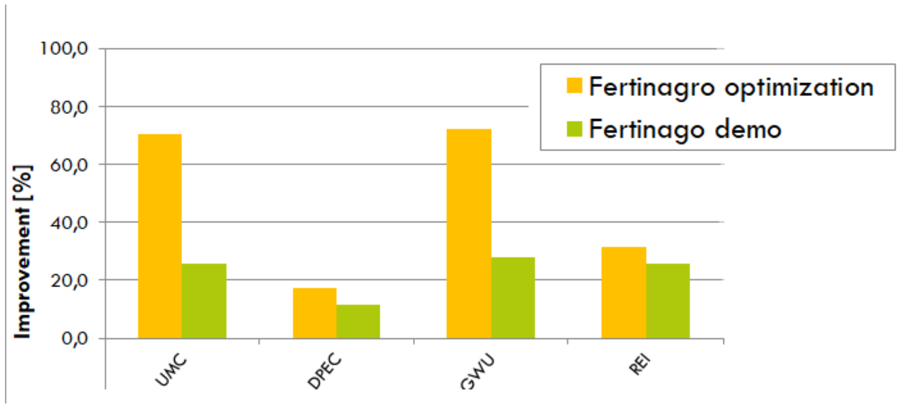


Figure 8: Comparison of the KRIs in the Fertilizer demo with those potential values provided by the M&O tool.

When the methodology is applied to the Chemical demo plant, it was found that it is possible to increase theoretically the energy and water consumptions up to 50% (see figure 9).

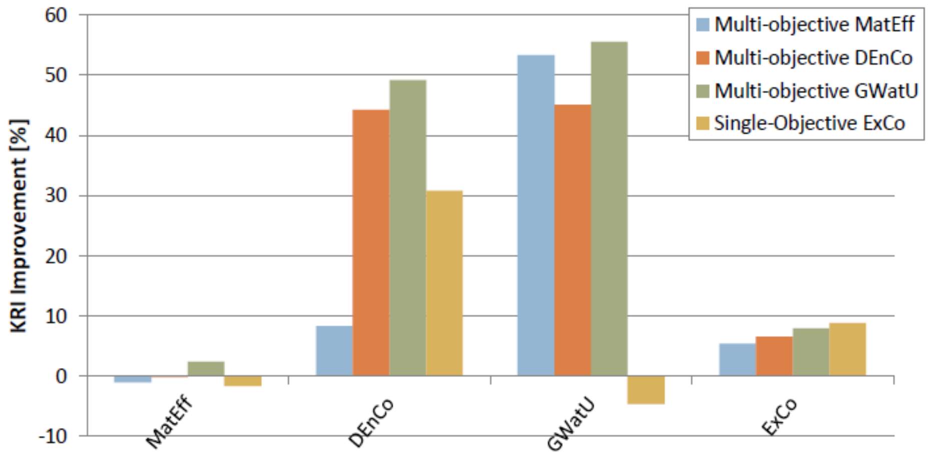


Figure 9: Potential optimization results in the Chemical case study.

It can be observed that the potential to improve the Exergy Indicator is in the range of 5 % to 8 %. The Exergy Costs are improved for each optimization case, whereas the largest improvement is achieved by the single-objective optimization. An improvement can be achieved at the expense of decreasing the material efficiency and the Gross Water use of the process. This means that this change could not be net positive in terms of profitability.

An entire application of the optimization results could not be performed during the demo activities, as the implementation of the demo cannot modify parameters in the process plant. However, the monitoring and optimization tool is installed at the DCI-facilities and first tests to analyze the reactions of the utility system are performed and evaluated being consistent with the current existing control system's results.

1.3.3. Standardization of the methodology and the KRIs

In order to improve the exploitation and the replicability of the results, a CEN Workshop Agreement (CWA) has been built and published: ***"CWA 17185:2017 Methodology to measure and improve the resource efficiency of resource intensive processes"***.

1.3.4. Demo results and impact in the industrial sites

After a demo period of 200 hours, where different trials were performed, in the fertilizer industry, the impacts achieved are the following:

- Reduction of exergy cost of 30 %
- Reduction energy costs of 80.000 € / year (natural gas and electric consumption). This is for a production plant of 8.000 Ton/ year.
    - Gas consumption per Kg of fertilizer reduced in 21,82 %
    - Electricity consumption per Kg of fertilizer reduced in 14,83 %
- Increase of 14% of production without any cost.

Considering the energy savings and the increase in the production, the economical evaluation of the ROI is approximately two years. The production in the demo plant is 4.000 Ton/year, which seems little compared with other production plants of FERTINAGRO in which the project is applicable, with production rates 30 to 50 times bigger.

In the case of DCI, due to the complexity of the processes the demonstration has been complicated and required a huge sharp and redo of the model, as well as a constant updating of the optimization tool.

The TOP-REF scope in the ethylene cracker of DCI as included the following items:

- Fired Equipment (Steam Producers)
    - Cracking furnaces (Fixed – No degree of freedom)
    - Boiler (Variable – Degree of freedom)
- Large Turbines & Compressors (Steam Consumers)
    - Efficiency
- Distillation columns (Secondary steam consumers)
    - Energy Balance
- Steam Grids (Steam Balance)
    - Steam Grid Balance
    - Exergy Performance analysis leading to new set-ups

At this point, the impact highlighted by DCI are:

- The simulation is validated and capable to simulate a scenario of 100% naphtha fed and an ethylene production at nameplate capacity with an accuracy of ±10%.
- The thermoeconomic and subsequent analysis from an energetic and economic point of view showed that venting SL steam is the most inefficient spot in the steam network (45% of the total economic losses and 55% of the total energetic losses). The annual savings in case all the SL steam was used in the facilities instead of being vented reach up to two millions € of savings per year

- Improvements ideas have been identified to mitigate energetic losses: better control strategy, steam recovery and potential new consumers for the excess of steam
- The development of two different softsensors are of high interest in terms of replicability

1.3.5. Replicability

The replicability to other sectors is another important aim of the project. In this sense, the methodology and tools may be easily applicable. In the case of solids drying or granulation, which presents similar equipment and production chain such as:

- Ceramic sector: Frits manufacturing
- Cement sector: Cement manufacturing
- Fertilizer sector: Every MKP fertilizer.

In the case of DCI and PETROGAL, the modeling will be replicable whenever steam grids and chemical distillation, compression or separation process are inter-connected

- Chemical sector: Refineries, olefin distillation and hydrocarbon manufacture
- Non-chemical sector: Almost every system where steam grids are found connected to thermal consumers:
- Thermal desalination plants
- Pulp&Paper
- Power plants

1.3.6. Contributions to the roadmap of SPIRE

TOP-REF is directly linked with SPIRE. In this sense, the activities of the project support and enhance the implementation of several Key Actions (KA) of the roadmap of SPIRE: http://www.spire2030.eu/

The specific contributions to each Key Action of the roadmap are included in the project deliverables in a dedicated section. The main KAs that the project is contributing to are included below.

- **KA 2.3:** Process monitoring, control and optimization. Methodology tools and indicators addressing specifically resource efficiency in industry
- **KA 2.4:** More efficient systems and equipment.
- **KA 2.5:** New energy and resource management concepts (including industrial symbiosis)
- **KA 4.1:** Systems approach: understanding the value of waste streams
- **KA 5.2:** Methodologies and tools for cross-sectorial Life Cycle and Cost Assessment as well as novel social Life Cycle Assessment of energy and resource efficiency solutions.

1.3.7. Other outcomes related to the project development

In addition, other results addressing to establish the knowledge and methodology of the project have been achieved, and are summarized below:

- Definition of the boundary conditions of the processes and excel questionnaire to gather industrial data.
- Benchmarking of current sectorial tools and indicators
- Synergies and common points between processes and sectors.
- Identification of process outputs' constraints and requirements for each processes, including a KPA calculator for fertilizer process and thermal processes of DCI and PETROGAL

1.3.8. Foreground exploitation

The main goal of Deliverable 8.2 is to identify the Key Exploitable Results (KERs) of the TOP-REF project and provide the basis for a business model for each. The following five KERs were identified as having the greatest potential and maturity:

- KER1: Model and simulation of industrial steam networks
- KER2: Thermoeconomic analysis
- KER3: Monitoring and optimization of industrial sites according to EN/DS17185:2017
- KER4: Soft-sensors
- KER5: Model-coupling framework

The project partners have expressed interest for further developing specific KERs either for further scientific or market exploration as shown in following table:

Partner	KER1	KER2	KER3	KER4	KER5
Circe	Yes	Yes	Yes	Yes	Yes
BIO	No	No	Yes	No	No
Tecnalia	No	No	Yes	Yes	No
Cosmo Tech	No	No	No	No	Yes
Inosim	No	No	No	No	Yes
TUDO	Yes	No	No	No	Yes
DS	No	No	Yes	No	No

The deliverable is strategically aligned with the Key Action (KA) 2.3 (Process monitoring, control and optimization) of the SPIRE roadmap.

1.4. Potential impact

1.4.1. Impact in the Industry

Fertilizer industry

After a demo period of 200 hours, where different trials were performed, in the fertilizer industry, the real more relevant impacts achieved from an industrial point of view are the following:

- Reduction energy costs of 80.000 € / year (natural gas and electric consumption). This is for a production plant of 8.000 Tn/ year.
- Increase of 14% of production without any cost.

Considering the energy savings and the increase in the production, the economical evaluation of the ROI is approximately two years. The production in the demo plant is 4.000 Tn/year, which seems little compared with other production plants of FERTINAGRO in which the project is applicable, with production rates 30 to 50 times bigger.

In the case of Fertilizer industry, Fertinagro has already identified other production sites where the TOP-REF methodology can be easily implemented:

- Huelva 200.000 tn/year
- Teruel >400.000 tn/year
- Misson 120.000 tn/year

Moreover, the developed KRIs are identified as an opportunity to be used a benchmarking tool, currently non-exiting in the sector.

Regarding the replication in the overall sector, some big numbers can be provided:

- The total European Production of NPK granulated fertilizers, where TOP-REF approach is fully and directly applicable is $1,2 \times 10^6$ Tn /year.
- Reaching a success rate in the whole market in Europe of 20 %. The total gas natural saved means approx a saving of 1×10^9 kWh of Natural gas(11,7 kWh/Nm^3).
- Considering that the of natural gas per habitant and year in Europe is 2500 kWh. TOP REF Project saves the equivalent of 400.000 inhabitants per year (saving Bratislava per year)
- The succesfull application of TOP REF in a 20% of the production in EUROPE will lead to a increase of 200.000 Ha of production o cereals only in EUROPE.
- The reduction of the emissions achieved is equivalent to the emissions of 21.000 Vehicules per year.

Chemical sector (Ethylene Cracker)

In the case of DCI, due to the complexity of the processes the demonstration process were complicated and required a huge sharp and redo of the model, as well as a constant updating of the optimization tool.

At the end of the project, the impact highlighted by DCI are:

- The models are validated and capable to simulate a scenario of 100% naphtha fed and an ethylene production at nameplate capacity with an accuracy of ±10%. This is relevant in order to connect the steam grid simulation and the ethylene production plant simulation that is, at this moment, unlinked.

- The thermoeconomic assessment pointed out that venting low pressure steam is the most inefficient spot in the steam network (45% of the total economic losses and 55% of the total energetic losses). The annual savings in case all the steam was used for productive purposes, according to DCI calculations, could reach up to 2M € per year.
- Improvements ideas have been identified to mitigate energetic losses: better control strategy, steam recovery and potential new consumers for the excess of steam.
- Two different soft sensors, one for obtaining the Raw gas composition at the exit of the cracker and another to obtained the top section composition of a distillation column have been developed. These soft sensors has result of being of high interest in terms accuracy and replicability.

Moreover, the objectives and results of the project provides to the industry new paths to follow the cooperative goals for sustainability as is shown the case of Dow Chemical Iberica (see figure 10).

Figure 10: DoW Chemical 2025 sustainability goals

Regarding the replication in the overall sector, the potential savings in natural gas in case a reduction of 40% of the exported (bought) natural gas from the network (about 6.0 KTon/year), about 3.0 MM€/year

A 25% successful replication of TOP-REF Project in the whole EU Ethylene production (19,225 kTon/year) will lead to reduce the consumption of Gas natural of 756.000 inhabitants per year in the city of Barcelona (800 kWh per inhabitant and year. As well as 21 M€ in savings per year for the industry.

In terms of natural resources impact, the potential savings in water in the total Ethylene production in Europe will lead to save 175 M litres of process water per year. Concerning the emissions, a 25 % successful replication of TOP - REF will reduce the emission in the industry in 101.5 kTn of CO2 per year (almost 82.250 diesel vehicles in year).

1.4.2. DIssemination

In the table below are included the key events in which the TOP-REF has participated

Event	date	scope
International Society of Automation conference	6th June 2014	Presentation and publication
General assembly of the Spanish Platform of Sustainable Chemistry (SusChem Spain)	30th September	Workshop and project presentation
Standards: Your Innovation Bridge", the international reference conference on safety and quality standards	30th October 2014	Presentation and stand
Style project KoM	29th January 2015	Project presentation
SPIRE Workshop	21st 22nd April 2015	Impact presentation
Resource efficiency in chemical Industry . Workshop organized with the Spanish Technological Platform for Sustainable Chemistry	1st Ocotober 2015	Workshop and panel discussion
10th European Congress of Chemical Engineering	27th October 2015	Poster (2) presentation
Life Cycle Management (LCM 2015) international conference	30th August 2015	Project presentation
SPIRE Workshop on Resource Efficiency Monitoring, Assessment and Optimization	3rd February 2015	Workshop
Technical University of La Almunia (Zaragoza) Conferences	15th may 2015	Project presentation
Spanish Biennial of machine tool	June 2016	Oral presentation
Industrial Technologies Conference	23th June 2016	Poster and oral presentation
AIChE Annual Meeting	17th November 2016 (USA)	Oral presentation
30th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems (ECOS 2017)		
Workshop within SPIRE for SPIRE members 2017 EU PROCESS INDUSTRY CONFERENCE: A LOOK TO THE FUTURE	19th September 2017	Workshop
Workshop in the 10th world Congress of Chemical Engineering	4th October 2017	Workshop

Usually the key and more tangible results of a project are available during the last months of the project. Thus a short overview of the key events is provided as follows:

AIChE Annual Meeting 17th November 2016 (USA)
*Presentation **"The Top-Ref Approach to Improve the Resource Efficiency of Energy Intensive Industrial Processes"***

The AIChE Annual Meeting (organized by the **American Institute of Chemical Engineers)** is the premier educational forum for chemical engineers. Academic and industry experts gather yearly at this event to cover a wide range of topics relevant to cutting-edge research, new technologies, and emerging growth areas in the field of chemical engineering.

The presentation was scheduled within the session "Going to a Decision Point in Sustainability", and raised great interest among the professionals that attended the conference. The audience was especially interested in the TOP-REF methodology and the first results

30th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems (ECOS 2017) (USA)

The 30th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems was held in San Diego (USA), by the beginning of July, and gathered top international scientist and specialists on energy efficiency and exergy analysis.

The purpose of TOP-REF presentation was to show and validate the KRI methodology to a scientific audience. Particularly, the exergy indicator is one of the KRI selected under TOP-REF methodology and it was important to show how exergy can be also used to assess non-energy flows. Particularly, TOP-REF methodology has been applied to relevant industrial sectors: the cement, the ceramic and the fertilizer industries.

Workshop within SPIRE for SPIRE members **2017 EU PROCESS INDUSTRY CONFERENCE: A LOOK TO THE FUTURE (Advisory board)**

In the framework of the three days SPIRE workshop held in Brussels between 19th and 21st September. CIRCE organized a specific session with the title "**Process optimization towards new feedstock and energy challenges"** during this session some of the results of the project TOPREF were presented. In addition, during the second part of the session the advisory group of the project focused in the replication of the project results among SPIRE industries participated in a debate.

The advisory group were composed by the following persons:

- **Rolf Sorbo**, R&D Director, Elkem (non-ferrous metals)
- **Bernhard Kohl,** Strategic Environment Management Unit, Voestalpine (steel)
- **Hugo Bosio**, project manager, BOSIO, AICHELIN Group (Industrial furnaces)
- **Ludo Dils**, Vito and Univ. Antwerp (representing fine chemicals)
- **Christian Artelt**, Heidelberg Cement (cement)
- **Ignacio Martin** (CIRCE) Chair of IRIAG and Member of the Board of SPIRE

The conclusions and remarks of the session and the advisory board have been gathered and under review to be published.

In the table below may be found a summary of the publications done in the project.

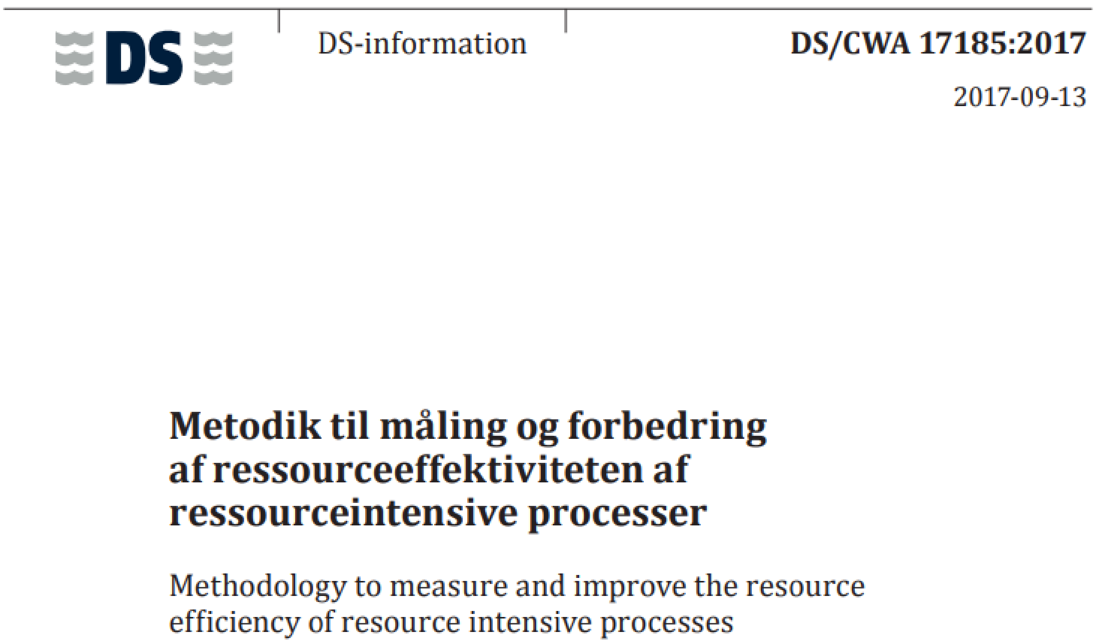
Publication	Publication site	Scope	Language
TOP-REF: More competitive, efficient and sustainable industries	Automática e Instrumentación	Spain	Spanish
An European project towards more efficient and sustainable industries	Smart quimic	Spain	English
Fertinagro takes part in a European project to be more efficient and sustainable	Tervalis magazine	Spain	Spanish
An European project to make industries more competitive, efficient and sustainable	FuturEnergy magazine	Spain	Spanish & English
Exergy as a resource efficiency indicator for	paper in ECOS 2015	worldwide	English

industries			
Optimization of a NPK Fertilizer plant	poster in WCCE 10	worldwide	English
Presentations at SPIRE workshop Feb 2016	presentations of the project	Europe	English
Innovative solutions for the energy efficiency in industries	European Energy Innovation magazine	Europe	English

Table 1 key publications

In addition, it is remarkable that the project partner Danish Standards has recently published the CEN Workshop Agreement (CWA) Methodology to measure and improve the resource efficiency of resource intensive processes. This European CWA specifies a cross-sectorial methodology for identifying, characterizing and implementing a set of indicators whose purpose it is to enable an organization to improve the resource use efficiency of a process or the impacts associated with the consumption of these resources.

The CWA is free for downloading


DS-information

DS/CWA 17185:2017

2017-09-13

Metodik til måling og forbedring af ressourceeffektiviteten af ressourceintensive processer

Methodology to measure and improve the resource efficiency of resource intensive processes

Figure 3 CWA published by Danish Standards

1.4.3. Impact over SPIRE roadmap and industrial performance.

In the pattern, for the deliverables of the project was include a specific session to summarize how the deliverable may support the implementation of the Key Action of the SPIRE roadmap.

The Key Actions addressed by TOP-REF are the following

KA 2.3: Process monitoring, control and optimization:

- Tools for modelling and simulating.
- Indicators to improve the resource efficiency.(energy + material)
- Monitoring and control strategies and methodology

KA 4.1: Systems approach: understanding the value of waste streams:

KA 2.4: More efficient systems and equipment

KA2.5 New energy and resource management concepts (including industrial symbiosis)

Industrial symbiosis,, waste2 resources and process intensification by an exergy KRI to assess the quality, cost and potential of the resource

KA 5.2: Methodologies and tools for cross-sectorial Life Cycle and Cost Assessment as well as novel social Life Cycle Assessment of energy and resource efficiency solutions:

- Thermoeconomic assessment methodology for process diagnosis.
- LCA assessment including the use of KRI indictors developed within the project

1.5. Project web site

Through TOP-REF Platform Website www.toprefproject.eu/, the project has presented its methodology and results. In this way, the project became a node of information.

It will also include an overview of the concept, objectives, the partnership and the activities

All in all, TOP-REF website includes a collection of the project documents, where all the key public deliverables will be easily accessed as the first step for all the sector stakeholders.

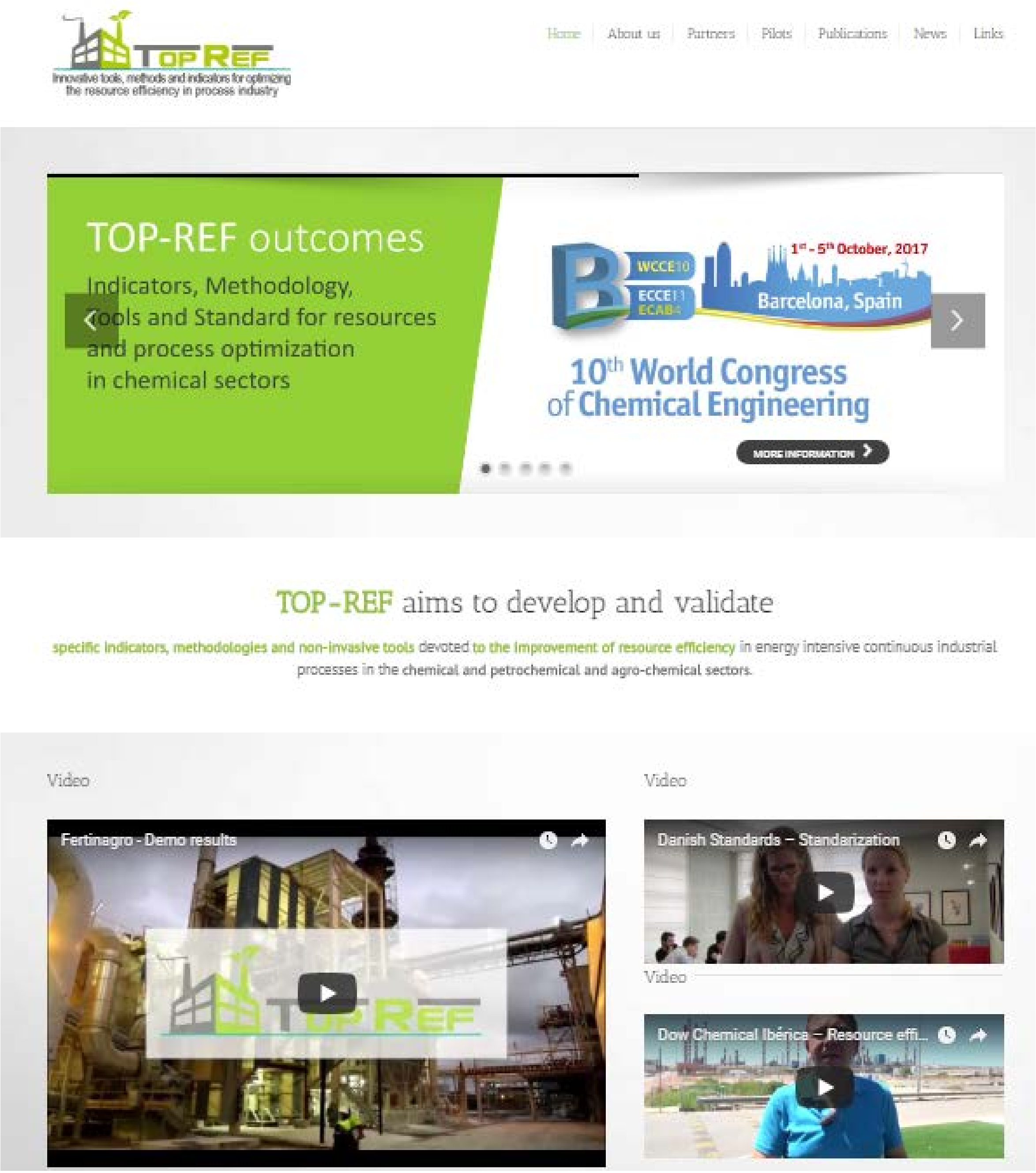


Figure 4 Home page of the TOP-REF web-site

Regarding the impact of the web site, it is remarkable that the country with more visits to the web is USA as may be seen in the figure below

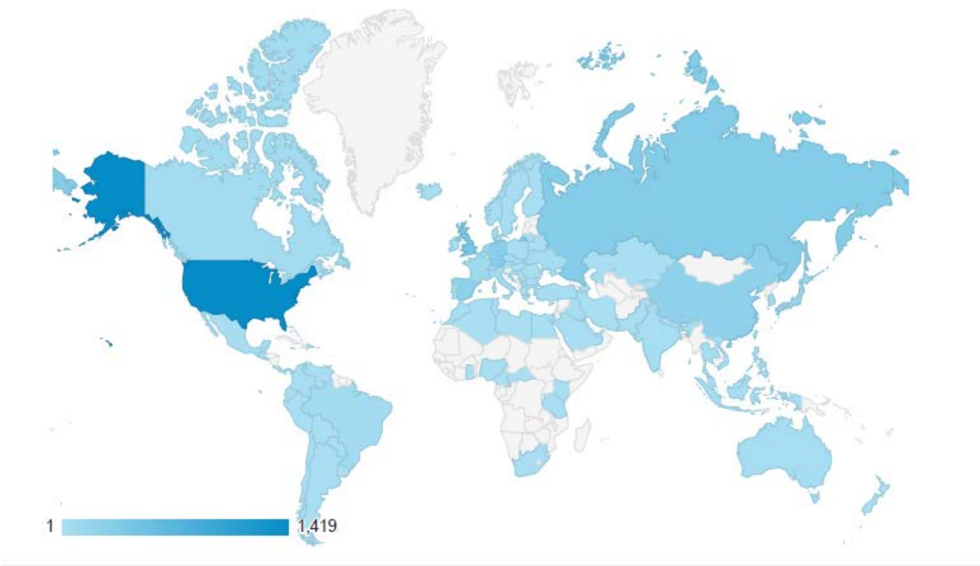


Figure 5 Map overlay (google analytics)

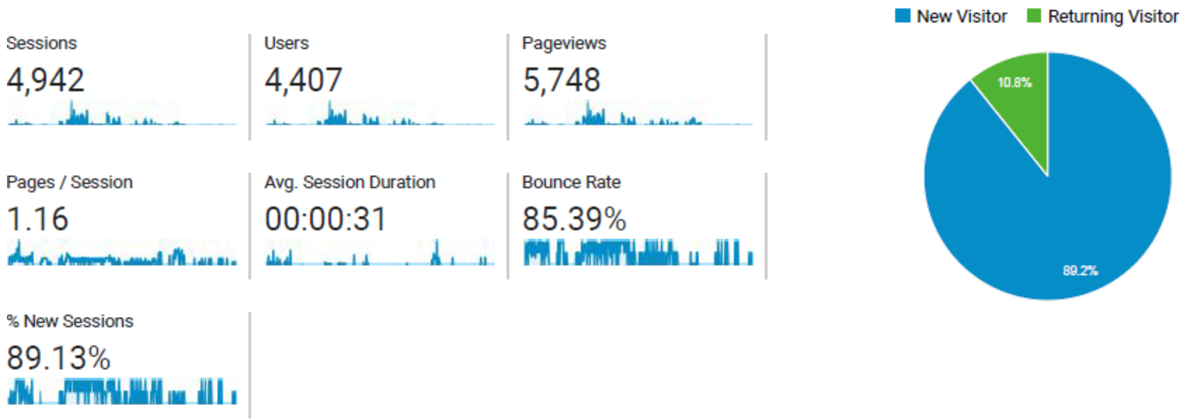


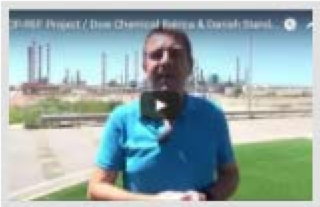
Figure 6 Audience overview (google analytics)

During the Project, several videos have been developed in order to facilitate the dissemination of the Project in a easy and friendly manner.

All the videos are included in the web site in the publications/dissemination material section.

Fertinagro – Demo results

Sergio Atarés (Fertinagro) explains the impacts of the Project at their industrial plant and the results of the TOP-REF project



Dow Chemical Ibérica – Resource efficiency

Eduardo Gadea (DCI) explains the impacts of the Project at their industrial plant and the link between their activities and TOP-REF objectives

Danish Standards – Standarization

Signe Annette and Charlotte Vincentz (Danish Standards) explain the importance of standardization, specially in a project of this kind.

TOP-REF aims to develop and validate specific indicators

TOP-REF aims to develop and validate specific indicators, methodologies and non-invasive tools devoted to the improvement of resource efficiency in energy intensive continuous industrial processes in the chemical and petrochemical and agro-chemical sectors.

Figure 7 TOP-REF videos