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Novel concept of context sensitive energy and environmental management system for support sustainable development of industrial companies

Fouad Al-Mansour
Jozef Stefan Institute – Energy Efficiency Centre
Jamova cesta 39
SI-1000 Ljubljana
Slovenia
fouad.al-mansour@ijs.si

Boris Sucic
Jozef Stefan Institute – Energy Efficiency Centre
Jamova cesta 39
SI-1000 Ljubljana
Slovenia
boris.sucic@ijs.si

Matevz Pusnik
Jozef Stefan Institute – Energy Efficiency Centre
Jamova cesta 39
SI-1000 Ljubljana
Slovenia
matevz.pusnik@ijs.si

Tomaz Vuk
Salonit Anhovo, d.d.
Anhovo 1
SI-5210 Deskle
Slovenia
tomaz.vuk@salonit.si

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Abstract
The concept of sustainable development is broad and represents the way in which human activities impact on economic development, the environment and social well-being. The objective of sustainable development is to ensure economic growth without jeopardising economic development, social well-being and natural environment of future generations.

Energy consumption in industry plays a key role in reaching the goals set for the transition towards the sustainable economy, putting energy efficiency up front with the highest priority. The role of Information and Communications Technologies (ICT) is defined as an enabler of energy efficiency across the economy. Insufficient or inappropriate monitoring of energy consumption usually leads industrial companies in wrong directions and not knowing what potential they have for profitable energy investments. The use of system control and data acquisition systems (SCADA) for monitoring process behaviour in industrial companies has increased, but in many cases such systems are not connected to the energy consumption optimisation.

The paper presents a novel concept of the context sensitive energy and environmental management system and a case study of its implementation in energy intensive industry. A concept of the tool has been developed for achieving energy savings and emissions reduction through the system of metering, monitoring and evaluation of energy, environmental and economy performance. The main pillar of the tool is the knowledge repository and its integration with ambient intelligence based systems. The presented case study shows a repeatable and practical application of energy cost centres based modelling of energy consumption in energy intensive industrial companies. Also, it has been confirmed that monitored energy consumption enriched with context from ambient intelligence data can be the basis for the identification of energy savings.

Introduction
The main objectives of the energy and climate policy of European Union (EU) are decreasing the greenhouse gases emissions, increasing the energy efficiency and share of the renewable energy sources (RES) in energy balance and decreasing the energy dependency. Comprehensive review of the EU energy and climate policy framework together with the instruments to tackle identified gaps can be found in (Kanellakis, 2013) and (Helm, 2014). In the past, many countries have defined challenging energy and climate related long-term objectives but lack of clear definition of responsibilities with deadlines for the implementation of proposed measures was the crucial reason why many goals have not been achieved (Klinge Jacobsen et al., 2014).

Insufficient or inappropriate monitoring of energy consumption may hinder the companies' potential by not capitalizing fully on their energy investments (Harris, et al., 2000). A common mistake of energy and environmental management projects is that the adopted approach is too narrow and the focus is only on the utility side, specific technical solutions or computerized control. Importance of the production side of a factory, and importance of human factors are not sufficiently appreciated. Therefore, in such cases, a number of opportunities for performance improvement will be missed, and overall results will be moderate (Trianni et al., 2013). Majority of industrial companies are production focused and, as such, they consider energy and environmental performance as marginal issues to production output and quality considerations, but many examples may be found around the world to prove that there are important reasons for them not to be separated operationally as they usually are organizationally (Harris et al., 2000; Thollander et al. 2013).

During the research work presented in this paper, an important challenge related with the clear need for the appropriate decision support system which should enable simulation and analysis of hypothetical future situations in terms of energy consumption, related costs, market changes, environmental impacts and emissions trading has been recognized. Production planning support involves the elaboration and evaluation of alternatives in order to reach a decision about the most suitable (optimal) solution. This paper presents a concept of interactive and comprehensive platform for energy consumption analysis in energy intensive industries. Proposed concept aims at supporting energy experts in industrial companies in optimizing energy performance of both supply and demand side aspect of their work. Proposed concept of interactive platform has a potential to fill the gap and help in harmonization of interests between the energy intensive companies. The developed system has been tested and trained on measured energy consumption data obtained from the real industrial environment in largest Slovenian cement production company Salonit. By taking into account the selection of different fossil and alternative fuels, energy market prices and CO_2 emission allowances a decision support for long term production planning is enabled.

Methodology

The overall idea behind proposed concept is to provide a tool for achieving energy savings and emissions reduction through the system of metering, monitoring and evaluation of business, energy and environmental performance. This support is in form of ICT building blocks (BB), which combine context awareness, ambient intelligence monitoring and standard energy consumption data measurement. The proposed concept focuses on clearly specified performance targets and objectives related both to people performance and underlying process performance with the goal of achieving continuous energy and environmental performance improvements. With the aim to assure continuous energy and environmental performance improvements proposed concept is based on decentralised responsibility for energy and environment through EECs along the actual process and energy flows in an industrial company. EEC based modelling of industrial energy consumption has been introduced by Morvaj and Gvozdenac (2008). Unfortunately, a comprehensive literature review did not provide any fixed rules on how to setup a model of ECCs for each particular industrial branch. An ECC can be any department, section or machine that uses a significant amount of energy or creates significant environmental impacts. However, the guiding principle for modelling setup is to follow the production process stages as given by the process flow chart for each industrial branch, and try to define the ECCs so that they coincide with the existing production quantity control boundaries (Morvaj and Gvozdenac, 2008). Energy consumption in each ECC enriched with the contextual information represents key element for the calculation and evaluation of performance indicators, interpretation of performance level against given targets and decision support for implementation of corrective actions. Also, important challenge that has been recognised during the comprehensive survey among energy intensive companies in Slovenia is related with the clear need for the appropriate decision support system which should enable smoother integration of the energy efficient technologies in a real industrial environment. Figure 1 illustrates the envisioned reference architecture and general information flows of the proposed context sensitive energy and environmental management system. The objective of the proposed reference architecture of the context sensitive energy and environmental management system is to provide a holistic service oriented integration of the architectural components and the existing shop-floor infrastructure. In this case, context variables are variables that affect the process behaviour but that are kept steady for periods that go beyond the process time constants.

The information flow starts from the different sources of information on the shop-floor level (Ambient Intelligence [AmI] data received from various locally installed meters and sensors, energy measurement data, data from existing systems like SCADA systems or enterprise resource planning [ERP] systems, manual inputs by end-users, other information about the manufacturing processes from different sources) and goes through the building blocks for AmI Data Acquisition and Context Sensitive Processing, enhancing energy measurement data with context information. The results of data acquisition and context-sensitive processing are provided to the other building blocks via common knowledge repository in order to enable different types of calculations/predictions and eventually provide decision support to the users, either via user interfaces or in the form of a "feedback loop" into existing systems. After the verification of new data, AmI/Context building block may automatically initiate/trigger new energy consumption/prediction and emission calculation or decision support. The foundation of the proposed concept is a common data model and knowledge repository to enable interoperability between the different components. The knowledge repository is necessary to systematically capture, organize, and categorize knowledge-based information provided by building blocks of the proposed concept. The knowledge repository serves as a comprehensive follow-up instrument, which is necessary in the process of continuous improvement of energy efficiency in any industrial facility since it connects people, their responsibilities, performed actions and achieved results. As a backbone to the knowledge repository, an abstracted data access layer is designed to handle every access, read or write. Notifications about events and availability of new data are implemented directly between building blocks. Energy Modelling, Emission Calculation and Prediction Engine building block is responsible for the calculation and prediction of energy consumption and related emissions. Parameterisation of the energy models and configuration of energy cost centres is done through the setup and administration component which is generic software component of the proposed context sensitive energy and environmental management system. Users of the data after it was processed by the Energy Modelling, Emission Calculation and Prediction Engine building block and stored in the knowledge repository are AmI/Context and Decision Support building block. Decision Support Services are providing systematic mechanism for support for immediate reactions and support for process reconfiguration and ETS. Support for immediate reaction involves the definition of a strategy to respond automatically to an abnormal situation that must be resolved. This approach implies the application of a automatic corrective measure based on real-time measurements. Support for reconfiguration and ETS involves the elaboration of scenarios which will then be evaluated in order to reach a decision about the best alternative. This action is triggered by the end-user and is not directly interacting with production process in real time (Marques and Neves-Silva, 2013). The proposed set of building blocks together with the knowledge repository allow the identification of energy profiles and energy consumption patterns and their interrelations to support energy efficiency optimisation and CO_2 emissions reduction, using the combination of the knowledge management and smart metering technology for innovative data/information/knowledge processing.

Case study – largest cement producer from Slovenia

Salonit Anhovo (Salonit) is the largest cement-producer in Slovenia, one of Slovenia's largest CO_2 emitters and it is included into emissions trading scheme (ETS). Company has a rich industrial tradition and it has been producing cement since 1921. Due to financial and economic crisis yearly production is currently reduced to around 500 thousand tons of cement, primarily used on Slovene and neighbouring construction markets. Before the crisis yearly production was around 900 thousand tons of cement (overall production capacity is 1.2 million tons of cement). Constant need for competitiveness on the market is forcing Salonit to systematically and continuously analyze all possibilities for the optimization of production activities and related costs reduction. The main challenges of Salonit's future development are:

- How to remain the leading cement producer and how to further strengthen its leading position on the local and neighbouring markets?
- How to achieve a leading position in production and marketing of lime?
- How to sustainably increase production capacity?
- How to continuously enhance environmental, energy and economic efficiency – reduce the use of non-renewable energy sources in all parts of the production process?

The main energy cost centres within the Salonit's production process have been given in Figure 2. For the further elaboration two energy cost centres, ECC 5 and ECC 7, were selected. ECC 5 represents clinker burning process and it is the most energy (heat) intensive process in the cement production, Figure 3. ECC 7 represents cement grinding process and together with the ECC3 (raw material grinding process) is the most electricity intensive process in cement production.

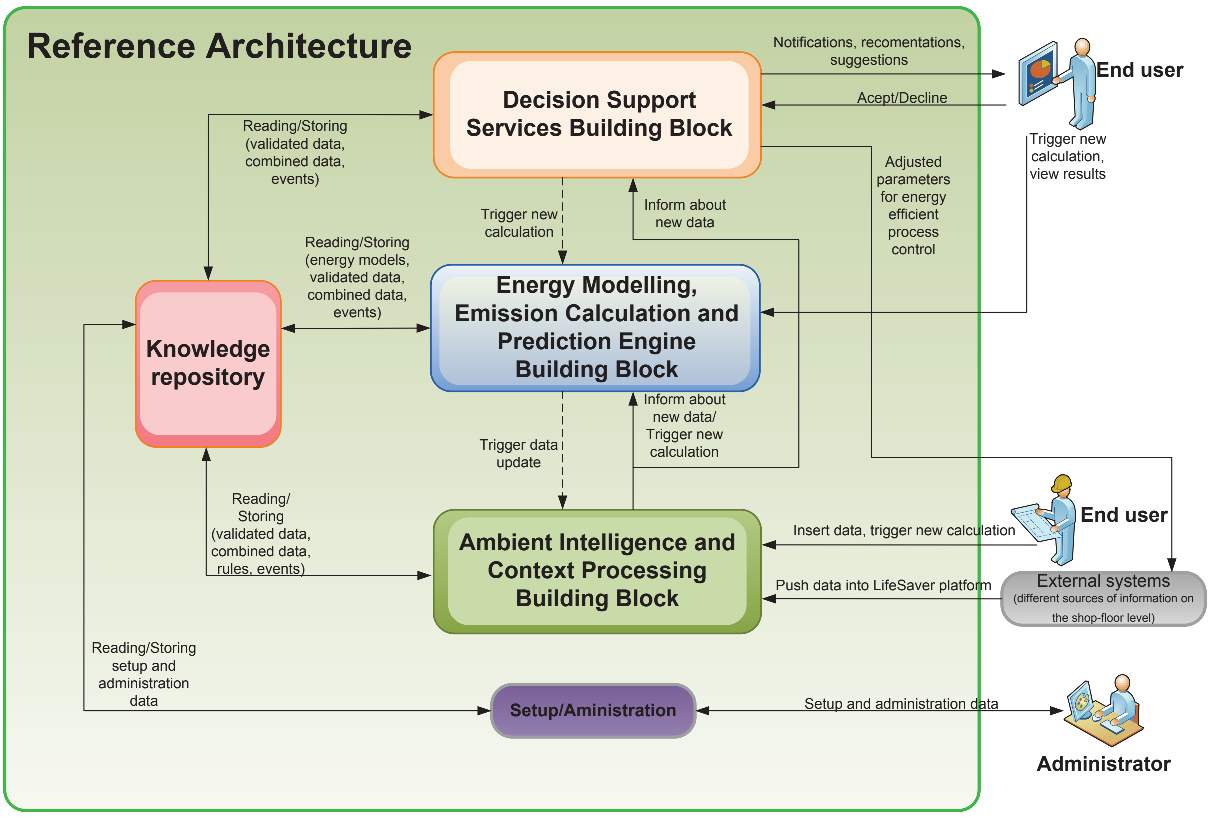

Figure 1. Reference architecture and general information flows of the proposed context sensitive energy and environmental management system.

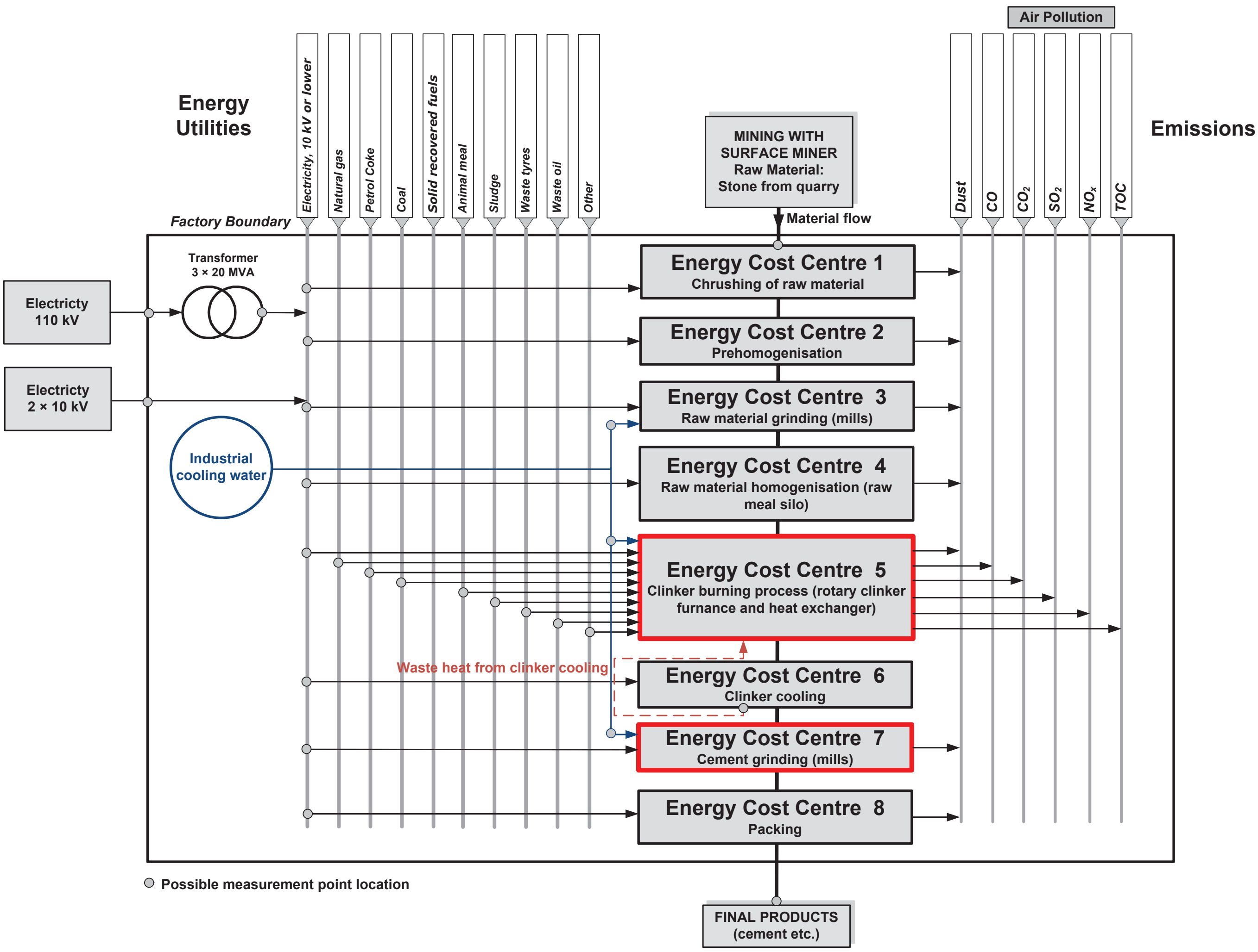

Figure 2. Energy cost centre based modelling of the cement production process – Salonit use case

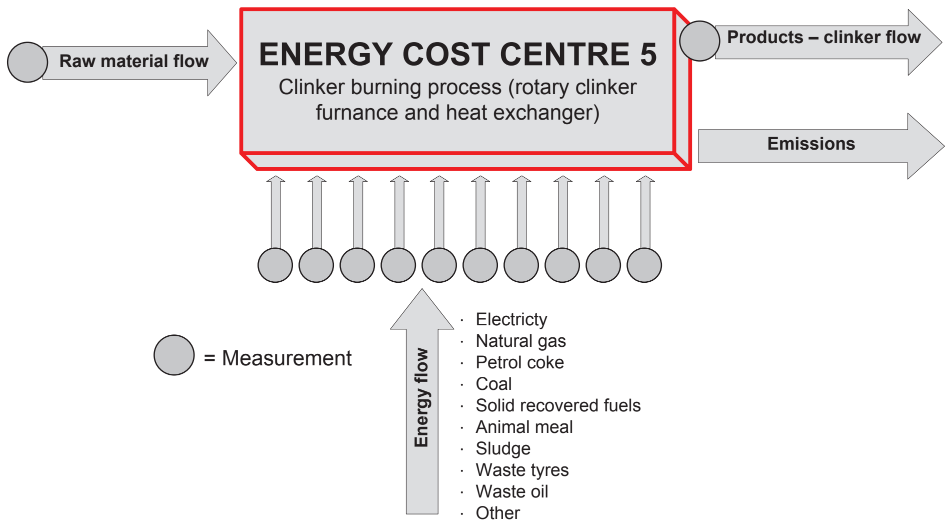

Figure 3. Detailed representation of flows (raw material, energy, products, environmental impacts) in ECC 5, clinker burning process – Salonit use case

Regarding the selected ECCs it has to be emphasised that Salonit's expectations are closely linked with the development of expert and decision support systems for optimal process regulation, where energy consumption and fuel choice is of large importance. Using knowledge already existing in the company and using expert knowledge from cement industry new methods of on-line monitoring and regulation of processes are expected to be developed in the scope of the context sensitive energy and environmental management system. Technical objectives of Salonit regarding the context sensitive energy and environmental management system are closely related with the cement production process improvement and decision support system for short and long-term prediction of future energy consumption, related CO_2 emissions and verification of energy savings. More specifically, the proposed concept should enable the following:

- On-line calculation of specific energy consumption for process control, planning and comparison,
- Complex evaluation of process parameters influence on energy consumption, CO_2 emissions and costs,
- Complex evaluation of the energy and environmental performance in the factory, based on actual energy consumption, production data and related environmental issues,
- Simulations of hypothetical future situations for decision making (production planning, energy consumption prediction and emissions trading, etc.) and past decisions results tracking,
- Separate treatment of 8 different cements in two mills including the comparison of the specific consumption on a short and long term basis for more precise equipment adjustment.

Short description of all actors that are expected to interact and request functionalities from the context sensitive energy and environmental management system in Salonit are given in Table 1.

For research and validation purposes Salonit provided testing data related to a rotary clinker furnace. Within the energy model of the Salonit factory the rotary furnace has been defined as a single ECC as presented in Figures 2 and 3. For the initial testing the data samples were collected on a one minute interval for the period of seven days, which resulted in 10,080 samples of each input signal. For the advanced testing the data samples were collected on a one minute interval for the period of one year, which resulted in 525,600 samples of each input signal. Reliable and accurate long term predictions are of vital importance for appropriate operation and planning in energy intensive industrial companies. Thus achieving lower operating costs (CO_2 emission allowances, fuel/electricity purchasing costs, maintenance costs etc.) and higher reliability of process control (smoother operation/production) is necessary for the overall optimization of the production process. Since, the presented research problem (reliable and accurate long term predictions) corresponds to the time series prediction and modelling type of mathematical problem, during the testing phase neural net fitting rotary clinker furnace model for simulation/long term prediction of energy consumption has been

Table 1. List of actors in Salonit having requirements on context sensitive energy and environmental management system.

Actor	Description
Energy manager	The energy manager is the end user of context sensitive energy and environmental management system at Salonit, who shall get decision support related to evaluation of the energy and environmental performance in the factory, based on actual energy consumption, production data and related environmental issues. From the point of view of the context sensitive energy and environmental management system energy manager can be seen as a business expert having knowledge about the relationships between energy and context data on the factory level. Together with the process operator, the energy manager knows specific information required by the context sensitive energy and environmental management system for customisation of energy cost centres. Also, the energy manager is responsible for making the final decision (accepting or rejecting) about recommendation/suggestions obtained from the context sensitive energy and environmental management system on the factory level (strategic decisions).
Energy trader	The energy trader is the end user of the context sensitive energy and environmental management system at Salonit, who shall get decision support related to hypothetical future situations regarding energy and emissions trading.
Process operator	The process operator in the production control room is the end user of the context sensitive energy and environmental management system at Salonit, who shall get decision support related to proper selection of process parameters that influence energy consumption. Together with the energy manager, process operator knows specific information required by the context sensitive energy and environmental management system for customisation of energy cost centres. Also, the process operator is responsible for making the final decision (accepting or rejecting) about recommendation/suggestions obtained from the context sensitive energy and environmental management system on the process level (short term decisions, fine tuning of process parameters – immediate reactions).
Administrator	This role represents an "advanced user" of the context sensitive energy and environmental management system at Salonit who is an IT expert having required skills to define and edit the rules that system needs for data acquisition, context-sensitive data processing and energy model configuration.

developed. Also, the Levenberg-Marquardt back propagation algorithm has been used for network training. The model has been developed using 9 input parameters, 10 hidden neurons and 8 output parameters. The clinker furnace modelling problem has been defined as follows: the user (in this case that is the production planner, energy manager or energy trader) selects the mix of fuels for the clinker burning process, presents expected production flow and raw material flow used in the process, and as a result, a prediction of the energy consumption of the selected fuel alternative is obtained. Required input data for the energy mix is represented by the presence or absence of a certain fuel, where "1" represents the presence and "0" the absence of a certain fuel.

The results of net fitting network clinker furnace model have confirmed the possibility of using such model for simulations and long term predictions of energy consumption in energy intensive industry and fits well in the proposed concept of the context sensitive energy and environmental management system. Energy consumption, corresponding energy costs and CO_2 emissions are calculated through the use of caloric values, fuel prices and fuel emission factors obtained directly from the addressed cement company and multiplied with the modelled (predicted) consumption of the material and energy fuel flows provided by neural net fitting network. Selected indicators (energy consumption, costs and CO_2 emissions) are used as direct inputs for the decision support module where the production planning alternatives are analyzed through the process of multi-criteria decision making. Through the use of available historical data, past decisions result tracking is also enabled.

For the case study five different fuel choice alternatives (at specified production) were selected. The selected alternatives were analyzed using the net fitting based production planning and decision support system in terms of energy consumption, costs and CO_2 emissions.

The most representative fossil fuels used in the clinker burning process are coal, petrol coke and natural gas. For the alternative fuel mix, waste tires, waste oil, solid recovered fuels, animal meal and sludge is used. Since Salonit is one of Slovenia's largest CO_2 emitters it is also included into emissions trading scheme (EU-ETS). CO_2 emissions from fuel combustion or other processes involving chemical or physical reactions other than combustion are therefore subjected to emission trading legislation, which was in the first periods mostly based on grandfathering. In that manner Salonit was able to avoid large influence of emission coupons prices on the spot market. For the period of 2013 to 2020 a closer look into emission production is needed as emission allowances are not granted anymore in such way. In that context, optimizing emissions and constant monitoring and regulation is of high priority.

Selected scenario alternatives represent different operating regimes correlated to the mix of fuels used in the clinker burning process. Five days of process operation were simulated with one minute sample interval. Measured and predicted minute values were averaged and aggregated into hourly values, since the minute dynamics of the process is not really useful for long term production planning (day, week or month ahead).

For all scenario alternatives, fuel specific caloric values, emission factors and fuel prices were applied and discussed with the industrial partner. The analyzed scenario alternatives were developed for the real life situations in Salonit cement production process. As presented in Table 2, all analyzed alternatives are including fundamental mix of fuels: petrol coke, waste tires and solid recovered fuels. The results of decision support analysis are presented in Figure 4. Addressed alternatives were all normalized with the daily production of physical product (clinker produced in tons/day) since the production of the clinker varied for each scenario alternative. The most suitable or "optimal" alternative is represented by the value 1 (optimal alternative = 1). For example in terms of costs, the Alternative 2 is 25 % more expensive than the Alternative 1.

According to the results obtained, it is evident that in terms of costs the most suitable alternative is the Alternative 1, followed by Alternative 4, 3, 5 and Alternative 2 being the most expensive.

In terms of energy consumption and corresponding CO_2 emissions which are directly linked to the energy use (process emissions were not taken into account in this analysis, due to their presence not being connected to the selected fuel mix) the following results were obtained: Alternative 5 is the most suitable one, followed by Alternative 1, 4, 3 and Alternative 2 being the most energy intensive. However, it can be concluded that although Alternative 1 is amongst the alternatives with high energy consumption, it is evident that in terms of costs it is the most suitable one, due to the use of alternative fuels with negative prices. Initial testing results have confirmed the potential of costs savings up to 10 % enabled by proper long term production planning and decision support services. Early contextualisation of energy consumption was very valuable and enabled elimination of unnecessary leakages and was the first visible result during the testing phase which boosted the confidence of industrial end-user. Also, proposed concept proved its potential for the identification of critical elements in the clinker burning operations and enabled early validation of implemented corrective actions. However, limitations of the proposed concept are related with the requirements for expert knowledge during the training period and the definition of the initial set of context sensitive benchmark values.

Conclusion

One of the basic precondition for the sustainable transformation and overall energy efficiency improvement in energy intensive industries is the knowledge about energy consumption, especially how much, when and where the energy is consumed since investments profitability are strongly affected by these variables. The objective of presented research work was to propose a novel concept of the context sensitive energy and environmental management system including reliable, fast and accurate model for simulations and long term predictions of energy consumption and related costs. The proposed concept enables the simulations of hypothetical future situations and provides the required support in the decision making process (production planning, energy consumption prediction, emissions trading, etc.). Furthermore, an overall integration of such system in the energy intensive company can facilitate and increase the investments into energy efficient technologies. The complexity of such system, as described above on the example from the cement production facility, arised from significant number of variables that are providing valuable information and directly influencing energy consumption like availability

Table 2. Analysed scenario alternatives – long term production planning, Salonit use case.

Fuels	Scenario Alternative				
	1	2	3	4	5
Petrol Coke	1	1	1	1	1
Coal	0	1	0	0	1
Waste oil	0	1	0	0	0
Waste tires	1	1	1	1	1
Solid recovered fuels	1	1	1	1	1
Animal meal	1	0	1	0	0
Sludge	1	1	0	1	0

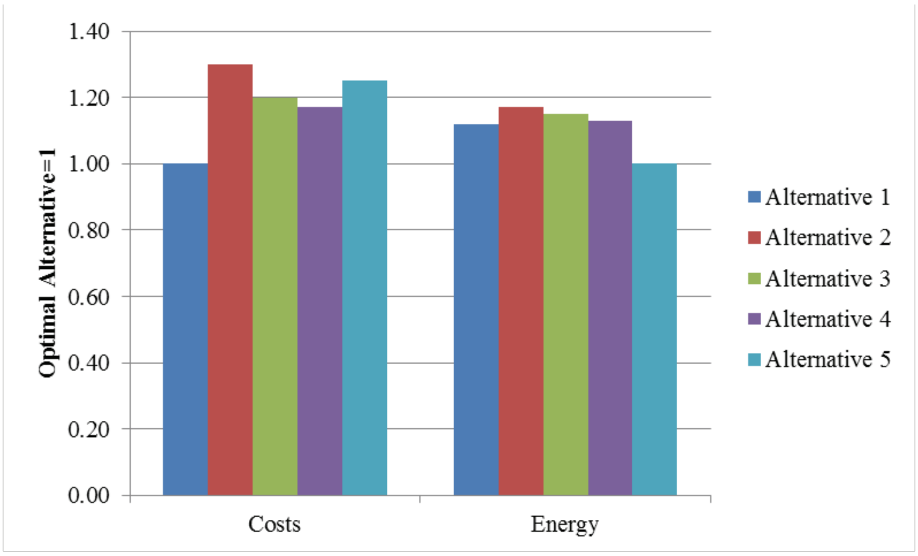

Figure 4. Normalized results of addressed alternatives (optimal alternative = 1) in terms of energy costs, consumption and CO_2 emissions – Salonit use case.

of the fuel with the negative price or renewable energy sources, hourly electricity price, employees (operators) in the control room and available fuel mix. Besides long term simulations, which are necessary for the production planning and cost optimisation, proposed concept enables on-line calculation of specific energy consumption for process control, comparison and alarming, complex evaluation of process parameters with significant influence on energy consumption based on actual energy consumption and production data. However, a lot of work has to be done on signal processing, minimization of input variables and complexity reduction. Also, in order to fully utilize potential of the proposed concept of context sensitive energy and environmental management system, further work must concentrate on the development of the low-complexity decision support services for the integration of new and advanced technologies in the complex industrial environment.

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