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Harnessing business intelligence in smart grids: A case of the electricity market

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ABSTRACT

This paper discusses analytical aspects of smart grids and offers insights into the development of a business intelligence solution for the electricity market. The goal is to design a system that provides an emerging electricity market with the necessary data flows and information for forecasting, data analysis and decision making, leading to better business results and more control over the market. By employing a methodology specifically suited to the electricity market domain, we designed a business intelligence solution for the Serbian electricity market operator "Elektromreža Srbije". The research results show that the proposed approach leads to more effective market management in data-rich smart grid environments, while still being dynamic enough to adapt to frequent rule changes in the still developing grids and their markets.

1. Introduction

Throughout history, as well as in modern times, the energy sector represented a key factor for accelerating economic growth and achieving sustainable development. Nowadays, the energy industry constantly needs to seek new ways to achieve higher levels of energy efficiency in order to answer the ever-increasing demands of consumers, businesses and governments. The key factor in achieving optimum energy efficiency is surely the development and adoption of smart grid technologies [1].

Smart grid technologies bring many innovations to the electric power industry, as well as changes to market structure, business models and services. As operators strive towards implementation of smart grids and accompanying technologies, they are faced with various problems concerning the ever-increasing consumer needs [2]. In order to succeed and thrive in this constantly changing business environment, electricity market operators must constantly seek to expand their access to operational data, and more importantly, improve their ability to convert the huge amounts of data into intelligence relevant to the operation of the grid [3]. In turn, the adoption of smart grid technologies must lead to consequent changes in companies' information systems. The dynamic nature of the energy business would serve as the perfect grounds for implementing analytical systems capable of meeting these requirements [4]. Business intelligence (hereinafter: BI) and knowledge management infrastructures have existed in business environments for many years, and their importance is an established fact. The necessity for such infrastructures in large energy systems has been recognized, as well.

BI in smart grids is considered to be one of the essential mechanisms of maximizing the "smartness" of the grid. A business intelligence model suited for the needs of a smart grid must offer a way to generate immediate business value from the new disparate data sources, including modern metering and supervisory data. The focus on the utilization of newly acquired data implies that the grid and market operators that are still in the process of smart grid adoption could gain the most from the implementation of a BI solution. This provides an opportunity to influence the future development of the metering infrastructure, allowing the grid to evolve into an information-rich environment where any decision could be based on actionable intelligence [5].

On the other hand, the majority of electricity markets in the developing countries still do not operate in the smart grid ecosystem. In order to adapt to the expected changes, it is necessary to design the current projects in such a way that they can be easily adapted to future smart grid expectations. Taking this into

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account, this research aims at proposing a bottom-up approach for developing BI solutions that support future developments of the deregulated electricity markets in the developing countries. Energy markets in this new environment will need to adapt to the newfound flexibility in energy demand, as well as to the consumers, who will become market participants and take an active role in energy generation [6]. Under these conditions, the energy systems still need to remain stable, in the sense that energy demand must be equal to its supply. Stable energy systems require adequate management of energy supply, and to some extent, of the demand, as well, in order to meet the optimum operational plans. For this purpose, it is necessary to develop and use analytical and BI applications in the markets. However, the literature does not offer much information about methodologies and best practices for designing BI solutions that incorporate all the specifics of rapidly evolving energy markets.

With the idea of making a contribution to filling in this gap, the focus of the research was placed on designing BI models capable of supporting an emerging electricity market. The models were specifically shaped for the electricity markets of the developing countries, which are in the process of grid modernization and migration to a smart grid. The developed BI model includes the required analytical data structures, as well as a set of key performance indicators (hereinafter: KPI) specifically suited for the three core processes of an emerging energy market: Balance Responsibility, Balance Mechanism and Allocation of Cross-border Capacities. While the energy market rules may differ from one country to another and from one market to the other, these processes remain largely unchanged. For this reason, other emerging markets can easily adjust the model presented here to fit their market rules.

The proposed approach was developed and evaluated within the Public Enterprise Elektromreža Srbije (hereinafter: PE EMS), a Serbian transmission system and electricity market operator.

The paper includes four sections. The second section provides a theoretical background of the business intelligence systems and data warehousing technologies from the perspective of an energy transmission system operator. The third section offers insights into the project itself, the methodology used, as well as the specifics of the conducted project. A subset of notable key performance indicators is also presented in this section. The fourth section analyses the achieved results for each of the distinct business process groups that were identified. The fifth section contains the discussion and the conclusion of the paper.

2. Theoretical background

The importance of smart grid concepts for the energy industry is a well-established fact [7]. Smart grid is a complete information architecture and infrastructure system that encompasses the entirety of energy-related activities in the field of power generation, transmission and distribution [8]. Smart grid strives to optimize the delivery of electricity through bidirectional communication between the grid and its users. End users in the smart grid environment act interactively and are allowed to adapt their energy consumption according to their needs, preferences, environmental concerns or other characteristics [9].

The basic concept of the smart grid and its effects on the electricity market stakeholders are outlined together with the conceptual model described in the NIST Framework and Roadmap for Smart Grid Interoperability Standards [10]. This model describes communications across the smart grid and offers a framework for the identification of actors, their interactions and their potential capabilities. In addition, this model can offer a new view on the potential sources of data that need to be integrated into the BI system of electricity markets. The identified potential data sources are:

- Electricity producers generate electricity from various forms of energy. The use of energy production data allows for smart generation and load balancing.
- The transmission and distribution of electricity to the customers is achieved through transmission and distribution operators. The use of distribution and transmission data allows for advanced prediction, minimization of transmission losses and ultimately the actualization of a self-healing grid.
- Residential, commercial and industrial customers are the end users of electricity. In smart grids, they are also able to produce and distribute energy, and are therefore able to participate in the retail market.
- Markets manage wholesaling, retailing and trading in electricity. They connect service providers, operators and customers, and often act as a connection point where data from various elements of the smart grid must be exchanged. Market data allows for detailed market analyses, trend and pattern recognitions and advanced forecasts.
- Service providers perform customer management, billing, and installation and maintenance services. They are often the link between the markets, operators and customers. Service provider data enable insights into customer behavior at a higher level of aggregation.

The use of BI systems in the energy industry has a potential to bring new value to business models and become the leading influence in the empowerment of the energy industry [11,12]. The use of a BI solution, coupled with a data warehouse, allows the market operator to collect data from heterogeneous systems and translate them into KPIs and analytical models that could be further analyzed. For this reason, data warehouses are commonly regarded as a basis for BI and decision-supporting systems [13].

BI solutions based on data warehousing technology are becoming a standard in the electricity markets. The most frequent way these systems are used is facilitation of faster report-drafting, as well as serving as a common integration point for data originating from different systems [14]. While highly useful, these conventional applications of BI technologies are not sufficient to enable a smart grid, and for this reason, further analytical aspects of these systems need to be considered. Many electric utilities have decided to harness the benefits of business intelligence systems and advanced analytics capable of supporting data-driven decision making and planning [15]. Table 1 shows the taxonomy of smart grid analytics based on literature data [16]. These main areas draw their analytical capabilities both from the technical data and the business/user-oriented data.

Analysis of the literature shows that the existing BI solutions in the energy industry are mainly focused on the fields of data warehouse design, forecasting and customer relationship

Table 1
Smart grid analytics taxonomy [16].

Field	Applications
Operational analytics	Operational effectiveness System performance Asset management Load trends and forecasts
Business analytics	Demand profiles Market segmentation Nonlinear load parameters Demand response behavior/forecasts

management. Only few examples related to the specific application of BI in electricity markets are found in the literature.

Siksnys et al. [17] developed a data warehouse schema for managing the complex energy data within the Mirabel smart grid project. Their model includes certain electricity market aspects, such as balancing supply and demand while utilizing the flex-offers. The developed data warehouse, while suited to some of the goals of the market operator, is narrowly focused on data and, in particular, on flex-offers rather than on the business processes taking place in the energy market. This data-oriented approach towards building a data warehouse can cause end user adoption problems, as well as problems with reporting and analytics that are based on the business process in its entirety, rather than the particular subset of data which are in the focus. In addition, the solution was designed for real-time forecasting, aggregation and querying the data [18]. However, the authors have not considered any market-specific KPIs, nor have they delivered a fully functional BI system to end users.

Escobedo et al. [19] provide a comprehensive framework for BI projects in smart grids. However, their approach is rather general, and it does not offer specific guidelines and recommendations on how to design smart grid specifics. Martin-Rubio et al. [20] advocate the importance of selecting adequate KPIs within BI solutions of smart grid companies without providing specific examples. Additionally, Personal et al. [21] place the research focus entirely on KPIs, claiming that combining performance indicators capability with alerts allows a proactive performance management.

Recent research is shifting the focus on the application of business intelligence systems for solving particular problems in smart grid ecosystems. The problem of forecasting is the most obvious one, and analyzing historical trends and emerging patterns across the organization opens up the possibilities of making accurate predictions about possible outcomes [22]. Forecasting by using such systems is possible and allows for prediction of various issues that could arise during different scenarios. For example, Yang et al. [23] propose a new decision-making algorithm for analysis of high-speed streaming data in smart grids. Vardakas et al. [24] analyze power-demand scheduling scenarios of residential users who possess smart metering infrastructure, with the aim to accurately predict and reduce the peak demand. McLoughlin et al. [25] also analyzed the smart metering data, using data mining techniques to cluster households based on their pattern of electricity consumption. User behavior analysis and forecasting offer higher reliability and quality of the delivered electricity, better consumption management and decrease of technical and commercial losses [26].

BI technologies that offer an in-depth analysis of the grid functionality have the possibility to further improve these forecasts by intelligently using the data at their disposal either in its aggregated or in its historical form. More advanced applications for decision making in the electricity market have been proposed in [27,28]. Sueyoshi and Tadiparthi [27] developed a software for analyzing the price change in the U.S. wholesale electricity market. This software is based on artificial intelligence, and can be used by traders for decision making. The main disadvantage of the proposed approach for modern electricity markets is that it is not integrated with a company's information system, and the data set needs to be imported before analysis, which makes it hard to use for near real-time analytics frequently needed in electricity markets. The same applies to Sancho et al. [28], who developed a simulation tool for analysis of electricity markets. Another issue is that these tools were designed for market participants, not market operators. Market operators may use these results to gain insight into to the use of BI and advanced analytics in the context of smart grid electricity market, but they cannot apply the same design principles.

Rahimi and Ipakchi [29] provide an overview of electricity market data quality and its integration with other services. They identified connectivity and information flows within the smart grid electricity markets and pointed out to the necessity for having an integrated view of smart grid data.

Literature analyses show that although many authors point out to the importance of BI and data analytics in smart grids, there are not many results showing successful development or implementations of smart-grid-specific BI systems. There is also an identifiable lack of results related to the design of KPIs for electricity markets. Further, developing countries, which are in the process of grid modernization, are struggling to find the right guidelines and recommendations that would help them to prepare for the expected changes.

3. Designing a business intelligence system for an electricity market

3.1. Methodology

The first step in designing a business intelligence system for an electricity market is selecting the appropriate methodology. The choice of methodology needs to be guided by the specifics of the business environment, the existing software and hardware infrastructure and by the conditions of each electricity market, in particular.

While designing a business intelligence system specifically suited for the Serbian grid and its market, we have recognized that much of the project could be implemented by using the Kimball's methodology [30]. Kimball's methodology for data warehouse development is a de facto standard for any modern data warehouse project. It is characterized by its strict bottom-up approach, where particular attention is paid to the analysis and modeling of the business process upon which the BI system is built. Alongside the fairly well-structured business requirements, the methodology sets a precedent for how data modeling is handled. In addition, Kimball's methodology recognizes the difficulty of making a BI system for non-standard business processes and recommends the iterative-incremental agile approach suitable for BI projects that are likely to have the project requirements changed many times during project implementation. This iterative-incremental approach was the main reason why we used this methodology as the basis upon which we designed our own approach.

The main constraint placed upon the choice of methodology was the need to work within the SAP ERP suite and SAP Business Warehouse framework. This constraint is often present in companies that employ SAP ERP suites, and as such often place their own unique limitations upon any project. The most basic of the constraints is the need to roughly fit in all the project activities within the SAP ASAP roadmap (SAP, na; [49] in order for the project to be effectively tracked and standardized with all the other projects within the system. The use of a SAP-based BI platform (SAP BW) offers its own development methodology that focuses on predefined data extractors and data structures that are activated and modified to fit the needs of the project. SAP BW methodology, while representing a perfect example of a platform-based methodology, falls short when encountering a problem for which there are no standardized extractors and data structures, energy markets being a prime example. While we were able to use the SAP ASAP for BW methodology in its entirety on the part of the project that pertained to building a BI for SAP-FI/CO module, we were not able to effectively use it for the purposes of the energy market. Additionally, SAP BW BI platform has its own constraints. Unlike most platforms, it does not use a star schema model, but rather the snowflake model. For this reason, it posed some problems during the Kimball dimensional modeling phase, which is based on the star schema model. By using ASAP elements to complement those of Kimball's, we defined our own brand of dimensional modeling that revolves around the snowflake model and is inspired both by Kimball and ASAP. Additionally, we recognized the rather rigid nature of the ASAP methodology in that it relies on well-defined project requirements, and any project requirement changes during the project are not well received. For this reason, we had to devise an iterative/incremental approach inspired by Kimball to handle all the requirement changes, while still being under the constraint to fit all the increments in the ASAP phases that were required.

In addition to all the particularities of the SAP projects, the main project phases and activities pertaining to the SAP environment were taken from ASAP, while other activities that were closely related to the development of a BI system are a modified version of Kimball. This blend of ASAP and Kimball allowed us to take the best of both worlds, the robustness and the fine detail of the Kimball's approach coupled with the ASAP methodology suited for working within a SAP environment. Table 2 shows the main gaps related to Kimball's and ASAP methodology, as well as our approach in overcoming these gaps.

A simplified iterative process developed by modifying the Kimball's lifecycle is shown in Fig. 1. The proposed method was developed so as to maintain the generic nature inherent to Kimball, which is easier to understand due to its widespread use, reinforced with elements from the ASAP methodology, which makes the implementation within a SAP environment much quicker and standardized. While the proposed approach is somewhat SAP-centric, it can be used in any BI implementation, but particularly targeting the modernizing grids and emerging energy markets.

The phases of the modified approach, as seen in Fig. 1, can be closely related to traditional Kimball's phases as well as to their corresponding ASAP phases. The model contains more phases than ASAP, as each ASAP phase is now broken down into multiple phases for the purpose of better control, and in order to take advantage of the agile approach. For example, the Blueprint ASAP phase, whose result is a document detailing all project requirements and specifics of the implementation, is in fact a sum of three phases: Business Requirements, Dimensional Modeling and Report Design and Analytics.

The dimensional modeling phase stands out in particular as it bears most resemblance to Kimball's, given that the ASAP methodology was lacking when it came to dimensional modeling of non-SAP-supported processes. The fine detail, which Kimball provides for designing the dimensional models, allows us to produce an entity-relationship model that can be easily converted into a multi-dimensional model. This data model is closely tied to the process it depicts, and the resulting data mart is able to meet all the analytical needs of the selected business process. Kimball's methodology of designing these models is helpful in overcoming the complexity of the business model, as the energy market processes are not widely known, and considerable amounts of domain-specific knowledge is required in order to understand their inner workings.

The physical design phase, as opposed to dimensional modeling, is almost entirely ASAP based, as it is tied to the SAP BW BI platform. ASAP's close ties to the platform allow for a streamlined development of Infocubes, characteristics, hierarchies and aggregations. The master data management model designed in the previous phase was instrumental in tying the business side of things to the corresponding data structures in data warehouse. After the first iteration of the physical design, a data integration phase must take place in order to complete the ETL cycle, with the initial load of data. Specific to the project was the diversity of data sources that needed to be integrated. The ETL tools that were at our disposal performed poorly in the initial iteration, and more efficient ways of ETL needed to be found. For this purpose, we extended the data integration phase, which was entirely ASAP based, with Kimball's elements that pertain to the development of an in-house ETL application that suits the needs of the project.

What is characteristic of both the physical and dimensional phase is that they are both actualized in an incremental/iterative fashion, as it is almost certain that the user will, upon seeing the initial prototype, provide the developers with a list of new requirements and changes to the model itself. In projects of such

Table 2
Existing gaps in methodologies and our approach.

Methodology	Gap	Our approach
Kimball's methodology [30,32]	Kimball's methodology is universal and platform-independent. It needs to be adjusted to the particularities of the platform used for implementation.	We adapted the Kimball's approach to better suit the SAP BW BI platform, while still keeping it as close to the original as possible.
	Kimball uses the star schema, while a snowflake schema design was needed for the purpose of the project.	Our model, due to being platform-dependent, was restricted to a snowflake schema design; we used ASAP guidelines, as well as Kimball's process-oriented approach, in order to further enhance our dimensional modeling phase.
	Kimball's project management style was not appropriate for any company that has put in place its own in-house project management procedures. In our case, SAP ASAP, and all the phases and milestones that come with it, cannot be exactly matched to each phase and activity in the Kimball's approach.	Due to the limitations posed by the SAP ERP system, and the project management procedures that are put in place, Kimball's approach had to be heavily modified to fit the standardized ASAP projects, which are traditionally very strict and non-agile. We tried to keep the agile approach that Kimball proposes while still maintaining the company policy and ASAP methodology. Additionally, relying on SAP phases allows seamless transfer of the testing system to the production system, which in turn allows a more streamlined and quicker deployment.
ASAP methodology (Yılmaz and Ozcan, [50]; Kalaimani, [33])	ASAP is based on the waterfall model, which is sequential, non-iterative and non-agile.	By making it iterative/incremental within each phase we do still maintain the project flow, all the while conforming to ASAP.
	ASAP is not suited for developing new models that are not based on SAP ERP modules.	Our model heavily relies on the development of new models. We wanted to keep Kimball's process-oriented modeling approach and combine it with ASAP's snowflake schema design.
	ASAP is focused around using existing structures and pre-built extractors for most of the ETL purposes.	ASAP does not offer much in terms of ETL development that is not standardized and working with already known data sources. For this reason, we had to use Kimball's approach for developing ETL applications, while still keeping a fair part of the ETL process on the OLAP side where ASAP could be used.

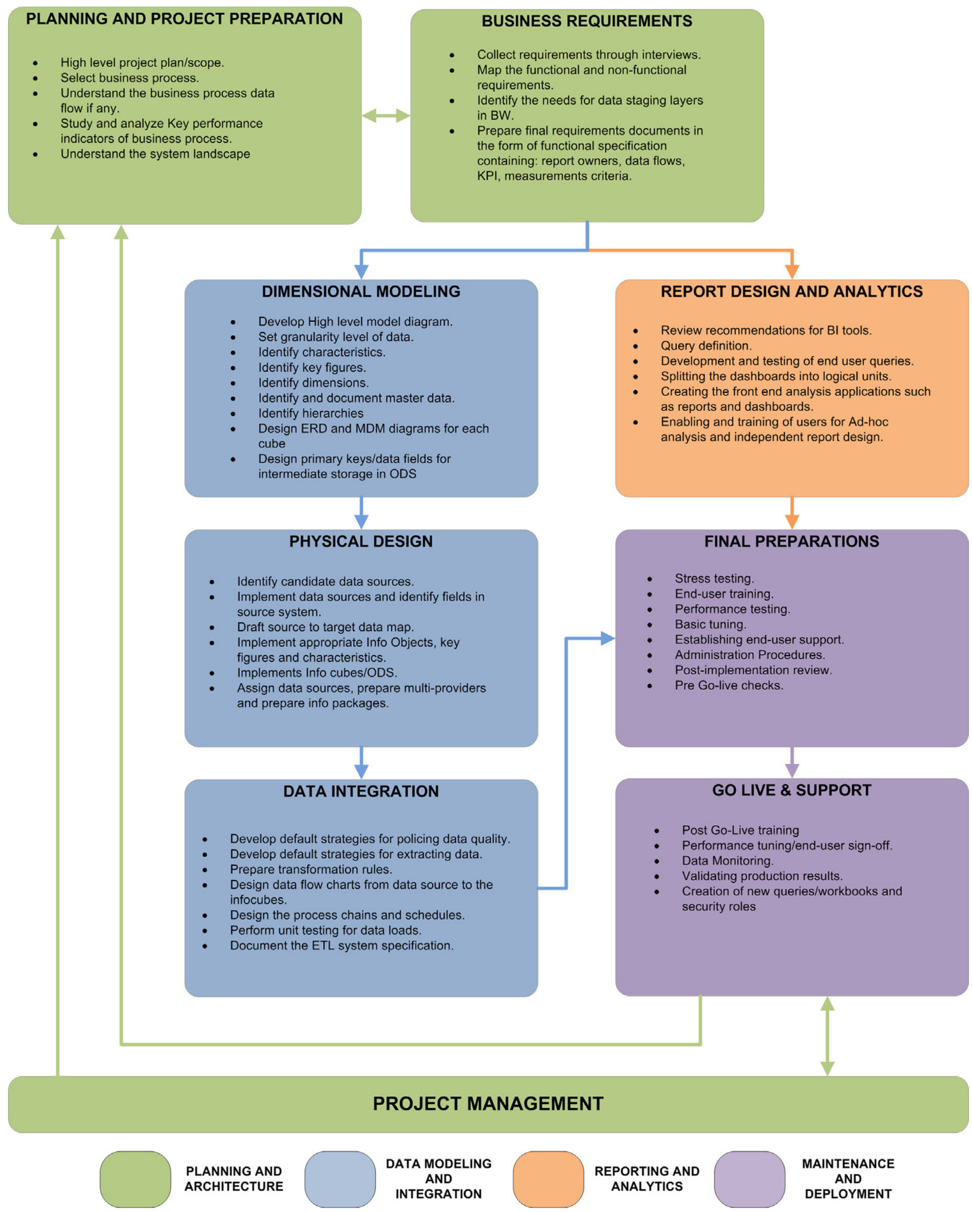

Fig. 1. Model for developing a business intelligence system for an electricity market.

complexity, it is often the case that understanding of business processes on the part of the designers is not sufficient in order to provide a comprehensive data mart that can meet all the users' analytical requirements. Therefore, it is critical to push for the first iteration in order to diminish the risk incurred when the project moves forward with its later stages. The final phases – "Final preparations" and "Go Live & Support" –are usually specific for each enterprise, as each company has its own policies regarding final testing, user training and usual preproduction and postproduction phases. In our case, these stages were provided by ASAP, and the standardized manner in which they are conducted has proven to be helpful for making sure that everything is in working order and that all the required steps were completed before the system was brought into its production state.

Additionally, we recognized that BI projects consist of the following critical phases that must be treated with utmost attention, whereby each of them presents its own unique challenges that must be overcome for the project to succeed: Planning and project preparation, Business requirements, Dimensional modeling and data integration, Report design and analytics. Each of these four phases are described in more detail in the following text.

3.2. Planning and project preparation

While compiling project requirements, we noticed that the information systems of utilities have a tendency towards making point-to-point solutions that create separate data silos. However, in the smart grid era, a unified approach is needed. This unified approach needs to be flexible and able to transform strategic initiatives into action-driven operations quickly. The challenges of establishing this unifying data infrastructure reside in the collection of data from disparate sources that originated from different organizations and from different platforms. The implemented BI system needs to provide capability for information integration across the applications such as DAMAS, SRAAMD, SCADA, and other systems originating both in the transmission and the distribution layers of the smart grid. Alongside tackling the problem of data integration of existing and increasingly complex applications, there is an ever-present problem of integrating the unstructured and semi-structured forms of data from other sources. These sources are usually other organizations operating inside the electricity supply chain, or the market department itself in the form of generated spreadsheets, XML files and various other formats.

Having this in mind, the main objective of the project was to supply the users with information, advanced reports and analyses relevant to the following business processes within the electricity market: balance responsibility, balance mechanism and allocations of cross-border capacities. Accordingly, the architecture of the BI system was designed (Fig. 2) to enable data integration and consolidation required for the functioning of the market processes in the Serbian electricity market.

The integrated data can be used by analytical and reporting applications to provide new interpretations of data. The design of the framework is constructed in such a way that it aims to increase performance and reliability of current market processes by focusing on each of the processes separately, before moving on to integrating and aggregating them further for the purpose of reporting and analysis. Additionally, the added benefit of process-focused design is the ease of use by those who are intimately familiar with the market data, allowing the market engineers to create their customized ad-hoc analytics in a self-service model.

3.3. Business requirements

Business requirement definition phase included the mandatory interviews with end users, where the majority of functional and non-functional requirements was identified. The focus was on the improvement of the processes taking place in the Electricity Market Division of the enterprise. The process groups chosen for this purpose were asked to provide an in-depth perspective on the market functionalities. KPIs were defined based on the best transmission system operator practices and company policies [34]. They strive to cover the full scope of the core activities and offer further insights into market behavior and cross-border capacity. Based on the requirements of the Electricity Market Division, the data were translated into measurable indicators, each having its own unit and formula. Before the implementation, over 40 existing KPIs were identified in various applications and platforms, often encompassing different subsets of data, and rarely portraying the full picture due to their inability to acquire and integrate data from different platforms and applications. As a part of the business requirement phase, the users defined the KPIs they wanted to be tracked through the BI system. For the purpose of this paper, a subset of the KPIs is provided, as shown in Table 3.

3.4. Dimensional modeling and data integration

Designing the data model for an energy market has proven to be a daunting task. The processes involved are of high complexity and are not subject to most commonly used “good practices” since each energy market does business under different market rules, which can be highly volatile, particularly in the case of developing markets. In addition, vast amounts of data originating from the metering and monitoring infrastructures need to be integrated. This is a difficult task because data needed for adequate electricity market analysis are located in a multitude of different internal or external systems owned and operated by different organizations. In order to cope with this, the developed solution had to be equipped with advanced information management capabilities suited for managing data collection, data modeling, information analysis and data integration [36]. In order to meet these requirements, an original dimensional model fully capable of supporting the current and future market rules of the Serbian market needed to be developed.

The data model designed for these purposes was modeled with the SAP Business Warehouse (SAP BW) platform. In order to store

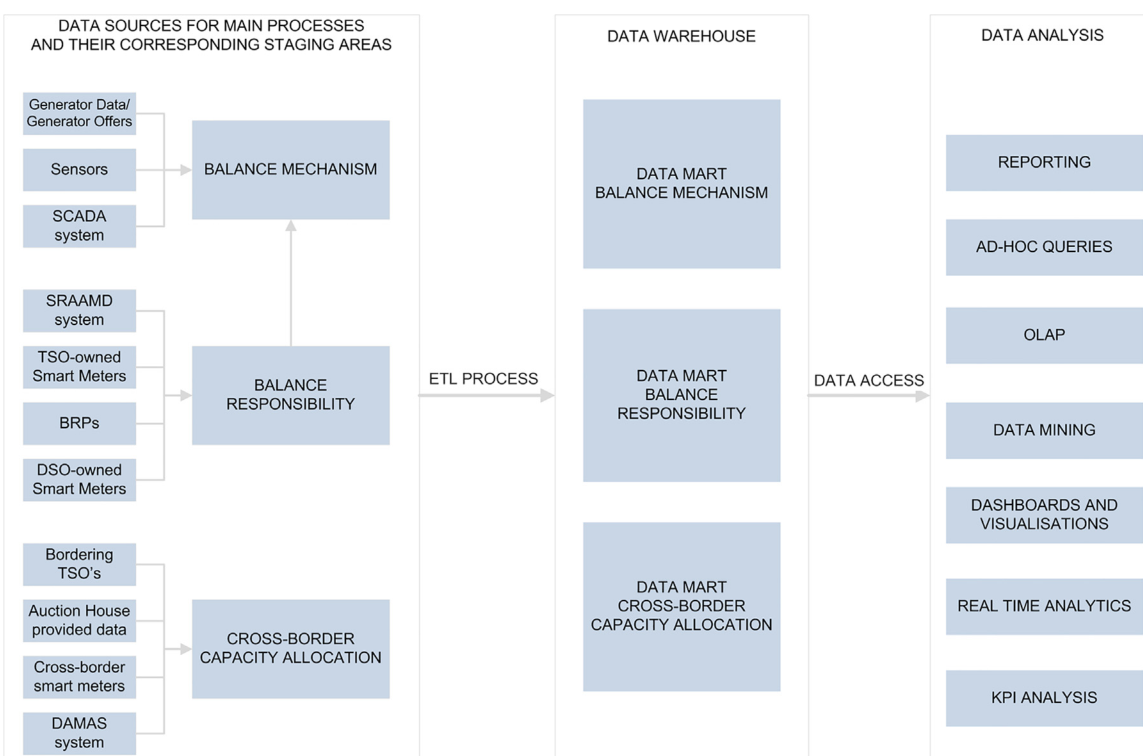

Fig. 2. Business intelligence framework for the electricity market.

Table 3
Representative subset of indicators for monitoring the electricity market [35].

Indicator/Definition	Unit	Calculation	
BALANCE RESPONSIBILITY			
Total nominated balancing group position (UPP)	MWh	$UPP = (\sum BRP_{BOS,oi} - \sum BRI_{BOS,oi}) + (\sum EU_{BOS,oi} - \sum EI_{BOS,oi})$ where: BRP - accepted block of internal exchange of electrical energy which one balancing group takes over from the other balancing group; BRI - accepted block of internal exchange of electrical energy which one balancing group delivers to another balancing group; EU - accepted block of cross-border electricity exchange which a balancing group takes over from the other market area; EI - accepted block of cross-border exchange of electricity which a balancing group delivers to another market area; BOS- index designating BRP in charge of the respective balancing group; oi - index designating accounting interval.	
Total metered balancing group position (UOP)	MWh	$UOP = (\sum UPR_{BOS,oi} - \sum UPO_{BOS,oi})$ where: UPR - total delivered electricity to the places of handover; UPO - total taken electricity in places of handover; BOS- index designating a BRP responsible for the respective balancing group; oi - index designating accounting interval.	
Imbalance settlement price (ISP)	EUR	Settlement price can be a maximum of 1.5 times greater than the maximum price for the engaged balancing energy in regulation upward in the respective accounting interval.	
Balancing group deviation(OBOS)	MWh	$OBOS_{BOS,oi} = UPP_{BOS,oi} + UOP_{BOS,oi} - BEN_{BOS,oi}$ $BEN_{BOS,oi} = [BES_{BOS,oi} + BET_{BOS,oi} + BETS_{BOS,oi}]$ where: UPP - total nominated balancing group position; UOP - total metered balancing group position; BEN - total engaged balancing energy of the balancing group; BET - balancing energy as a result of tertiary regulation engagement for system balancing; BES - balancing energy as a result of secondary regulation engagement; BETS - balancing energy as a result of tertiary regulation engagement for ensuring secure power system operation; BOS - index designating BRP in charge of the respective balancing group; oi - index designating accounting interval.	
Acceptable Imbalance of the Balance Group (POB)		Value of acceptable imbalance of the balancing group (POB) is determined for each day and is equal to:	
		MAX (1 MWh; 3% of maximum scheduled hourly consumption from the balancing group's daily schedule)	In the event that the balancing group is associated with at least one Withdrawal/Injection point (hereinafter: WIP point), the respective BRP assumes the role of Consumption Responsible Party and does not have the role of Production Responsible Party.
		MAX (1 MWh; 1,5% of maximum scheduled hourly production from the balancing group's daily schedule)	In the event that the balancing group is associated with at least one WIP point and that BRP assumes the role of Production Responsible Party and does not have the role of the consumption Responsible Party.
		MAX (1 MWh; 1 MWh and summarized value of 3% of Maximum scheduled hourly consumption and 1.5% Maximum scheduled hourly production from the balancing group's daily schedule)	In the event that BRP assumes the role of Consumption Responsible Party and the role of Production Responsible Party.
		0 MWh	In the event that BRP assumes role of Trade Responsible Party.
Risk value (R)		R = max (P1, P2, P3)× D× C	
		where:	
		R - risk value; P1 - average value of the balancing group's daily consumption of electrical energy during the preceding twelve-months period; P2 - average value of the balancing group's daily generation of electrical energy during the preceding twelve-months period; P3 - average value of daily notified blocks of internal and cross-border balancing group's electrical energy exchange in the direction of the receipt, during the preceding twelve-months period.	
		D - number of days (D=3)	
		C - estimated prices (mean value of peak product on EPEXSPOT Germany from 1st October in Year Y-2 till 30th September in Year Y-1)	
BALANCE MECHANISM			
Total balancing energy engaged in the power system in the secondary regulation ($BES_{system,oi}$)	MWh	$BES_{system,oi} \sum (SRG_{be,oi} - SRD_{be,oi})$ where: BES_{system} - total balancing energy in the transmission system as a result of a deployed secondary regulation; SRG - balancing energy as a result of engagement of the secondary regulation upward; SRD - balancing energy as a result of engagement of the secondary regulation downward; be - index designating balancing entity; oi - index designating accounting interval; system - index designating electric power system.	
Total engaged balancing energy in the power system in the tertiary regulation ($BET_{system,oi}$)	MWh	$BET_{system,oi} \sum (TRG_{be,oi} - TRD_{be,oi}) + \sum BEU_u$ where: BET_{system} - total balancing energy in the transmission system as a result of engagement of the tertiary regulation for the purposes of system balancing; TRG - balancing energy as a result of engagement of the tertiary regulation upward for the purposes of system balancing; TRD - balancing energy as a result of engagement of the regulation downward for the purposes of system balancing; BEU - balancing energy as a result of activation of contractual operating reserve by issuing orders for the purchase of energy; be - index	

Table 3 (*Continued*)

Indicator/Definition	Unit	Calculation
		designating balancing entity; oi - index designating accounting interval; u - index designating contract on provision of ancillary services between transmission system operator and supplier, a contract regulating the sale of emergency energy between transmission system operators and a contract regulating the joint usage of balancing reserve in a regulation block; system - index designating electric power system.
Total quantity of engaged balancing energy in the power system in the tertiary regulation, required for ensuring secure operation of the power system ($BETS_{system,oi}$)	MWh	$BETS_{system,oi} \sum (TRGS_{be,oi} - TRDS_{be,oi})$ where: $BETS_{system}$ - total balancing energy in the transmission system as a result of engagement of the tertiary regulation required for ensuring secure power system operation; TRGS - balancing energy as a result of engagement of the tertiary regulation upward required for ensuring secure power system operation; TRDS - balancing energy as a result of engagement of the tertiary regulation downward required for ensuring secure power system operation; be - index designating balancing entity; oi - index designating accounting interval; system - index designating electric power system.
ALLOCATION OF CROSS-BORDER CAPACITIES Available Transfer Capacity (ATC)	MW	joint: $ATC = NTC - AAC$ split: $ATC = 0.5 * NTC - AAC$, $NTC = TTC - TRM$
		where:
		NTC - Net Transfer Capacity
		AAC - Already Allocated Capacity
		TTC - Total Transfer Capacity
		TRM - Transmission Reliability Margin
Congestion scale: total demanded/total allocated capacit	–	If the total required capacity exceeds ATC, then Yes, otherwise No
No. of participants in auctions	–	Number of participants who submitted auction bids for the respective auction
Auction Price (marginal price)	EUR/MWh	The price of the last accepted auction bid during one auction

the information inside SAP BW, adequate data structures capable of holding the market data needed to be defined. The difficulty concerning SAP BW data objects is the fact that they are not particularly similar to the objects found in any data warehousing paradigm, and function in a somewhat different manner than those found in conventional BI solutions. The choice of platform might seem odd considering its particularities, but if one considers the utility industry and the high likelihood of the market operator possessing the SAP ERP software suite, then this choice holds far more merit than a design of a generalized solution that relies on no platform in particular.

For the purpose of this paper, only the objects from the highest layer are discussed: infocubes, which are an extended star schema, and multi-providers, which are subsets of data from multiple infocubes.

For reporting and data access purposes, the end users can access either one of these two types of objects. Infocubes were created in a way that closely follows Kimball's approach [30], where each “data mart” is focused on the individual process or sub-process. Each of the designed cubes contains a minimum of 10 dimensions with their respective attributes, and as such are difficult to present in a detailed manner. The infocubes which are essential for the purpose of reporting and analysis of the electricity market are presented in Fig. 3. Each of the presented cubes, coupled with other utility cubes, can be grouped into multi-providers, which allows for a more detailed analysis that can span multiple business processes and is often required for a more detailed insight into the causes of market behaviors.

Designing a data warehouse and business intelligence system was performed iteratively by using the methods proposed in [30,37]. During each iteration, new subject areas were loaded into the warehouse and incrementally improved until they conformed to the user requirements and data quality standards. The main data model elements were identified by interviewing key users and by analyzing the source system database schemas. The developed data warehouse was designed with the extended star schema [38].

Internal sources of data used were operational databases that employed by different information systems, such as the system for auctioning cross-border transfer capacities – DAMAS, and the system for remote acquisition and accounting of metering data – SRAAMD. External data sources include data from generators, consumers, market participants, electricity traders, other transmission system operators and distribution systems operating in the territory of the Republic of Serbia. By encompassing all of the internal and the external data sources, we aimed at developing a system that could offer actionable intelligence across the entire electricity supply chain, necessary for the effective coordination of energy-related business activities [39,40].

3.5. Report design and analytics

In the previous phases, BI models were defined and implemented for each of the selected processes (balance responsibility, balance mechanism, auctions of cross-border capacity). These models allow for intuitive drilling up and down through data, as well as quick and easy aggregation and calculation that spans across multiple processes. Some of the standardized analyses within the developed system are provided in Table 4.

In addition to the required reporting capabilities and the calculations of the defined KPIs, one of the most important results of the implemented BI system is the ease with which the users can access the data. Users are able to make their own reports based on the data.

The reports are presented to end users in a highly visualized manner, such as dashboards. The created dashboards are used for

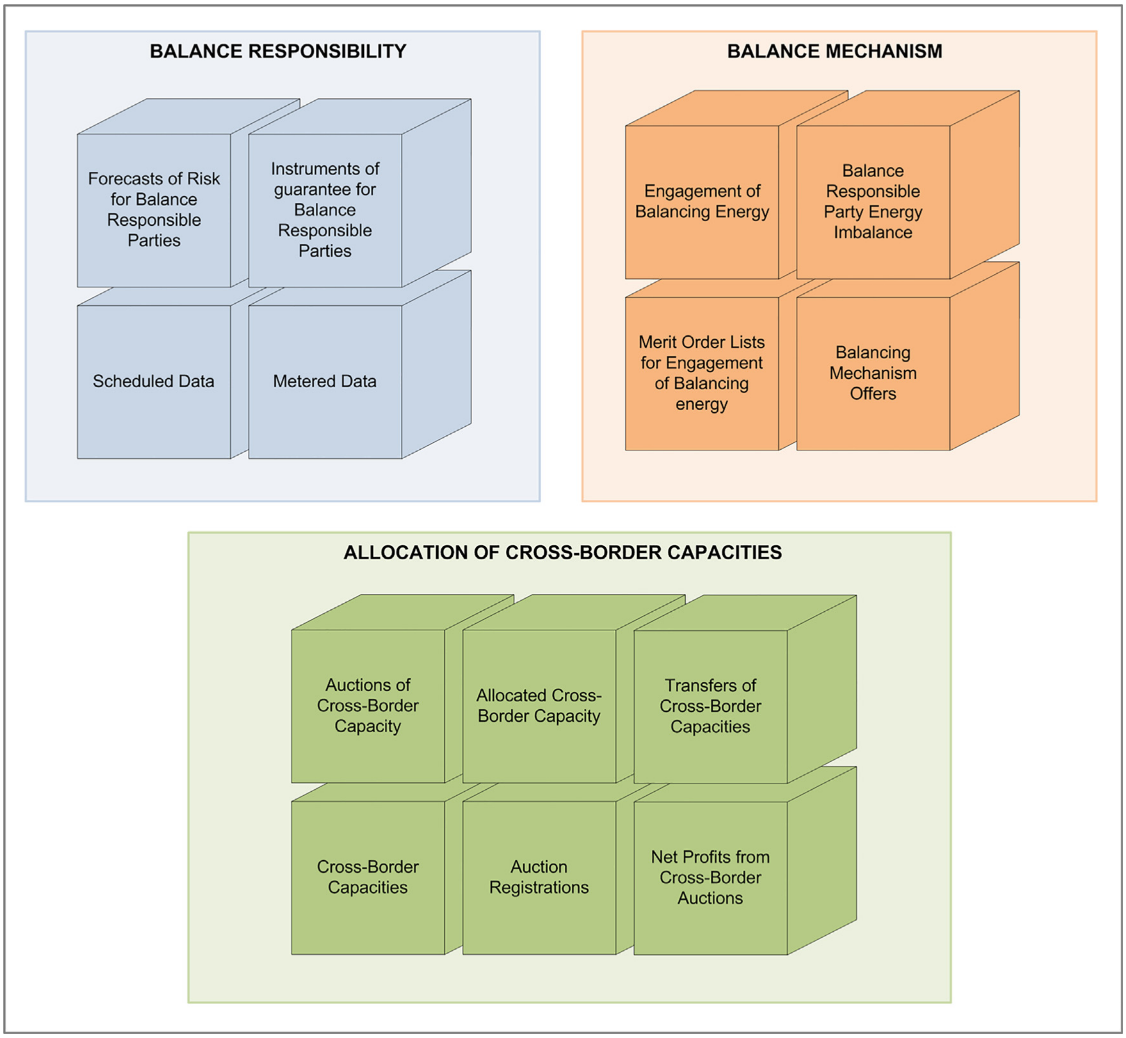

Fig. 3. Data marts containing the key infocubes.

measuring the performance in the related fields, analyzing reasons behind gaps and descriptions of the possible corrective and preventive actions.

4. Analysis of the results

4.1. Context

The proposed business intelligence system for the electricity market was developed and evaluated within the Public Enterprise Elektromreža Srbije (PE EMS), a Serbian transmission system and electricity market operator. As the Serbian electricity market is constantly evolving and adapting to the modern smart grid principles, the market rules are constantly changing and the developed BI solution must reflect this fact by being dynamic enough to accommodate the data and rules regarding it. In order to explain the effects on the current business processes taking place in the market department of PE EMS, a short overview of the state of the Serbian market was provided, as well as a description of some of the specifics of the market and its processes.

Since the beginning of 2013, all customers connected to the electricity transmission system have been obliged to purchase electricity in the open retail market [26]. As of 01.01.2014, the market is open to the customers whose facilities are connected to the medium and low voltage distribution networks, allowing households and small consumers to become market participants. This opening of the retail market goes hand in hand with the increase in regional and European initiatives for a unified Balancing energy market, as well as a common intraday energy market. As of 2016, the first organized Serbian energy exchange (SEEPEX) was opened, which further increased the share of energy that was traded under market conditions.

These market innovations are a major step towards supplying most, if not all of the energy through the energy market. The proposed BI solution aims to accommodate for this transition by allowing for more insight into the wealth of information that is at the operator's disposal.

While unable to show detailed reports due to data confidentiality and the ongoing process of developing a better KPI front-end platform, we are restricted to revealing only the reports in their most aggregated state.

4.2. Balance responsibility analysis

In accordance with the Calendar of Invoice and Payment in the electricity market and pursuant to the Electricity Market Rules, PE EMS is obliged to perform the calculation of the monthly fee for deviation of the balancing group in the accounting period and to submit it to the BRP. The balance responsibility of the participants in the electricity market for each accounting interval means the obligation to undertake financial responsibility towards the transmission system operator for all deviations caused by

Table 4
List of notable implemented analyses [41].

BALANCE RESPONSIBILITY
– Calculation and analysis of the imbalance settlement price for specified accounting intervals;
– Calculation of weighted price and average imbalance settlement price;
– Analysis of the reported positions of balance responsible parties (registered internal and external transactions, reported production and consumption);
– Analysis of the metered data (production, consumption) of balance responsible parties per time accounting intervals, BRP, System Operator;
– Review and analysis of the of WIP points specified accounting intervals, BRP, System Operator;
– Calculation and analysis of the risk value for every BRP participating in the Serbian Market;
– Review of the composition of the balancing group (the number of WIP points, approved power, nominal power);
– Calculation of the Balance Responsible Party Imbalance Settlement;
– Calculation and analysis of acceptable Imbalance per BRP in combination with the calculated financial fee for BRP Imbalance.
BALANCE MECHANISM (BM)
– A trend analysis of bids submitted by BM participants in the Serbian Balancing Energy Market;
– The analysis of engagement of balancing energy per;
– type of regulation (tertiary, secondary);
– accounting interval level;
– BM participants;
– Balancing entity.
ALLOCATION OF CROSS-BORDER CAPACITIES
– A trend analysis of the value of cross-border transmission capacity available in the market for various accounting periods, as well as in all or some borders;
– An analysis of ratio between the required and allocated capacity which might be observed from different time perspectives or the viewpoint of different borders, as well as of all participants in the auctions;
– A trend analysis of achieved prices at auctions per borders (directions);
– Overview of registered auction participants and their capacities;
– Review and analysis of cumulative revenue at auction per auction type, direction, time horizon;
– Congestion management.

unbalanced daily schedule after closing the intraday nomination process. Based on the calculation of the monthly fee, in case of a positive imbalance of the balance group, PE EMS will pay to the BRP, otherwise, BRP has to pay to the PE EMS [42].

- In order to facilitate Balance Responsibility, the following data are used for calculating the accumulated imbalance of the responsible parties:
- Internal exchange (withdrawn and injected energy separately).
- Cross-border exchange (withdrawn and injected energy separately).
- Activated secondary/tertiary regulation upward (from BM participants belonging to a specific BRP).
- Activated secondary/tertiary regulation downward (from BM participants belonging to a specific BRP).

Fig. 4. Settlement price analysis.

- Total injected electrical energy at the WIPs into the transmission and distribution system (grid).
- Total withdrawn electrical energy at the WIPs from the transmission and distribution system (grid).
- Total metered balancing group position.
- Total nominated balancing group position.
- Schedule imbalance.

The dynamically calculated BRP imbalance allows for a more controllable system imbalance and an easier identification of frequent balancing group deviations, as well as the hourly imbalance patterns. The implemented model supports data mining, specifically clustering of the BRPs according to their imbalance.

The settlement price calculation uses regulation prices provided by the balance mechanism system for tertiary and secondary regulation in order to calculate the Imbalance settlement price. Currently, the settlement price is calculated on an hourly basis, but the system allows for an easy transition to 15 min and 30 min time frames.

Fig. 4 illustrates the dashboard, which presents the calculated Imbalance settlement prices on an hourly basis. The BI system calculates these prices with the fine-grained data at its disposal, according to the business rules of PE EMS. The formula used for calculation is in full compliance with the Serbian Energy Law and Market Code. The calculated prices are then compared with the system-calculated prices for a different control level. Furthermore, advanced price analysis and trend analysis is possible. By analyzing the settlement price and drilling up and down the provided cube, the user can easily differentiate between the periods of the day and make comparisons between them, as well as identify anomalies and suspicious market participant behavior. Additionally, by employing the highest granularity, it is possible to analyze each participant in the market and their impact on the settlement price in order to get a better profile for each of the market participants and the patterns of their behavior. Fig. 4 shows a simplified report for settlement price analysis for each of the periods of day.

BI applications leverage the smart meter data collected in order to enable load forecasting for trading and demand-planning activities. The vast amounts of historical data on the previous forecasts, as well as the fine-grained nominated consumption and exchange of the BRPs allow for an in-depth analysis of the patterns of actualized load and the identification of frequent errors that have occurred for the day-ahead forecasts.

Fig. 5 provides an overview of the system load and the forecasted values for each hour in the selected day. The report shown in this figure can be used for historical analysis and drilling down towards each generator and smart meter in order to provide information as to the historical behavior on a more granulated level.

4.3. Balance mechanism analysis

PE EMS is responsible for the organization and administration of the balancing electricity market and for keeping the entire grid in balance. In order to provide secure power system operation, the implemented BI system is tightly integrated with the Balancing Market and provides new insights into buying and selling balancing energy by the electricity producers. BI system aggregates and calculates financial fees for activations of the balancing energy, including prices from activated offers and prices for secondary regulation, allowing a far more detailed view than the one enabled by the previous implementation of the business process.

Fig. 6 illustrates a highly aggregated view of the utilized balancing energy for secondary and tertiary regulation on an hourly basis. While this figure hardly shows analytical information, the underlying model allows for drilling down to the individual balancing offer and generator that has been activated. It can be used for an in-depth analysis of contingencies and their financial outcomes. In addition, by virtue of having an integrated solution, each of the contingencies could be linked to certain market behaviors in the balance responsibility process.

4.4. Allocation of cross-border capacities

PE EMS performs the allocation procedure for the rights to use cross-border transfer capacities on a yearly, monthly, weekly, daily and intraday basis. In order to harmonize its operation with the operators of the neighboring transmission systems, PE EMS determines the values of cross-border transfer capacities. The cross-border transfer capacity on the interconnections is allocated by the auction operator of the neighboring transmission system, according to the current agreements with the operators in the

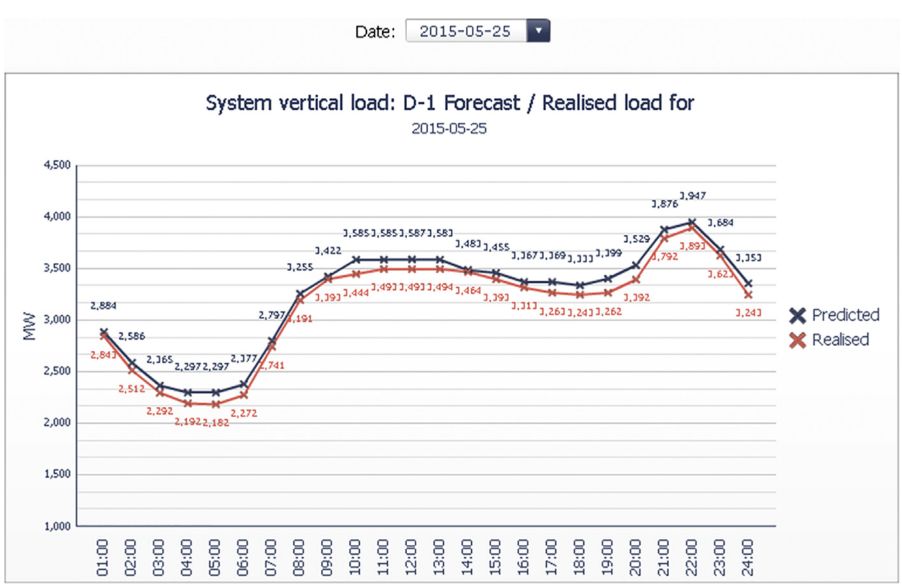

Fig. 5. System load forecasting.

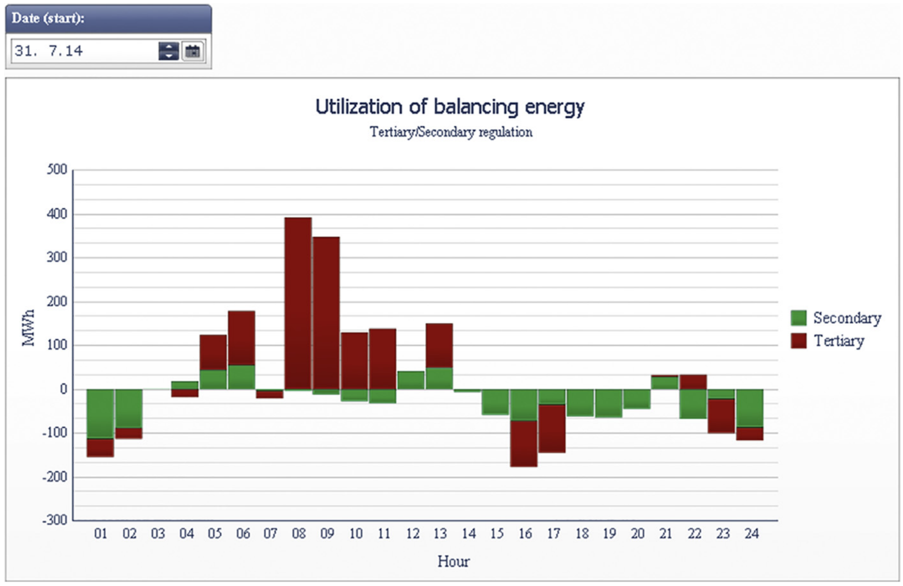

Fig. 6. Utilization of balancing energy.

neighboring countries and Auction Rules in the form of commercial transfer rights [43].

PE EMS is responsible for calculation, allocation and use of cross-border transmission capacities on all borders of the control area of the Republic of Serbia. For example, on the Serbian-Hungarian border, the Hungarian transmission system operator Transelectrica organized long-term (annual and monthly) and intraday (first come-first served) auctions for the allocation of 100% of the available capacity, while PE EMS allocated the available capacity on a daily level. The developed solution is able to use the auction system of the neighboring transmission system operators as a data source and offer an analysis of their auctions, alongside the ones organized by PE EMS.

There is a general concern on the part of market participants for reaching the correct business decisions when the operating schedule of the transmission line or the contribution to the Available Transmission Capacity (ATC) is concerned. The developed dashboards can be used for analyzing the allocation of transmission capacities at the borders in the control areas of PE EMS, as well as for monitoring behavior of the participants in the market, as one of many different scenarios. General data on auctions may vary depending on the neighboring country, the period and many more variables. With this data, dashboards are readily available to engineers for cross-border analysis in order to monitor the flow of energy along the grid, take actions and set goals for the upcoming years in order to achieve performance improvements, and therefore to increase the overall efficiency of the allocation process.

Fig. 7 illustrates general data on joint daily auctions for the allocation of 100% of available cross-border transmission capacities on the Serbian-Romanian border for May 1st, 2015. The report shows the aggregated data for each cross-border transmission and

Fig. 7. Daily Auctions ATC and Results for May 1st on the Serbian-Romanian border.

it allows the user to use the data from the process of balance responsibility in order to see in advance what the cross-border traders are planning and how they diverge from their plans. This integration between these two processes, which were previously separate, allows for a detailed analysis of each of the traders, and could be used to identify any suspicious bidding behavior.

5. Discussion and conclusions

The future of the energy industry is synonymous with smart grid technologies and their applications, with the end goal being the construction of a platform suited for new business models, the so-called "Energy Internet" [44,45]. For this to become a reality, the electricity companies will have to modernize and accept new paradigms if they wish to become adaptive to end users' needs and operate in competitive and deregulated markets [46,47].

Various reports have shown that the existing information systems are struggling to meet the current needs of participants in the energy industry. The challenge of improving operational and managerial capacity implies the need for an integrated business intelligence platform designed for KPI management, analysis and forecasts. Business intelligence can be effectively used to integrate large data volumes and support a variety of difficult and challenging energy market issues, such as prediction, load optimization, pattern recognition and others. In this complex scenario, selecting a BI approach is an important decision, and this paper offers one such approach that has proven to be adequate for the Serbian market.

The main contribution of the paper is the approach to designing a BI system that provides the emerging electricity market with the necessary data flows and information for forecasting, data analysis and decision making. As such, this approach may be adequate for countries whose electricity market is in the process of development.

The diversity between energy markets and their ever-changing market rules, coupled with the fact that there are not as many markets in the world, particularly those that are in the process of being formed, leaves the developer of a BI solution with little or no information related to standardized ways of implementation or "best practices". This poses a difficulty in finding individuals qualified for designing a BI solution for an energy market, whereby any domain-specific knowledge is precious.

Due to these reasons, the practical contribution of the paper is reflected in the insights it offers into the development of a BI model and architecture required for an emerging electricity market, with three key data marts: "Balance Responsibility", "Balance Mechanism" and "Allocation of Cross-border Capacities". These three data marts are the backbone of any energy market, and their understanding is a key factor in the success of any undertaken BI project. Understanding these models based around business processes and use of appropriate methodology allows any market operator to use the proposed approach for the development of a BI system adjusted to its specific market needs.

Finally, the authors acknowledge certain drawbacks of the presented research. Larger volumes of data from the electricity market are necessary to achieve higher quality of information. Although the Serbian electricity market is difficult to analyze because it is still developing and experiencing yearly changes in the form of new business rules, we have tried to fill this gap by offering a highly detailed model that supports the market operations and facilitates its growth.

The future course of this research will take several directions. First and foremost, a detailed analysis of the project results shall be conducted. This will serve to modify the approach accordingly in order to make it more flexible, responsive and agile for further extensions of the system. As more advanced metering and sensor technologies are used, the amount of generated data will exceed the current capabilities of the system, which will require devising more efficient methods for storing and managing the data. Furthermore, there are plans to incorporate more business processes that are taking place in PE EMS in order to construct a more unified and centralized data repository that can truly leverage the wealth of information provided by the new smart grid technologies. Finally, new research will focus on real-time BI and big data analytics and its application in the energy markets [48].

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