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## CONTENTS

<b>Testing Approaches for an Electricity Market Simulator .....</b>	<b>3</b>
Anca Ioana ANDREESCU, Ana Ramona BOLOGA	
<b>Dashboard for analysis of electricity imbalances at the Balancing Responsible Parties level.....</b>	<b>17</b>
Simona-Vasilica OPREA, Adela BÂRA, Ciprian Georgian DRAGOMIR, Osman Bülent TÖR, Ştefan PREDA	
<b>Consumption Management Software for Electric Power Suppliers .....</b>	<b>31</b>
Ana-Ramona BOLOGA, Simona-Vasilica OPREA, Adela BÂRA, Florin-Constantin CIOBANU, Osman Bülent TÖR	
<b>Electricity Consumption Management Software Tool for Consumers - MY SMART HOME .....</b>	<b>41</b>
Anca ANDREESCU, Adela BÂRA, Simona-Vasilica OPREA, George Adrian IFRIM, Osman Bülent TÖR, Andrei BUCUR	
<b>Data Analytics for the Transmission System Operators .....</b>	<b>54</b>
Dan PREOȚESCU, Simona-Vasilica OPREA, Adela BÂRA, Niculae OPREA, Osman Bülent TÖR	

## Testing Approaches for an Electricity Market Simulator

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*Software testing methodologies represent different approaches and techniques to ensure that a particular software application is fully tested. This paper addresses the functional testing of a software system for simulating electricity markets. The tested functionalities are briefly presented and the main testing techniques compatible with this type of system are analyzed. The purpose is to recommend the best combination of techniques recommended in this case and to present results obtained by applying them to the simulator.*

**Keywords:** functional testing technics, behavioral testing, electricity market, simulator

### 1 Introduction

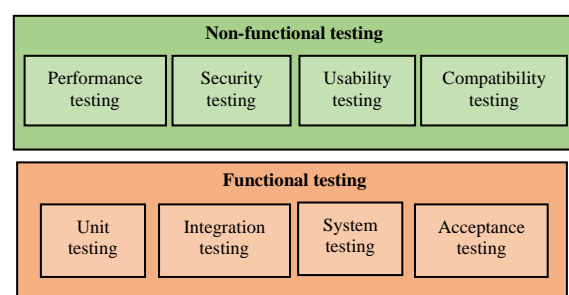
Software testing is one of the main stages of the development cycle of an IT system, vital for software quality assurance. According to IEEE, software testing can be defined as: “the process of exercising or evaluating a system or system component by manual or automatic means to verify that it satisfies the requirements” [1]. Often, however, software testing involves considerable costs and time, hence the continuous concern for reducing costs and streamlining the testing activity.

The test cases can be generated based on the results obtained in the analysis and design stages of the computer system or they can be obtained based on the code developed in the implementation stage.

This work will focus on functional testing and the main techniques recommended to perform a more complete and efficient testing of a computer system developed to simulate participation in electricity markets. The paper is structured in four parts, as follows: section 2 - a brief presentation of software testing approaches for complex systems; section 3 - the main functionalities a wholesale electricity market simulator for which test cases have to be prepared; section 4 – presents examples of various testing techniques that may be applied to the simulator, including their advantages and disadvantages; section 4 is dedicated to results analysis, discussions and conclusions.

### 2 Testing in complex software systems

Software testing methodologies represent the different approaches and ways to ensure that a particular software application is fully tested. Software testing methodologies must include a broad spectrum of elements, from testing individual module units, testing the integration of an entire system, to specialized forms of testing such as security and performance [2]. According to the types of requirements of a computer system, two general levels can be identified at the level of testing: functional testing and non-functional testing, each having a series of components presented in Fig.1.



**Fig. 1.** Types of testing for software systems [2]

Functional testing (black box) is performed using the functional specifications provided by the client or by using the analysis and design specifications, such as use cases.

Non-functional testing (white box) involves testing the system in accordance with non-functional requirements, which usually involves measuring / testing the system

according to the defined technical qualities, for example vulnerability, scalability or usability. Traditionally, software testing considers only static views of the code and does not sufficiently address the dynamic behavior of the computer system. But, during this stage, the testing of an entire system should be performed, based on its specifications, considering the specific dynamics and interdependencies.

If in the first case we are talking about *structural testing*, based on the code resulting in the coding stage, in the second case we are talking about *behavioral testing* based on the requirements and design specifications. The use of the models obtained during the analysis and design stages can lead to a reduction of the costs through reuse and the improvement of the verification and validation. In addition, the test activity can be started in parallel with the writing of the code, as soon as the modeling results are available.

For example, in the context of object-oriented modeling using UML (Unified Modeling Language), use cases and corresponding sequence and collaboration diagrams, class diagrams, can be used as sources of information relevant to the test cases. The analysis of the use case scenarios offers a complete understanding of the system, but, being an informal description, it is difficult to generate automatic test cases. Therefore, an active research direction is the formalization of specifications to make it possible to automatically generate test cases.

Ryser proposed a method of creating test cases starting from use cases, scenarios and use case diagrams called SCENT approach [3]. Use cases and scenarios are transformed into semi-formal representation state charts that are further used for test case generation. But the sequence dependencies between use cases was first approached by Briand and Labiche [4], who used an activity diagram of use cases for each actor in the system. Later, Touseef and Zahid [5] used the same approach for representing sequential dependencies

between use cases, but added some execution contracts for use case scenarios in form of logical expressions.

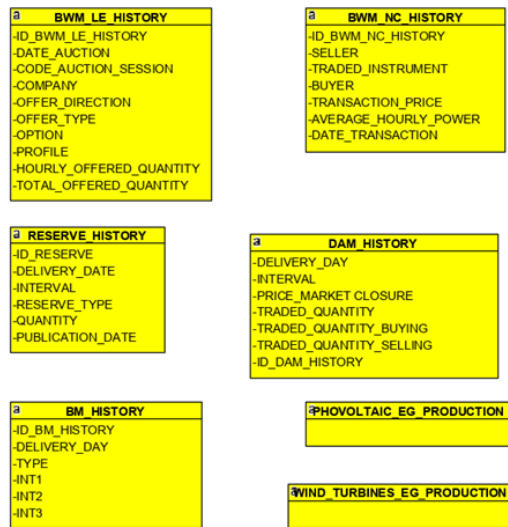
Use cases and sequence diagrams were used by Swain et al. [6] to generate test cases, taking into consideration the dependency sequences between use cases in form of a graph.

### 3 Main functionalities of the Wholesale Electricity Market Simulator

The system for simulating the participation of a producer / supplier / trader / consumer of electricity in different types of markets aims to identify how decisions regarding the price or quantities offered can influence profit optimization. It is a complex system, with numerous restrictions and operating rules, but also with important interdependencies of the decisions made on the different markets.

In this section we will describe the simulator's functionalities regarding the transactions on the following markets ([7], [8], [9], [10] and [11]): Bilateral Wholesale Markets (BWM), Day Ahead Market (DAM), Intra-Day Market (IDM), Balancing Market (BM) and Ancillary Services Market (ASM). Also, before simulating the market trading, several basic configurations are needed to be made in a General Settings Module.

For the implementation of the simulator, a series of classes have been identified that contain the entities participating in its construction. The identified classes represent abstractions of the objects that interact within the system. A distinction can be made between two classes of classes: basic classes, which include objects characterized by dynamic behaviour and independent classes, which have been used to retrieve data from other external systems. The class diagram in Figure 2 includes the independent classes found at the simulator level.



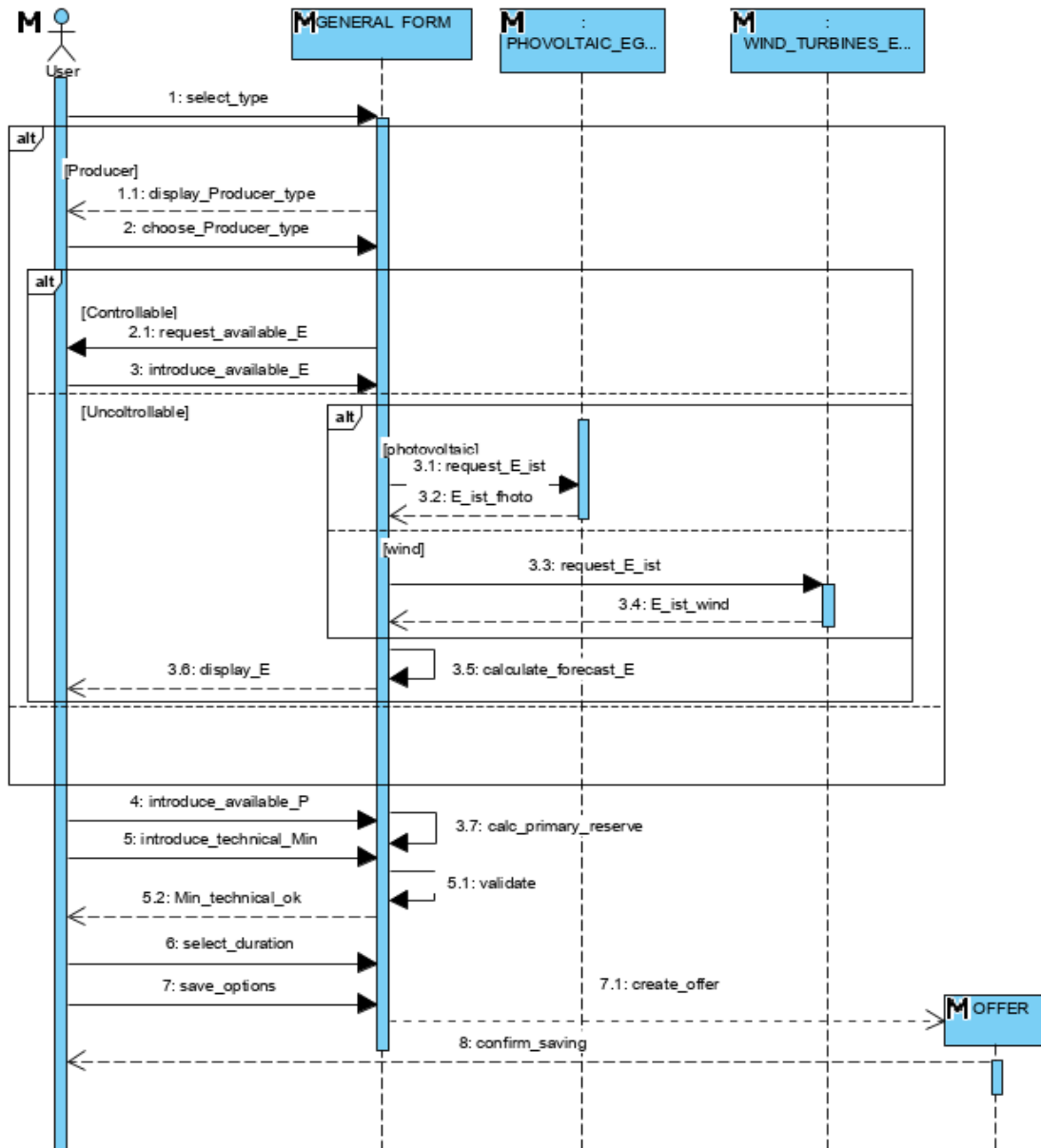
**Fig. 2.** Class diagram for the identified independent classes

A brief description of the information included in the independent classes is presented below:

- **BWM\_LE\_HISTORY**- Average hourly prices for deficit and surplus for the Balancing Market, contract type LE;
- **BWM\_NC\_HISTORY** - Average hourly prices for deficit and surplus for the Balancing Market, NC contract type (non-compliant);
- **DAM\_HISTORY** - Historical energy hourly prices for DAM;
- **RESERVE\_HISTORY** - Historical hourly prices for ancillary services;
- **BM\_HISTORY** - Average hourly prices for deficit and surplus for the Balancing Market;
- **PHOTOVOLTAIC\_EG\_PRODUCTION** - Data for estimating photovoltaic energy production;
- **WIND\_TURBINES\_EG\_PRODUCTION** Data for estimating wind energy production.

In order to model the dynamic aspects of the trading simulator, UML interaction diagrams were constructed. These diagrams are made up of a set of objects and the relationships between them, including messages that the objects send from one to the other. There are two types of interaction diagrams: the sequence diagram and the communication diagram. The two diagrams are semantically equivalent and can be transformed from one another. The sequence diagrams illustrate the messages exchanged between the actors / users of the system and the computer system, through the interfaces that it offers. We have started with simple versions of the message sequences, and later we detailed the involved objects.

Figure 3 shows the detailed sequence diagram for configuring the basic options in the General Settings Module. This was built by detailing the messages exchanged between the objects participating in the creation of the scenario. The scenario that underlies this sequence diagram is the following: the user chooses one of the predefined options to select which type of business is simulated: producer, supplier, trader or consumer. If it is a producer, it will choose whether it is type or controllable (thermo, hydro, nuclear) or uncontrollable (photovoltaic, wind). Subsequently, the user will enter the volume of electricity available for trading. The total available power per hour will be introduced, meaning the installed power, if it is a producer or the power required for trading or buying if it is a supplier, consumer or trader. Then, a technological minimum must be entered. The user must choose from a predefined list the periods for the simulation. Then, the month of the year with which the simulation begins will be chosen. The options will be saved, and the offer will be created.



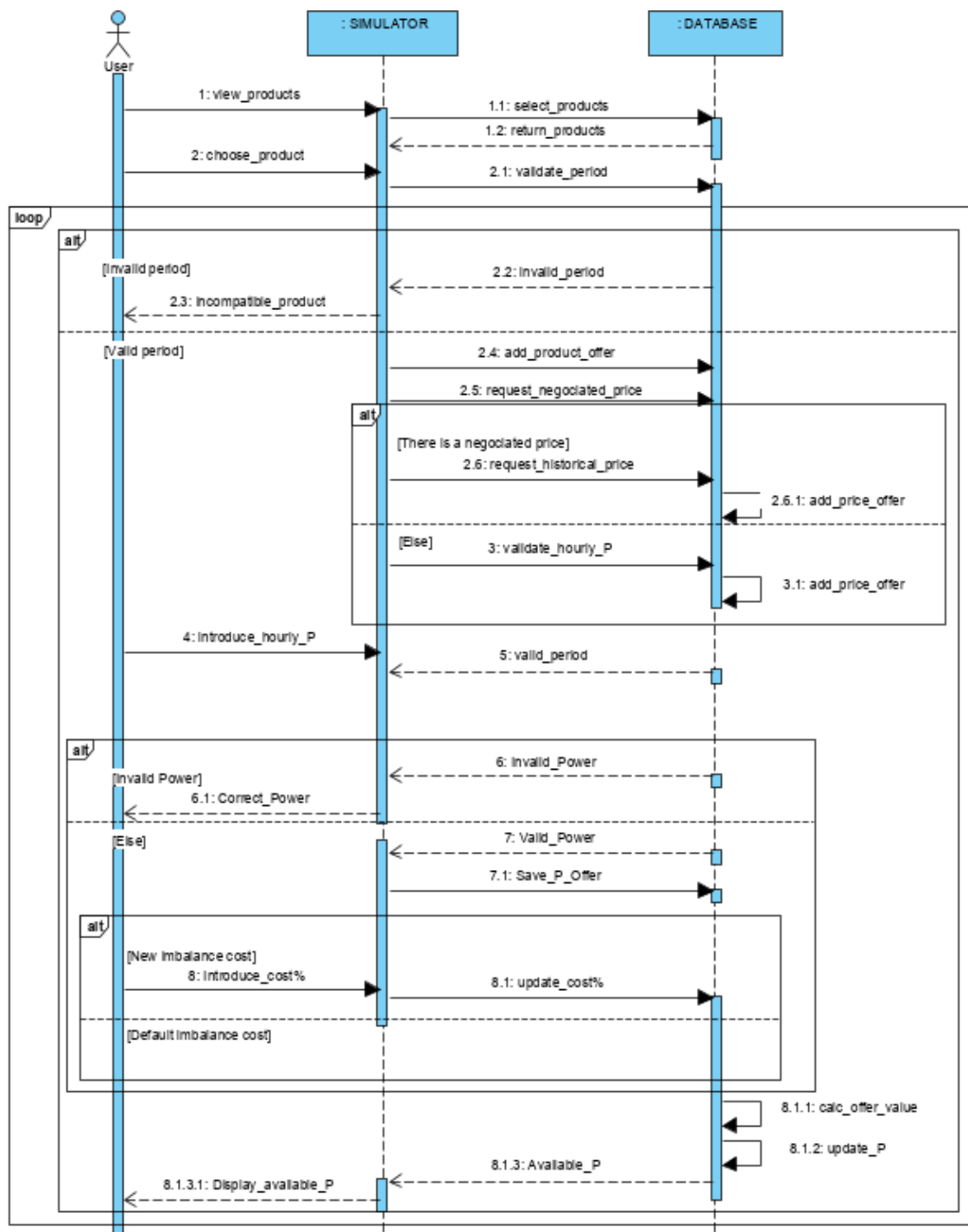
**Fig. 3.** Detailed sequence diagram for General Settings configurations

The sequence diagram in the figure 4 describe the simulation of trading on BWM and it is based on the following scenario: the user selects one of the options for sale or purchase on the BWM. Then, the user chooses from a predefined list of standard products offered by the Romanian Gas and Electricity Market Operator (OPCOM) the one for which the simulation of the transaction is desired, in accordance with the time-related settings in the general module. Once the selection has been made, a validation will be performed and will block the products in

the list that have overlaps with the selected product. Subsequently, the user selects information specific to the chosen product, such as semester, quarter, month or year. Will be available for access only the products that have an equal or a shorter period than the chosen period for simulation in the general module. Then, the user enters the desired hourly power to be contracted. This is validated in accordance with the settings in the general module or with other transactions performed on other markets. The cost of imbalances must be introduced, as a percentage of revenues, implicitly with

the value of 10%. This default percentage can be changed. The total hourly power offered on the BWM is calculated and

displayed for the chosen option (sale / purchase). Data is saved.



**Fig. 4.** Sequence diagram for trading simulation on BWM

DAM transactions can be simulated using the following scenario: the user selects one of the options for sale or purchase on the DAM and the desired month for simulation. The number of months for which the simulation is performed must

be less than the period specified in the General Settings Module and correspond to the periods of a possible simulation performed on the BWM. The available hourly power is displayed by correlating the settings in the general module with any sales



on the BWM and with the primary regulation reserve (for Producers). For information purposes, a historical monthly average price for the chosen month is displayed. Also, a correction coefficient for the selected month will be displayed. It has a default value of 25% and can be modified by the user. Average monthly per hour prices will be displayed for the period chosen by the user. These can be modified. The hourly power that is to be traded must be introduced. For selling, it must be checked that the maximum available power is not exceeded. The data is saved, and the total offer is displayed.

Trading simulation on ASM is based on the process described in the following. The producer selects the desired month for simulation. It is considered that the number of months for which the simulation is performed must be less than the period specified in the General Settings Module and correspond to the periods of a possible simulation performed on BWM or DAM. For this scenario, a historical price is displayed and used. It can be modified by the producer performing the simulation. The available power for reserves is completed and validated based on the total power offered in the general settings module and of the power contracted on BWM and DAM. If desired, the correction coefficient can be updated. Following data is saved. The simulator will calculate and display the total offer on ASM.

The next scenario was considered for trading simulation on BM: the producer selects the desired month for simulation. The number of months for which the simulation is performed must be less than the period specified in the General Settings Module and correspond to the periods of a possible simulation performed on the BWM or DAM. Historical monthly average prices per hour for deficit and surplus will be displayed. Historical prices can be modified by the user. The power offered

by the producer on this market is obtained as the difference between the total power completed in the general settings module and the quantities contracted by participating on other types of markets. Automatically a correction percentage is applied to the estimated revenues or expenses for the simulated period. By default, the risk level is 30% and can be changed. Data for the current month and the offer are saved. Total updated offer is displayed.

#### 4 Recommended testing techniques

The main components underlying the testing of computer systems are the techniques, activities, instruments and the controlled environment. Of the mentioned components, we will focus on the techniques used in the testing process. The techniques of designing the test cases can be divided into three categories [12]:

- a) Test techniques based on specifications or black box;
  - b) Testing techniques based on structure or white box;
  - c) Testing techniques based on experience.
- In the following, several types of specification-based techniques (black box) are presented in detail. These tests derive from specifying the desired behavior of the system. It starts from the basic idea that specifications should define what a system should do, not how behavioral specifications should be implemented.

##### 4.1 Partitioning into equivalence classes

The documents containing the system requirements normally indicate the rules that the system must follow. There may be rules that imply belonging to a certain range of values or there may be rules of the type if ... then. For example, Rule A might be "if  $n$  is less than one, then this is executed." Rule B could be "if  $n$  is greater than or equal to one and less than or equal to twelve, execute this".

We consider the rules for the values that a field can store for one month of the year. Thus, we have the following situations:

a) if the month is less than one, the value is not valid;  
 b) if the month is between one and twelve, it is admissible and the value can be accepted;  
 c) if the month is greater than twelve, the value is invalid and an error is displayed.  
 The entire infinite range of integers that could be introduced into the system for the value of the month must fit into one of these three criteria, one of these categories or classes: a) smaller than one; b) between one and twelve; c) greater than twelve. If a value is selected from each number class and we use it as a test case, it can be said that all three rules have been covered. Also, we can say that each value belongs to an equivalence class, hence the name of the technique.

There are three criteria that must be met when creating equivalence classes [13]:

- *Coverage*: each possible input value must belong to one of the equivalence classes.
- *Disjoint character*: the same input value cannot belong to more than one equivalence class.
- *Representation*: If, by using as input value a particular member of an equivalence class, the execution results in an error state, then the same state can be detected using as input value any other member of the class.

Partitioning into equivalence classes applies to all types of values, whether they are continuous or discrete. Using the scenario with the months of the year presented above, the following table can be defined for the partitions of inputs and outputs:

**Table 1:** Partitioning into equivalence classes for inputs and outputs

Rule	Input partition	Output partition
Month less than 1, display "Invalid, value too small"	Month <1	Invalid, too small
Month between 1 and 12, display "Valid"	(Month >=1, Month <=12)	Valid
Month greater than 12, display "Invalid, value is too big"	Month >12	Invalid, too big

## 4.2 Analysis of limit values

The errors tend to be grouped around the limit values. The assumption underlying this type of testing is that developers often omit special cases, represented by the "borders" of equivalence classes.

Using the previous example, we can see that in order to be valid, the month will have to fall within the "valid limit values" from 1 to 12. Also, for the month to be invalid, it must be outside these valid limits. The principle of testing with the limit value analysis is to use the limit value itself and another value as close to it as possible, to be able to reach any part of the limit, using the precision that was

applied to the partition. In the example presented, 0,1,2 are valid values for lower limit testing, while 11,12,13 are valid values for upper limit testing.

We can say that the limit values analysis is a particular case of the test method based on equivalence classes, which is centered on exploring the limit cases. Instead of choosing an arbitrary representative of the equivalence class for testing, the method involves choosing a "boundary" element, which represents a particular case. A good way to represent valid and invalid partitions and boundaries is in a table with the following structure:

**Table 2.** Example of partitions and limit values

Testing conditions	Valid partitions	Invalid partitions	Valid limits	Invalid limits
Average hourly price	10 RON –100 RON	<10 RON >100 RON	10 RON 100 RON 10,001 RON 99,999 RON	9,999 RON 100,001 RON

### 4.3 Testing based on decision tables

Equivalence class partitioning techniques and boundary value analysis are often applied to specific situations or inputs. However, if different combinations of inputs lead to certain actions, this may be more difficult to show using partitioning into equivalence classes and analyzing limit values, techniques that tend to be more focused on the user interface. The other two test techniques based on specifications, decision tables and transitions between states are more focused on business logic or business rules.

A decision table is an effective way of dealing with combinations of elements (for example, input data). This technique is sometimes referred to as the *cause-and-effect table*. Decision tables provide a systematic way of specifying complex business rules, which is useful for both developers and test engineers. Decision tables can be used in designing test cases, whether or not they are described in the specifications, as it helps test engineers explore the effects of different input combinations as well as other system states that need to correctly implement business rules. Decision tables help systematically select efficient test cases and can have the beneficial side effect of finding problems and ambiguities in specifications. It is a technique that works well in combination with partitioning into equivalence classes. The combination of the conditions explored can be a combination of equivalence partitions.

In using the decision tables for designing the tests, the first step is to identify a function or subsystem that has a behavior that reacts according to a combination of inputs or events. After identifying the elements to be combined, they can be placed in a table that shows all the combinations of True and False for each of the conditions. The next step is to identify the correct result for each combination. Each combination of inputs

and outputs is found in the specialized literature as a rule. From a testing perspective, a rule is a test case.

The outputs can be represented either in the form of an expected result (a single output line), or by listing each type of action that can be considered a result and specifying whether or not it will be performed according to the values of the input conditions. We illustrate below the two variants for specifying the results for the decision tables. For the first case, we create test cases for the purpose of verifying a login form, having the structure in the figure below.

**Fig. 5.** Login form

The constrained decision table for testing the functionality of the login form is presented in Table 4. The entry conditions verify that the user and password data have been entered.

**Table 3.** Decision table for testing the login form

Input	CT1	CT2	CT3	CT4
User	Yes	Yes	No	No
Pass-	Yes	No	Yes	No
word				
Login	Yes	Yes	Nu	No
Expected output	Syste m respon	Error messa ge	Error messa ge	Error messa ge

The following decision table was constrained to test the functionality of the electricity market simulator, having as input conditions the type of market that is simulated trading and the type of user. The expected results model the possibility of selling / increasing or buying / decreasing in one of the markets depending on the type of user.

**Table 4.** Decision table for testing the trading possibilities in the market simulator

Input	1	2	3	4	5	6
Producer	Yes	No	No	No	Yes	No
Supplier	No	Yes	No	No	No	Yes
Trader	No	No	Yes	No	No	No
Consume	No	No	No	Yes	No	No
BWM	Yes	Yes	Yes	Yes	No	No
DAM	No	No	No	No	Yes	Yes
BM	No	No	No	No	No	No
ASM	No	No	No	No	No	No
Selling/ Growth	Yes	Yes	Yes	No	Yes	Yes
Buying/ Drop	Yes	Yes	Yes	Yes	Yes	Yes

#### 4.4 Testing based on the transition between states

Testing based on the transition between states is used when a certain aspect of the system can be described in the form of what is called a "finite state machine". This shows that the system can be in a (finite) number of different states, and the transitions from one state to another are determined by the rules of the "machine". This model is based on both the system and the test cases.

Any system where a different output can be obtained for the same input, depending on what happened before, is a finite state system. Such a system can be described in the form of UML diagrams of state machines. A model that highlights the transition between states has four basic parts:

- The states in which the system can be located (for example, closed or open)
- Transitions from one state to another (transactions are allowed only between certain states)
- The events that generate the transitions
- Actions resulting from transactions.

It is noteworthy that, in any state, an event may cause a single action, while the same event, from a different state, may

cause another action or the transition to another state.

The test conditions can be derived from the diagram that models the machine with states in different ways. Each state can be considered a testing condition, as is each transition. The following table describes a general model for a state table that can be used to test a system in which finite states can be identified and modeled.

**Table 5.** General model for a table of states

		1 <sup>st</sup> test case	2 <sup>nd</sup> test case	3 <sup>rd</sup> test case	4 <sup>th</sup> test case
		1 <sup>st</sup> transition	2 <sup>nd</sup> transition	3 <sup>rd</sup> transition	4 <sup>th</sup> transition
STATES	A state				
	B state				
	C state				
	D state				

One of the advantages of the technique based on the transitions between states is that models can be built at the desired levels of detail and abstraction to verify the different critical or less critical aspects of the system.

#### 4.5 Use case-based testing

Use case-based testing is a technique that helps identify test cases for verifying the entire system from a transactional perspective. A use case is a description of a particular way of using the system by an actor. Each use case describes the interactions that the actor has with the system to perform a specific task (or at least a measurable result for the user). In general, actors are people, but there may be other systems. Use cases are a sequence of steps that describe the interactions between the actor and the system.

The use cases are defined in terms of the actor and from his perspective, not of the computer system. I often use business language and terms, rather than technical

terms. They serve as a basis for developing test cases for system testing and acceptance testing. Use cases may reveal integration defects, i.e. defects caused by the incorrect interaction between different components.

Each use case usually has a main scenario, as well as other additional alternatives (covering, for example, special cases or exceptional conditions). Each use case must specify any preconditions that must be met to operate the use case. The use cases must also specify the postconditions that can be observed and a description of the final state of the system, after the use case has

been successfully executed.

The system requirements can be specified as a set of use cases. This approach can facilitate the involvement of users in the process of collecting and defining the requirements, but also in the testing process. The following table shows the partial variant of a use case template that documents the simulation of the sale on the BWM market for the manufacturer. The basic and alternative flows are highlighted, with the highlighting of the actors involved. These will serve as input into the process of testing the scenarios involved in this use case.

**Table 6.** Partial description of a use case highlighting the actors involved

<b>Name</b>	Simulation sale on the BWM market for the manufacturer
<b>Preconditions</b>	The manufacturer specific activity settings from the general module have been introduced
<b>Postconditions</b>	The manufacturer has simulated its offer on the market of bilateral contracts for the period specified in the general module. The simulation data on the BWM were saved.
<b>Basic flow</b> <b>P: Producer</b> <b>S: System</b>	<ol style="list-style-type: none"> <li>1. P: Select the option to sell on the BWM market.</li> <li>2. P: Choose from a predefined list of products (OPCOM) the one for which you want to simulate the transaction, according to the time settings in the general module.</li> <li>3. S: Check overlaps with the selected product.</li> <li>4. P: Selects information specific to the chosen product, such as semester, quarter, month or year. (Only available products that have a shorter or a shorter period with the chosen period for simulation in the general module can be accessed.)</li> <li>5. P: Enter the desired hourly power to be contracted.</li> <li>6. S: The hourly power desired to be contracted will be validated in order not to exceed the declarant availability in the general module.</li> <li>7. S: A historical monthly average price for the selected product will be displayed</li> <li>8. S: The cost of imbalances is completed, as a percentage of the receipts, implicitly with the value of 10%.</li> <li>9. S: Calculate and display the total hourly power offered on BWM for sale.</li> <li>10. S: Saves data for BWM simulation.</li> </ol>
<b>Alternative flows</b>	3A: There are overlaps with the selected product - S: The products in the list that have overlaps with the selected product will be blocked.

6A: The hourly power exceeds the declarant available in the general module- S: An error message is displayed and the hourly power is re-entered

7A: The manufacturer wants to change the price - P: Changes the historical price

7B: There is a negotiated hourly price for a product - S: it will automatically fill in and use the negotiated price

8A: Manufacturer wants to change the cost of imbalances - P: Change percentage of imbalances

As an example of creating and using dependency charts, we selected only the participation of the energy producer on two electricity markets: BWM and DAM. The scenarios in which the Producer is the actor are:







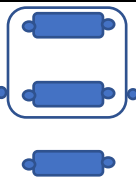
- (1) Basic configurations in the General module;
- (2) Select product for BWM transaction;
- (3) Fill in the hourly power to be contracted for the listed products;
- (4) Fill in the price of the imbalances as a percentage of the receipts;
- (5) Estimate the correction coefficient according to the weather forecast;
- (6) Fill in the offer for each time interval of each month.

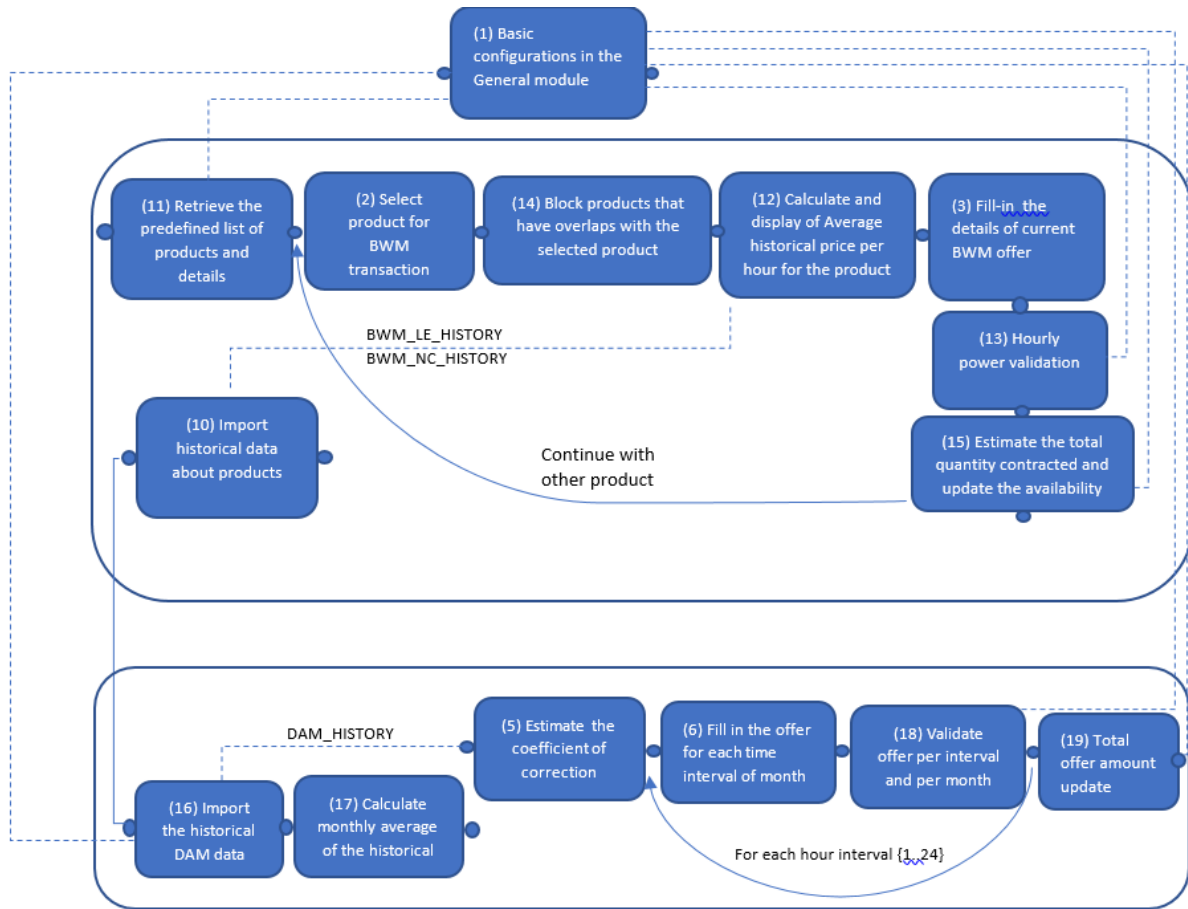
The scenarios in which the System is the actor are:

- (10) Import historical data about products;
- (11) Retrieve the predefined list of products and details;
- (12) Calculate and display Average historical price per hour for the selected product;
- (13) Hourly power validation;
- (14) Block those products from the list that have overlaps with the selected product;
- (15) Estimate the total contracted quantity and update the availability;
- (16) Retrieve the historical DAM data;
- (17) Calculate monthly average of the historical price;
- (18) Validate offer per interval and per month.
- (19) Total offer amount update

Dependency charts are very useful in testing, as they support derivation of additional test cases and ensure that dependencies between scenarios are tested. Dependency chart in Figure 6 uses the notations presented in Table 7.

**Table 7.** The notations for dependency charts [3].

Symbol	Explanation
	Unrestricted scenario
	General dependency
	Sequence
	Alternative
	Iteration
	Real time dependencies
	Structuring constructs



**Fig. 6.** A dependency chart for the electricity market simulator

**Table 8.** Examples of test case identification

<b>Test preparation</b>		Producer has entered basic configurations in the General Module	
<b>ID</b>	<b>Scenarios</b>	<b>Expected result</b>	<b>Description</b>
1.1	(11), (2), (14)	User can not be able to add the selected product to his offer	User select products on BWM that overlaps the previous selected product(s)
1.2	(11), (2), (14), (12), (3), (13)	An error message is displayed and the hourly power has to be re-entered	Hourly power exceeds the declarant available in the general module
1.3	(16), (17), (5), (6), (18)	An error message is displayed and per interval and per has to be re-entered	Offer per interval and per moth on DAM exceeds the declarant available in the general module

Use cases present their scenarios in the form of all possible paths for the specific functionality of the computer system. Therefore, all these scenarios must be verified for the actual implementation of the testing process. By crossing the dependency chart, the necessary test paths can be identified and the use cases efficiently generated. Table 8 presents some examples of test cases based on

scenario dependencies, where scenarios are indicated using their identification numbers between brackets.

## 5 Conclusions and future work

As our first development phases used UML for modeling, we find best fitted UML-Based Approach to System Testing, with its obvious advantages.

Each of the functional testing techniques presented above are frequently applied, each

with its own recommendations. Often these are used in a complementary manner to benefit from their specific advantages. In the case of a complex system, such as the system for simulating the participation in the electricity markets presented in this paper, where there are numerous and interdependent restrictions between the different functionalities, the test based on use cases will be the most appropriate technique.

## 6 Acknowledgment

This paper presents the scientific results of the project “Intelligent system for trading on wholesale electricity market” (SMARTRADE), co-financed by the European Regional Development Fund (ERDF), through the Competitiveness Operational Programme (COP) 2014-2020, priority axis 1 – Research, technological development and innovation (RD&I) to support economic competitiveness and business development, Action 1.1.4 - Attracting high-level personnel from abroad in order to enhance the RD capacity, contract ID P\_37\_418, no. 62/05.09.2016, beneficiary: The Bucharest University of Economic Studies

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## Dashboard for analysis of electricity imbalances at the Balancing Responsible Parties level

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*The paper presents the Dashboard for the analysis of imbalances at the level of a Balancing Responsible Party BRP (ABI-PRE). It describes the allocation between the members of a BRP of the costs/revenues generated by the net imbalances of the respective BRP and the calculation methodology implemented within the IT prototype. The reports created within the ABI-PRE Dashboard are generated following the analysis of specific indicators (contribution of BRP members to imbalances, revenues/expenses resulting from internal redistribution, additional revenues/expenses from system balancing, share of imbalance at BRP level, ratios between adjusted average prices and average prices on the Balancing Market) and BRP performance (BRP efficiency).*

**Keywords:** balancing market, balancing responsible parties, surplus, deficit, cost allocation method

### 1 Introduction

The rules for the functioning of the balancing market and the determination and settlement of imbalances need to be harmonized with European regulations. Commission Regulation (EU) 2017/2195 laying down a guideline on the balancing of the electricity system [1] provided, at European Union level, a set of technical, operational and market rules governing the functioning of balancing markets, including rules on the financial settlement of the BRP. At the ENTSO-E level, the Implementation Framework document was developed referring to the proposal created by all Transmission System Operators (TSOs) on the framework for the implementation of a European Platform for the process of compensating for imbalances, in accordance with [1]. Pursuant to Article 22 of [1], all European TSOs have developed a joint proposal for the framework for the implementation of an European Platform for the process of offsetting imbalances, setting out rules on activating energy

balancing and financial settlement of BRP.

Given that energy balancing offers will compete on balancing platforms across the EU, this will also have a positive effect at the competition level. It will also contribute to the goal of transparency in balancing markets, as the same rules and methodologies will apply to all TSOs.

After the entry into force of [1], it was necessary to adapt the legislation in the field, in accordance with the methodologies proposed by TSO and approved by national energy regulatory authority (ANRE). The rules for the transparency of balancing settlement were approved [2]. Any BRP has the responsibility to redistribute monthly to its members the additional income, respectively the additional cost from balancing the system, based on the contribution of each licensee (BRP member) to reduce, respectively to amplify the imbalance of the power system level.

Another stage in this process was the elaboration by TSO and the approval by ANRE of the clauses and conditions applicable to the BRP, which must comply with the framework terms for the creation of

European platforms for energy balancing exchange and for the process of compensation for imbalances. The proposal on the terms and conditions for the parties responsible for balancing [3], created by TSO, establishes rules for the registration of licensees as BRP, withdrawal/revocation of registration as BRP, delegation of balancing responsibility to other BRPs, transmission of data and information delivered to the TSO for the purpose of calculating the imbalance on each imbalance settlement interval; determining the imbalance generated by a BRP in each imbalance settlement interval, etc.

The Regulation for the calculation and settlement of imbalances of the parties responsible for balancing has been approved [4], which contains the rules for the registration and aggregation of parties responsible for balancing and for the determination and settlement of imbalances between production and consumption. At the same time, the correlation of the way of determining the imbalances with the transactions on the balancing market brings coherence and is in line with the European trends, necessary for the creation of the internal energy market.

To cover the differences between the planned/contracted values of consumption, respectively production and their values in real time, the TSO operates the balancing market, buying or selling energy considering the offers of dispatchable producers. The market participants that determine the imbalances, organized in BRPs, financially bear the value of these imbalances, paying for the energy deficit the price resulting from the increasing offers accepted on the balancing market, respectively receiving for the energy surplus the price resulting from the decreasing offers accepted by the system operator.

Using records from the balancing market databases, the TSO produces weekly, monthly and annual reports (for example, traded volumes, monthly values of transactions on the balancing market, the average square deviation of physical notifications and consumption forecast).

Participation in a BRP (own or delegating the balancing responsibility to another BRP) is mandatory for any licensee (producer, supplier, trader, distributor) who is active in the energy market and performs transactions. The activity of each BRP aims to balance the differences between the contracted electricity and the electricity measured at the level of the entire contour.

According to [2], each BRP applies uniformly the method of internal allocation of imbalances for all licensees who are members of the respective BRP.

According to the *procedure* on the allocation of imbalances registered in the Electricity Balancing Market, drawn up by each BRP according to the national legislation and which applies to all members of that BRP, the imbalances of the BRP members result as a difference between the notified quantities (sold/bought in the wholesale electricity market) and the measured quantities of electricity. The sum of the individual costs of the BRP members is always equal to the BRP costs and all participants always benefit from the advantages of aggregating the imbalances, but not necessarily in equal proportions at monthly level. The method of internal redistribution of payments ensures that all participants included in the respective BRP always benefit from the aggregation of imbalances.

According to [4], Annex no. 2, rules are established for:

- a) the registration of licensees as BRP, the withdrawal/revocation of registration as BRP, as well as the delegation of balancing responsibility to other BRPs;
- b) determining the imbalance generated by a BRP in each dispatching interval;
- c) the settlement of imbalances of the BRPs in a way that reflects the costs of balancing

the system, and the BRPs to be encouraged to balance before delivery and not to aggravate the imbalance of the system.

## 2 BRP activities and ABI-PRE module description

With the application of the provisions [4], the additional income, respectively the additional cost coming from the balancing of the system is redistributed monthly to each BRP, starting from its contribution to the reduction or aggravation of the system imbalance.

The allocation among the members of a BRP of the costs/revenues generated by the net imbalances of the BRP is performed for each time interval, according to the calculation methodology (*procedure*) which consists in determining:

- the net contractual position, for each BRP member, on the basis of hourly notifications of production or consumption for the following day, sent to the BRP by each member;
- the net contractual position at BRP level;
- the net measured position for each BRP member, based on the actual measured values received from the Distribution System Operator (DSO)/TSO;
- net position measured at BRP level;
- the imbalance of each BRP member;
- imbalance at BRP level;
- the amount of imbalances for each BRP member, for each time slot, based on deficit and surplus prices;
- the value of the imbalance for BRP;
- the sum of the values of the individual imbalances at the level of the entire BRP;
- total gain at BRP level;
- unit gain;
- revised deficit/surplus prices, applicable internally at BRP level;
- the hourly costs/revenues of each member of the BRP according to the imbalance of each member, resulting from the internal redistribution of the costs/revenues related to the imbalances;

- the direct contribution (direct cost/direct income) and the indirect contribution (indirect cost/indirect income) of each member of the BRP to the total imbalance of that BRP;

- the total cost/income of each member, respectively at the BRP level.

The percentages of the distribution of the total revenues/costs of each member of the BRP are determined. The redistribution of additional costs/revenues from the balancing of the BRP system to the BRP members is determined on the basis of the contribution of each licensee and each BRP, in each settlement interval, to the reduction of the system imbalance, respectively to the increase of the power system imbalance. The allocation of additional costs/revenues is performed in proportion to the resulting imbalance to the licensees according to the position (sign) of the SEN, the BRP and the licensee (BRP member), for each settlement interval. The additional costs/revenues from the balancing of the system, related to BRP, are distributed to the BRP members.

The following indicators for the evaluation of efficiency at the BRP level are determined:

- the share of the total energy imbalance at BRP level
- the ratio between the rectified average prices at the BRP level/the average prices on the Balancing Market (negative imbalances and positive imbalances):
- BRP efficiency calculated as the difference between the average deficit/surplus price within the BRP and the average deficit/surplus price of the market operator.

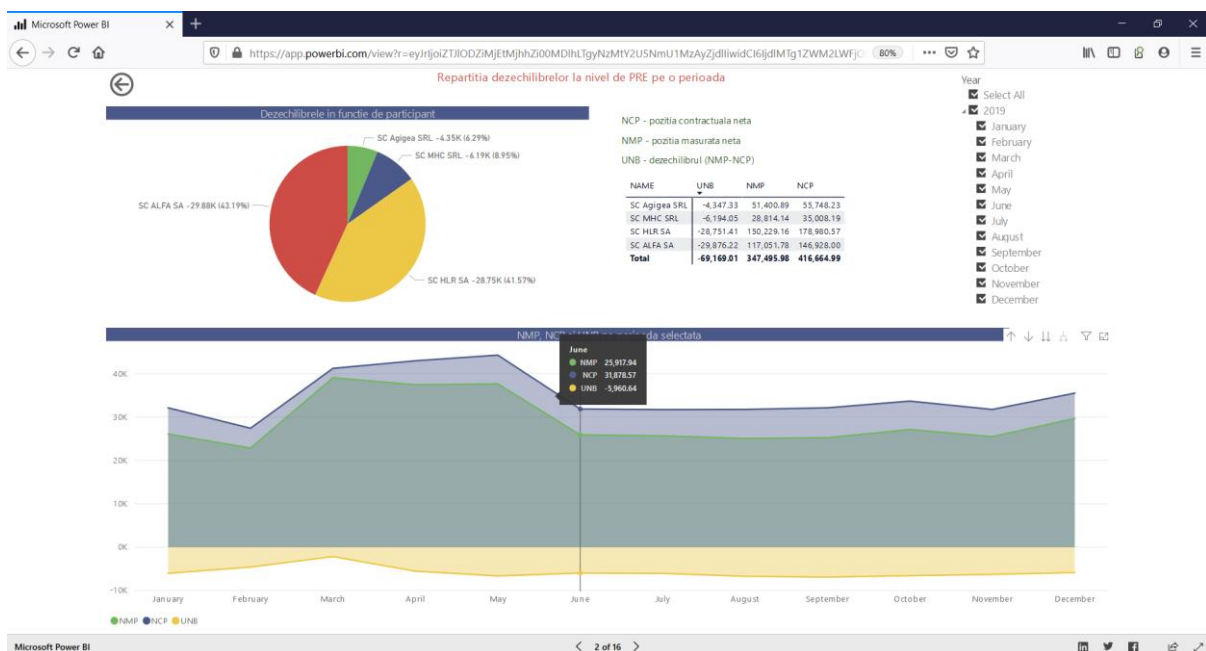
All calculations are made separately for each settlement interval. The presented methodology is implemented within the computer prototype developed by the authors of this paper [5]. The data is stored in the database, and the ABI-PRE module developed in Power BI connects to the database. The reports created within the

ABI-PRE module are grouped following the analysis of the following indicators:

- The contribution of BRP members to imbalances;
- Revenues and hourly expenses of BRP members resulting from the internal redistribution of imbalances costs/revenues;
- Additional revenues and expenses from balancing the system;
- The share of the total energy imbalance at BRP level;

- The ratio between the rectified average prices and the average prices on the balancing market;
- BRP efficiency.

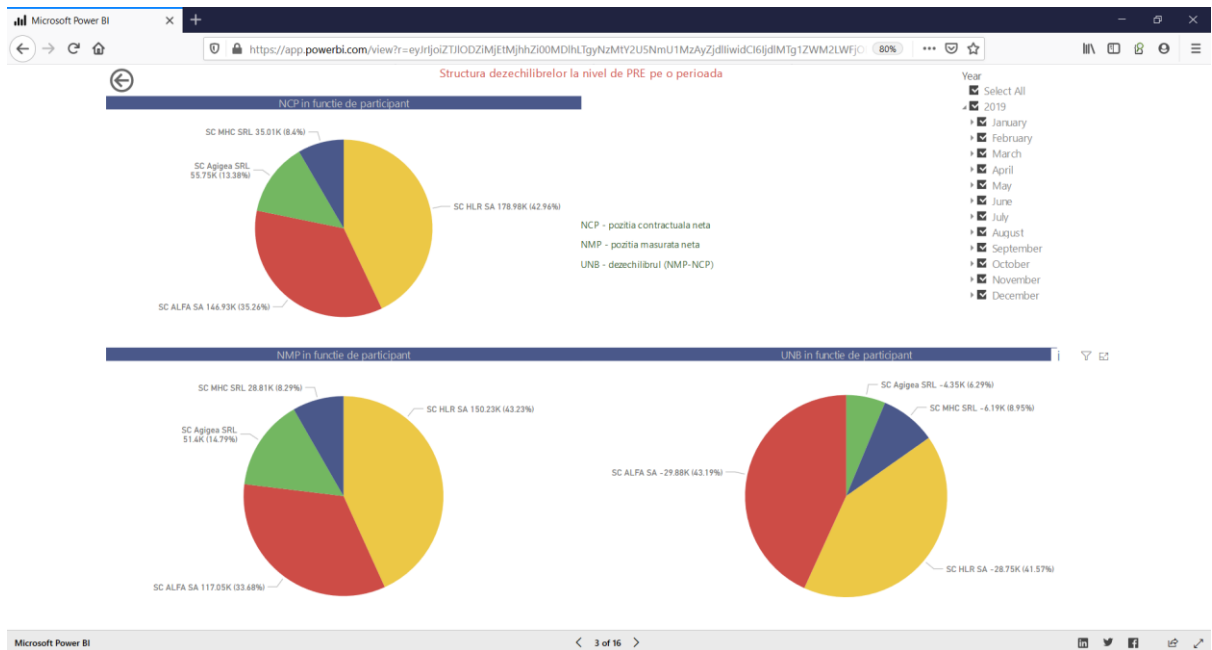
For the analysis of the contribution of BRP members to imbalances, reports were constructed through which the values of the following indicators can be analysed: Contractual net position, Measured net position and Imbalance. Each of the reports are displayed in a separate window including pie charts and stacked columns format, and tables. In Fig. 1 below, it is presented an example report.



**Fig. 1.** Distribution of imbalances at BRP level

The distribution of imbalances at the level of BPR analyses the distribution of imbalances on the members of BPR, for a certain selected period of time.

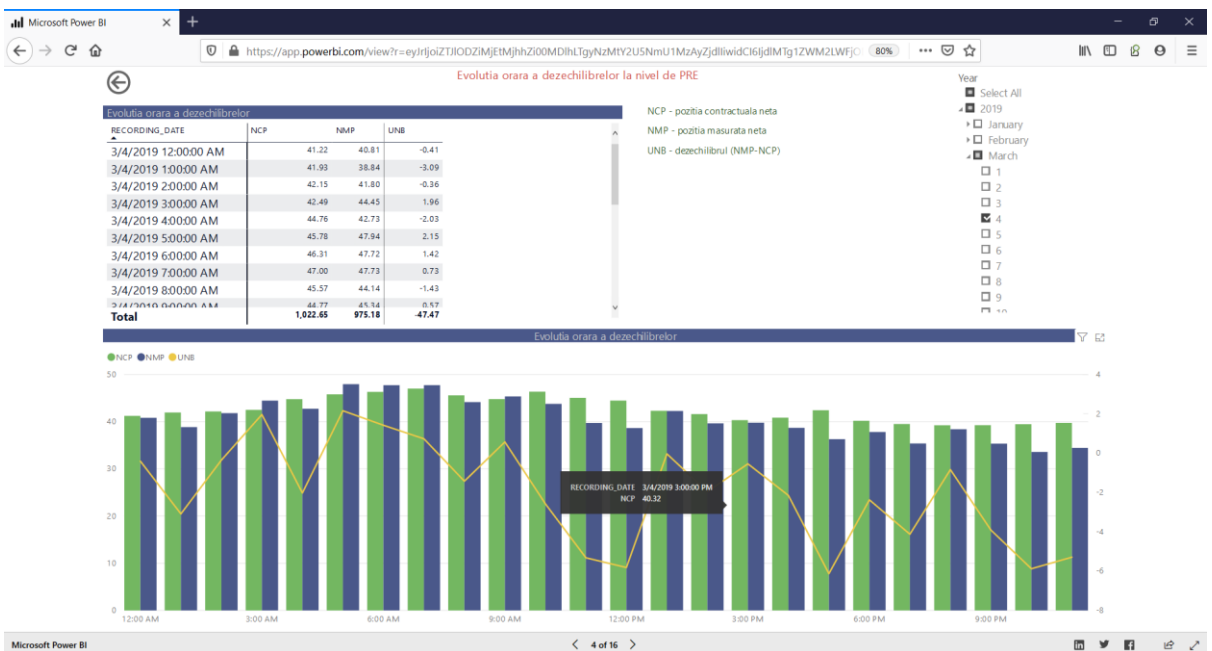
The share of imbalances recorded by BPR members over a selected period of time is presented in the report Structure of imbalances at BPR level (as in Fig.2).



**Fig. 2.** The structure of imbalances at the level of PRE

For the analysis of the evolution of the indicators: net contractual position, measured net position and imbalances at

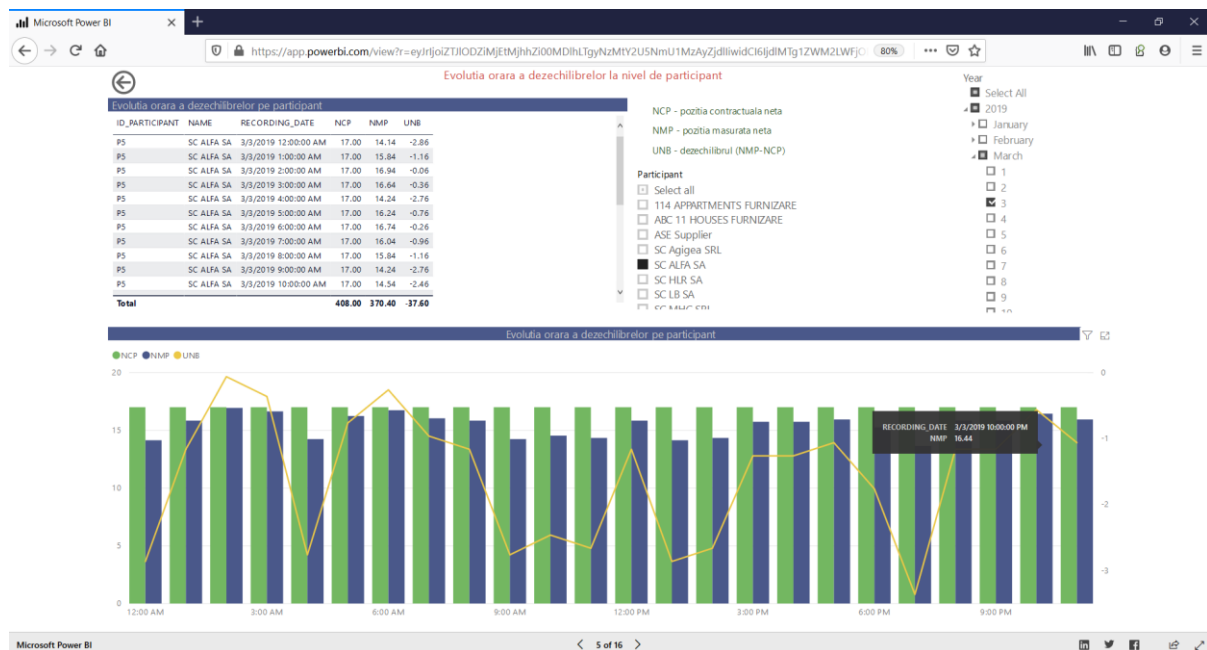
hourly intervals, during a day, the report Hourly evolution of imbalances at BRP level can be used (Fig. 3).



**Fig. 3.** Hourly evolution of imbalances at PRE level

Imbalances, as well as indicators of the net contractual position and the measured net position can be analysed for a specific

chosen participant, based on the hourly evolution, over a 24-hour period (Fig. 4).



**Fig. 4.** Hourly evolution of imbalances at participant level

For the analysis of the revenues and hourly expenses of the BRP members resulting from the internal redistribution of the costs/revenues related to the imbalances, the reports were built that allow:

- view the evolution of surplus and deficit prices over a given period;
- the comparison of the prices on the balancing market with the

adjusted prices applied at BRP level;

- analysis of the gain obtained by affiliation to the respective BRP.

The reports contain filters for selecting the period and the name of the BRP members, if a detailed analysis is desired. Fig. 5 shows the values of the imbalances for a certain selected period, at the BRP level.



**Fig. 5.** Evolution of revenues and expenditures from imbalances at BRP level



Imbalance costs are obtained by applying the deficit/surplus price to the value of the imbalance. The evolution of revenues and expenditures from imbalances can be tracked at the BRP level and is displayed tabularly and graphically. To visualize the evolution of surplus and deficit

prices, the report that compares the prices on the balancing market and the rectified prices to be applied at the BRP level can be used. Prices are displayed in hourly intervals depending on the month and day selected as parameters from the available filters (Fig. 6).



Fig. 6. The evolution of surplus and deficit prices

The distribution report of income and expenses from imbalances by participants (Fig. 7) allows the analysis of imbalances and gains obtained by a certain

participant, for a certain period, as a result of affiliation to BRP. The participant and the period (year, month) are selected from the filters available at the report level.

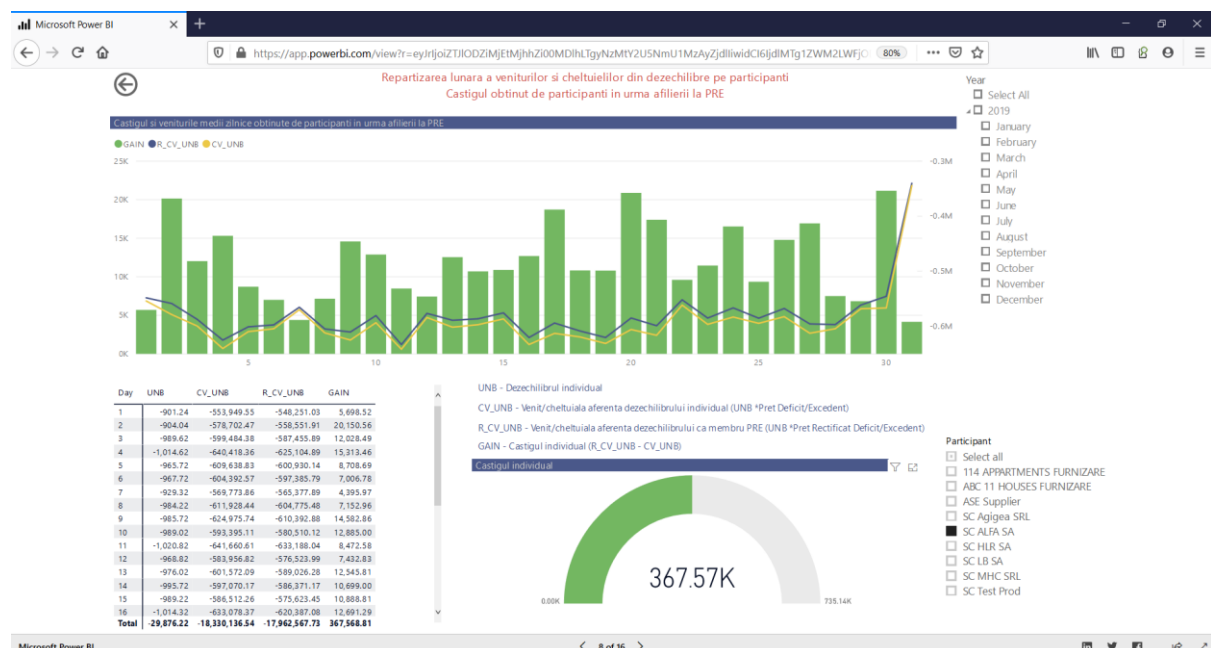
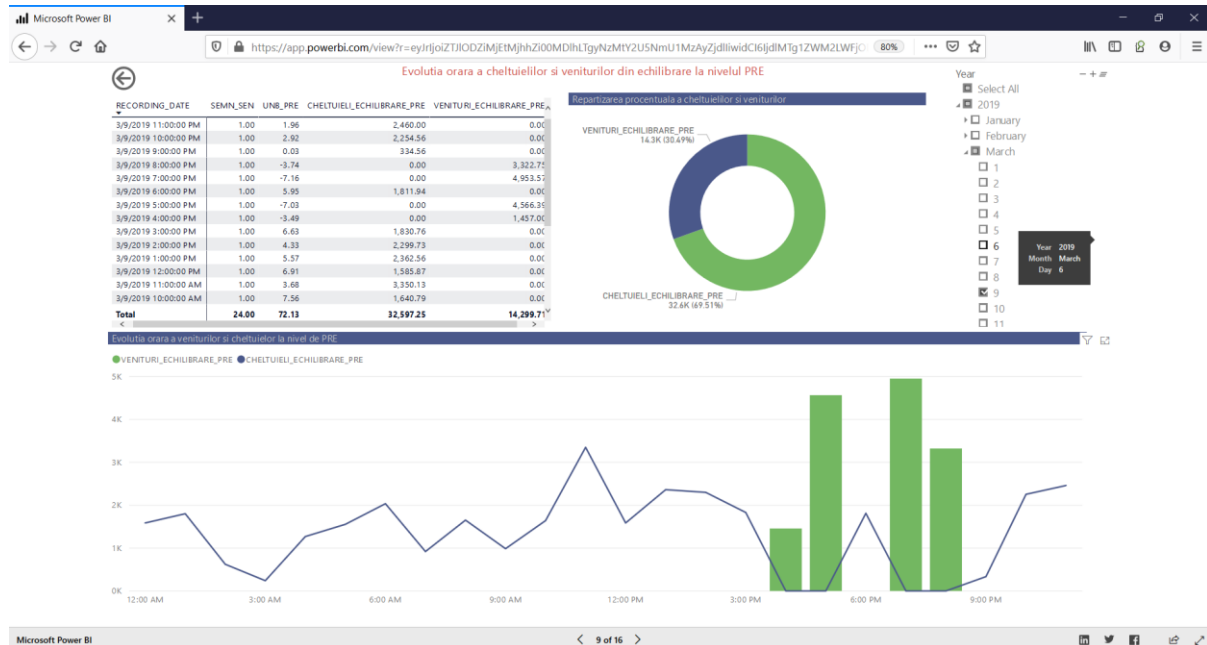


Fig. 7. Distribution of income and expenses from imbalances by participants



At the BRP level, it is possible to analyse the balancing expenditures and revenues by displaying the balancing expenditures and revenues obtained by the BRP at the

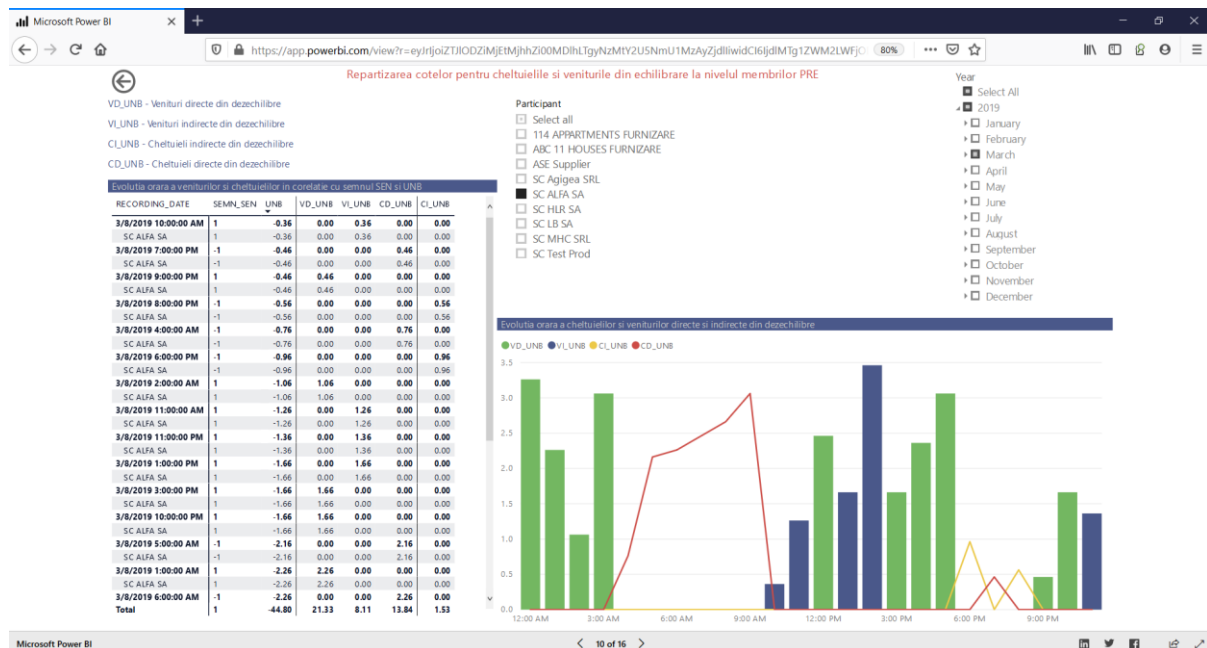
level of a day, taking into account the sign of the power system. To select the period, select the month and day from the available filters (Fig. 8).



**Fig. 8.** The evolution in time of the balancing expenses and incomes at the BRP level

The display of the distribution of quotas for direct and indirect revenues and expenses related to imbalances at the level of BRP members for a certain selected period is presented in Fig. 9.

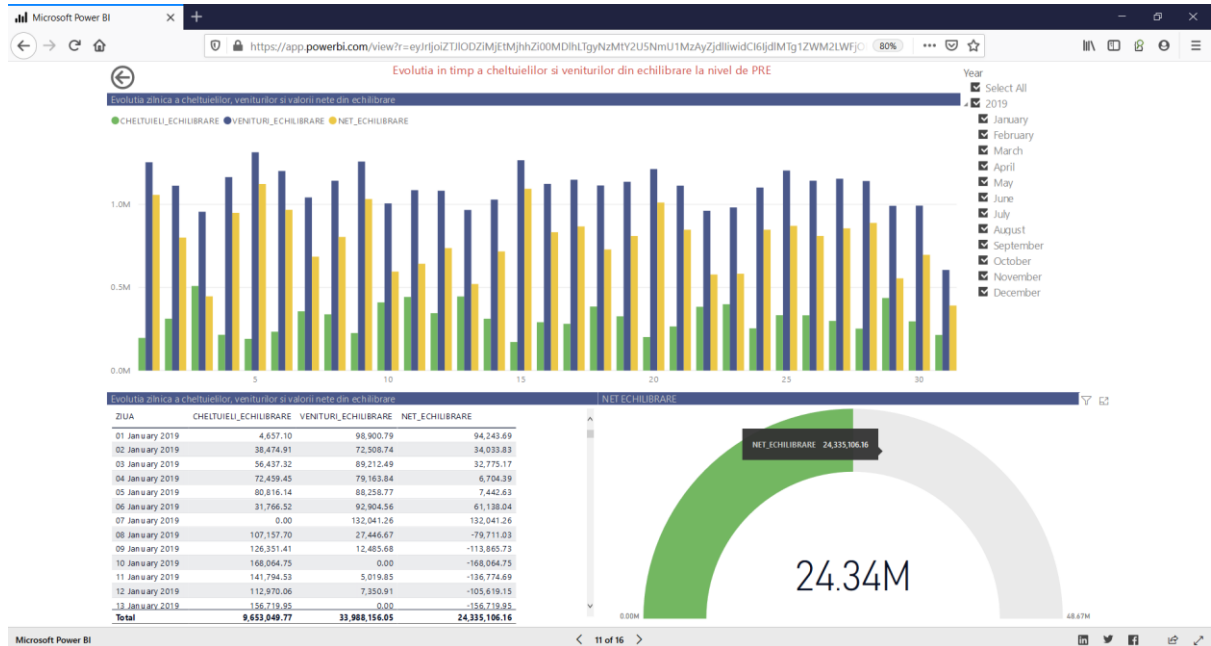
A filter is available to select the participant to display all participants and select them for analysis.



**Fig. 9.** Allocation of quotas for balancing expenses and income

For the analysis of balancing income and expenditure, reports are available in which the values are analysed at the level of BRP, over a certain period, and these amounts are distributed among members according to the quotas previously

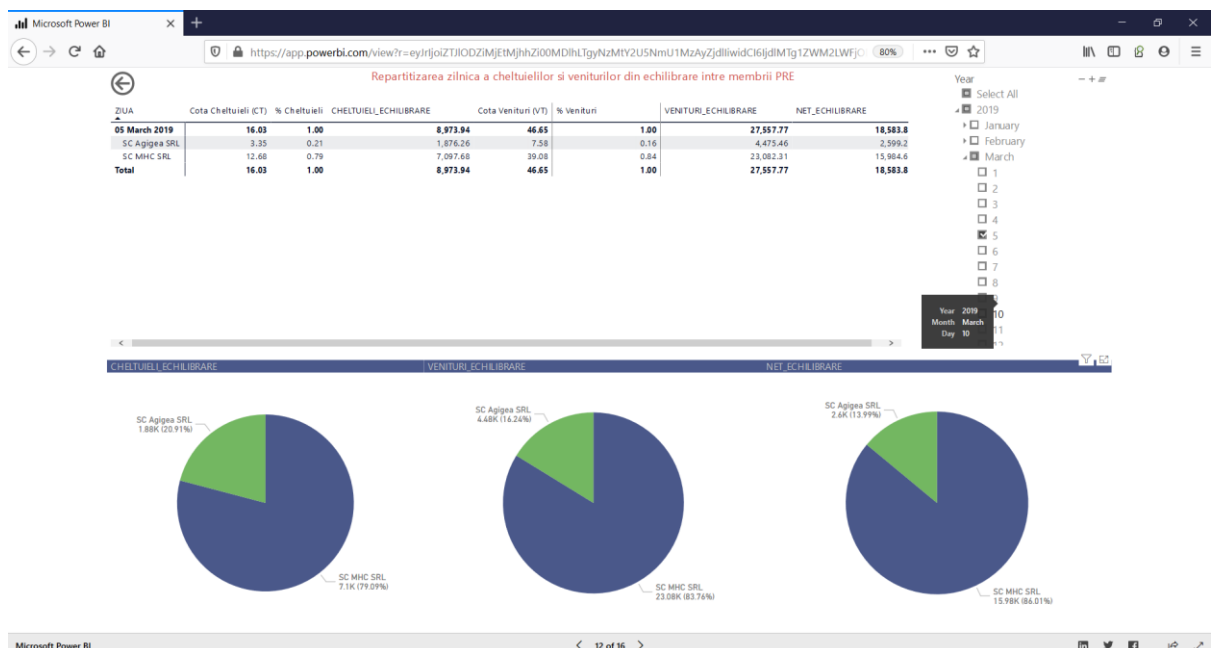
established. The evolution in time of the balancing expenses and incomes at the BRP level (Fig. 10) allows the analysis of the expenses, incomes and the corresponding net values at the BRP level for a certain selected period.



**Fig. 10.** The evolution in time of the balancing expenses and incomes at BRP level

The distribution of balancing expenses and revenues between BRP members is presented in Fig. 11. The allocation quotas and the corresponding percentages

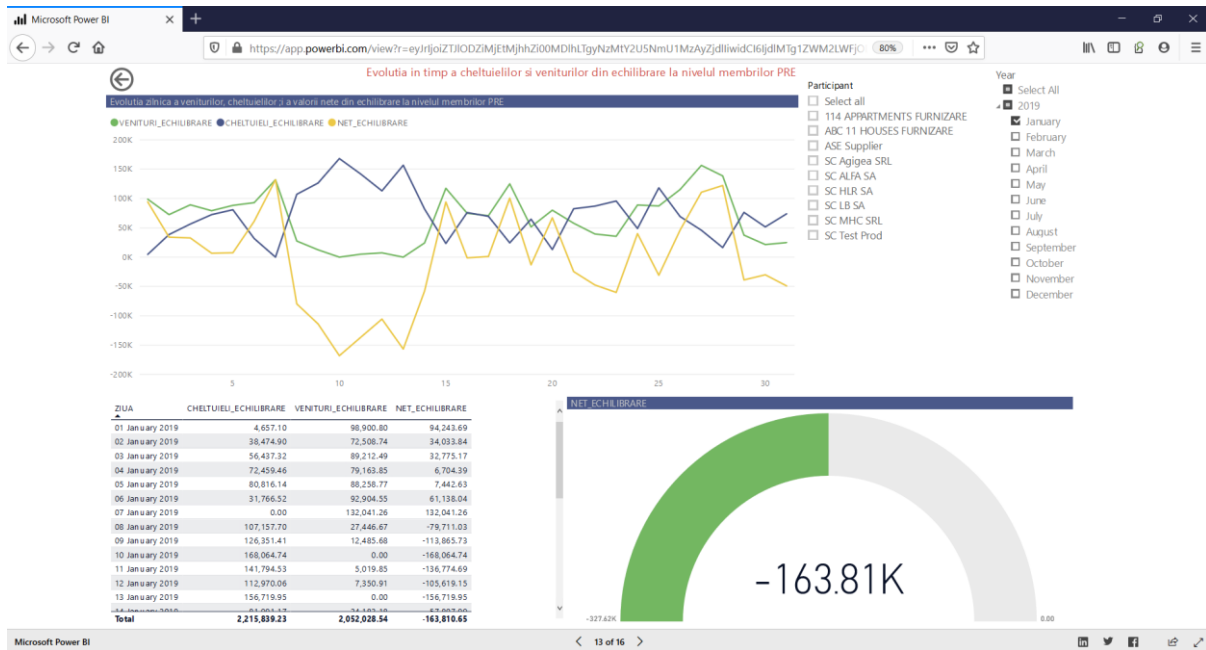
for a selected period are determined. The data are displayed tabular on each day and BRP member as well as graphically.



**Fig. 11.** Distribution of balancing expenses and revenues among BRP members

The evolution over time of the balancing expenses and incomes at the level of the BRP members (Fig. 12) allows the analysis of the incomes, expenses and the net value coming from the balancing of the system at the level of a selected

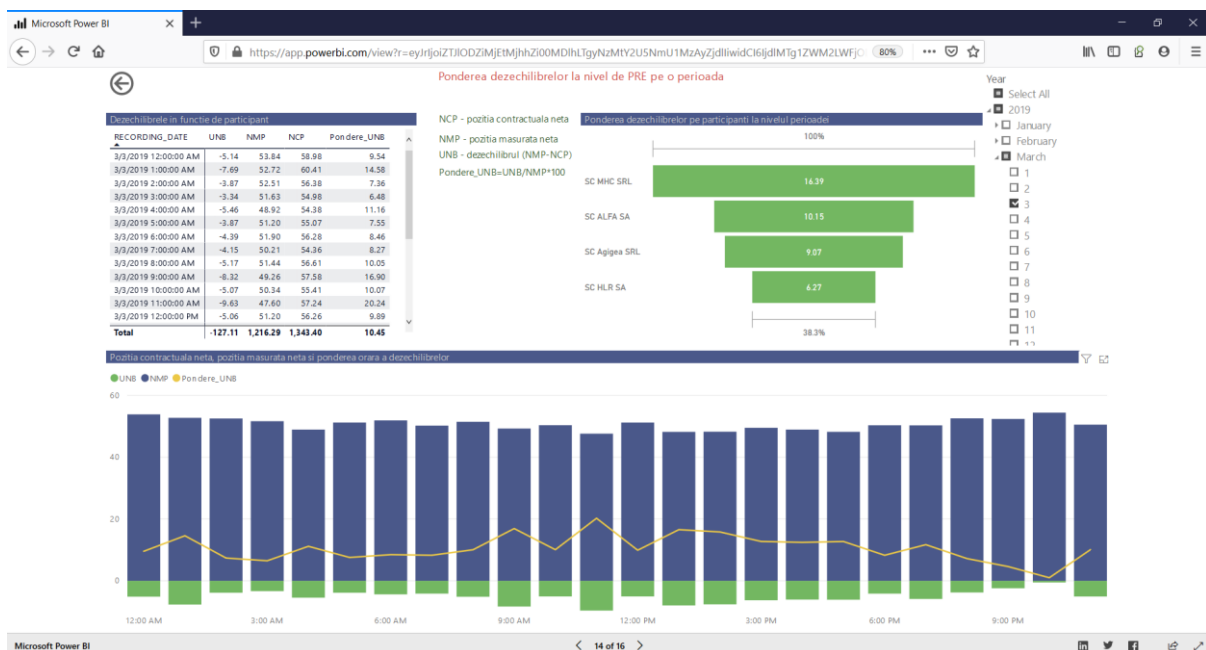
participant. The analysis can be performed for a period of one month selected from the available filters. The data are viewed in tabular form, and the evolution of the indicators is displayed graphically.



**Fig. 12.** The evolution in time of the balancing expenses and incomes at the level of the BRP members

It is possible to analyse the share of imbalances for each participant, as well

as at the BRP level, for a selected period (Fig. 13).



**Fig. 13.** The share of imbalances at the level of BRP over a certain period

For the analysis of the efficiency of BRP, the ratio between the average corrected price and the average market price for both deficit and surplus is determined.

The ratio between rectified prices and OPCOM (market operator) prices allows the analysis of these indicators over different periods of time, both tabular and graphical (Fig. 14).

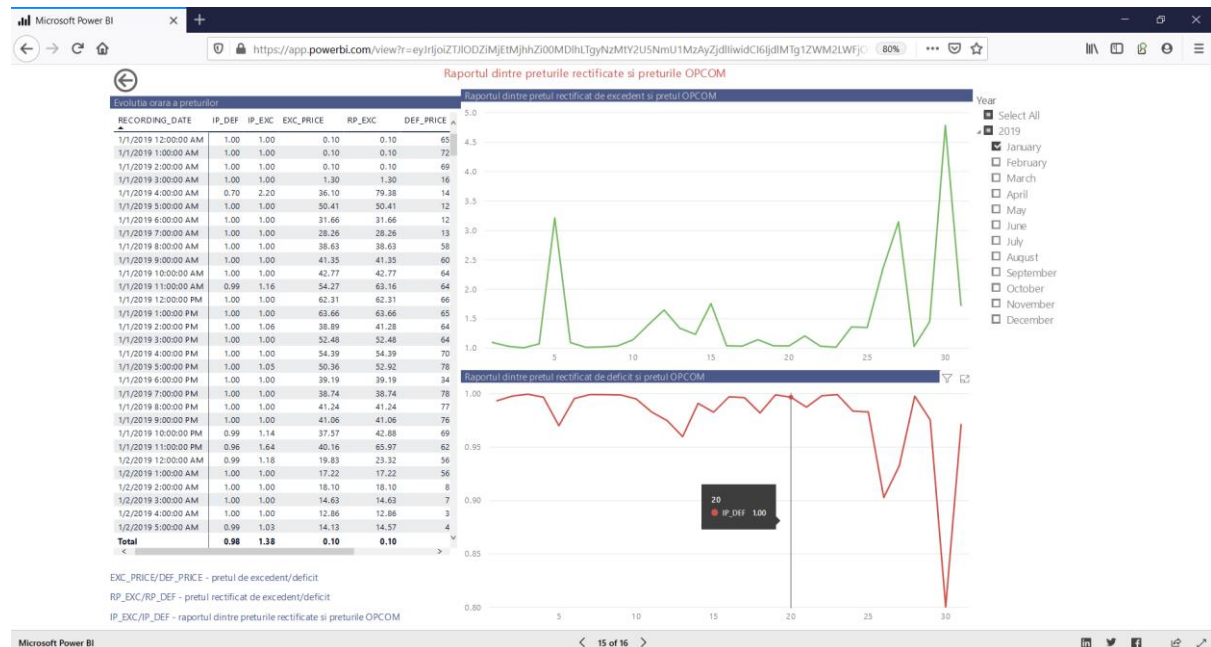


Fig. 14. The ratio between rectified prices and OPCOM prices

BRP efficiency is calculated as the difference between the average deficit/surplus price within the BRP and the average deficit/surplus price of OPCOM. The higher it is, the more

significant the advantage of participating in a BRP. The difference between the rectified prices and the OPCOM prices (Fig. 15) can be made for different periods of time.

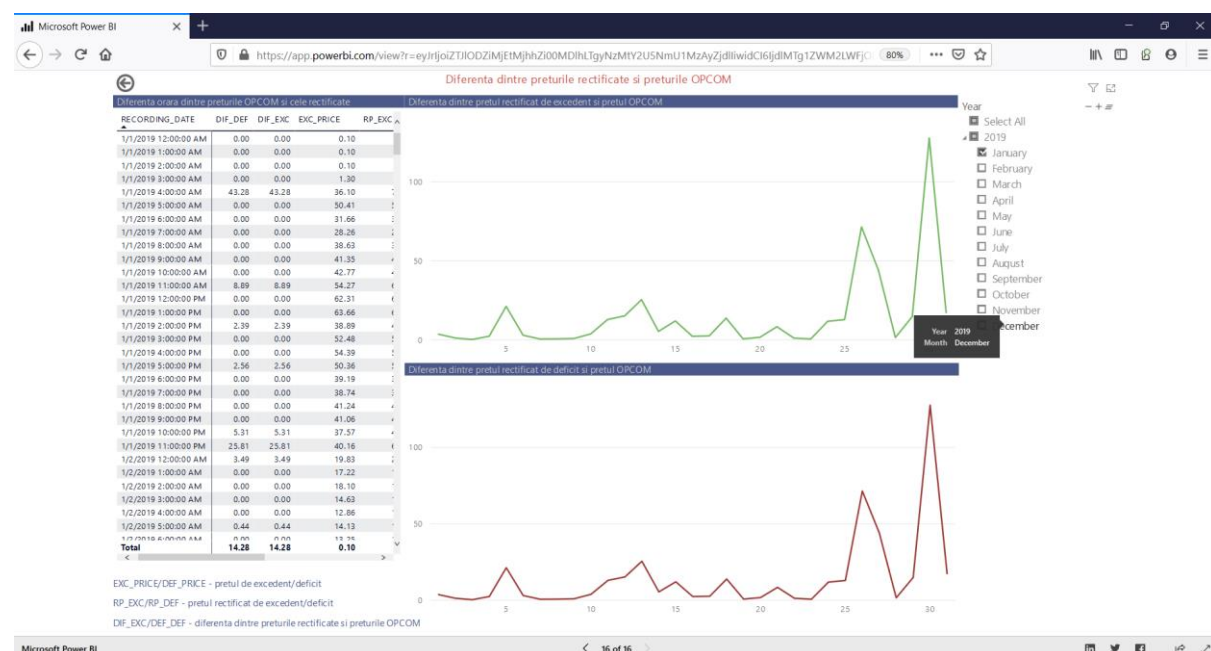


Fig. 15. The difference between rectified prices and OPCOM prices

The detailed reports made within the ABI-PRE module contain particularly useful information regarding the BRP activity. The reports allow the analysis and interpretation of the activity carried out at the level of each participant, as well as at the level of BRP. Among the editing facilities in the program can be

mentioned: filters, types of graphs used to display the evolution of the various indicators followed, the possibilities of selection for analysis and statistical data processing. The dashboard for ABI-PRE module to access the reports is presented in Fig. 16.

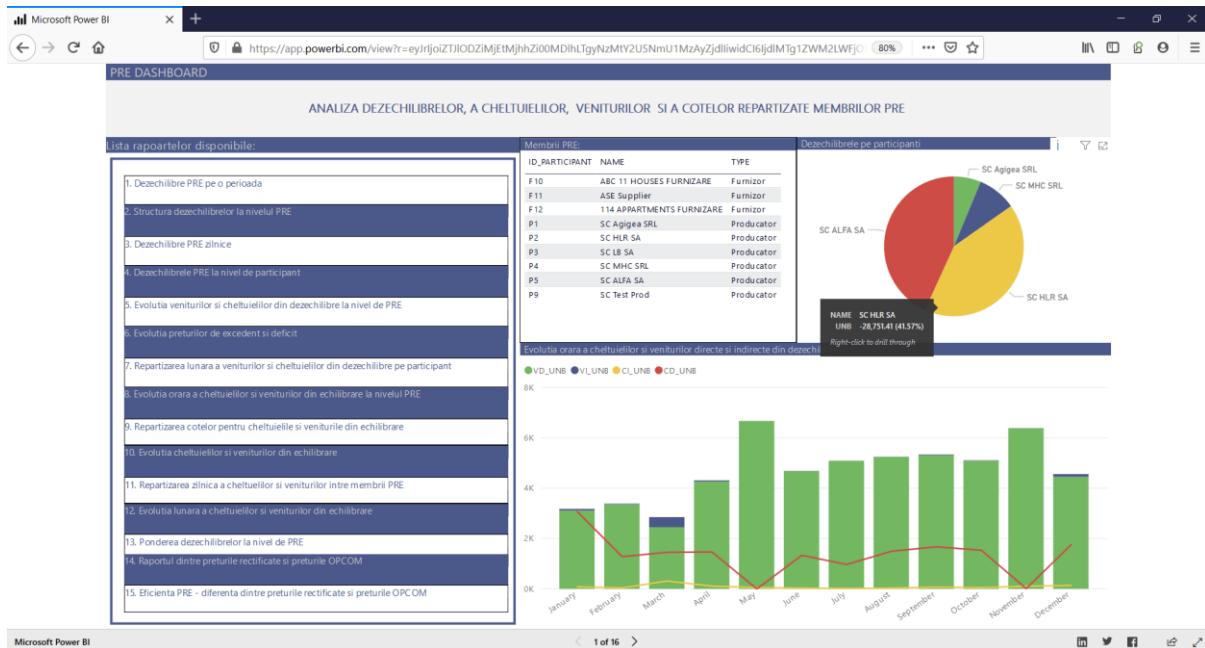


Fig. 16. Dashboard for ABI-PRE module

### 3 Conclusions

The purpose of the balancing market is to ensure the balance of the production/consumption balance of electricity in real time, using the resources offered in a competitive system. The European Union promotes the development of the balancing market at regional level and considers it useful to strengthen the regional cooperation of transmission and system operators. According to [6], regional cooperation should be compatible with the evolution towards a competitive and efficient internal electricity market. ENTSO for Electricity promotes cooperation between TSOs at regional level, ensuring interoperability, communication and monitoring of regional performance. The regional coordination centres complement the role of transmission and system operators, by fulfilling the

attributions of regional interest. The correlation of the way of determining the imbalances with the transactions in the balancing market is in line with the European trends necessary for the creation of the internal energy market. Each BRP assumes financial responsibility towards the TSO for the settlement of the total imbalances resulting from the aggregation of the individual imbalances of each participant that has registered in that BRP. Bringing together several participants within the same BRP determines the mutual compensation of individual imbalances and the efficient distribution of costs, but also of benefits. The software platform developed by the authors of this paper is equipped with a module specialized in analysing imbalances at the BRP level (ABI-PRE) and provides support in determining specific indicators for the entire BRP, but also in terms of the



contribution of each participant (BRP member).

The paper describes the allocation between the members of a BRP of the costs/revenues generated by the net imbalances of the respective BRP and the calculation methodology implemented within the prototype. The reports made within the ABI-PRE module are generated following the analysis of the specific and performance indicators of the BRP.

#### 4 Acknowledgment

This paper presents the scientific results of the project “Intelligent system for trading on wholesale electricity market” (SMARTRADE), co-financed by the European Regional Development Fund (ERDF), through the Competitiveness Operational Programme (COP) 2014-2020, priority axis 1 – Research, technological development and innovation (RD&I) to support economic competitiveness and business development, Action 1.1.4-Attracting high-level personnel from abroad in order to enhance the RD capacity, contract IDP 37 418, no. 62/05.09.2016, beneficiary: The Bucharest University of Economic Studies.

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## Consumption Management Software for Electric Power Suppliers

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*The electricity market is a very complex reality, with numerous participants, rules, factors that influence the evolution of energy production and consumption. This paper presents a software solution that supports electric power suppliers as participants in this complex market. The prototype uses machine learning algorithms to determine consumer clusters and forecast the next day's consumption, the purpose being to obtain the flattening of the consumption curve at the level of the electricity supplier. Based on the initial consumption planning of programmable devices transmitted by consumers, four consumption optimization algorithms are applied in parallel, giving the energy supplier the possibility to decide the optimal plan for the next day.*

**Keywords:** power sector, software, power suppliers, forecast, optimization.

### 1 Introduction

With the liberalization of the electricity market, the market participants faced a diversification of business models and services types and the need to adapt to the new market rules. In the case of electricity suppliers, these challenges were mainly related to establishing optimal tariff schemes, optimizing consumption and forecasting consumption in order to mitigate the costs of imbalances and ensure the economic efficiency and reliability of energy supply.

The software solution presented in the following sections represents a part of a multi-modular information system for the management of the Romanian electricity market, SMARTRADE [1]. The SMARTRADE project aimed to design and develop a prototype information system for forecasting, analysis and decision models for electricity market participants (suppliers / producers) established as Responsible Parties for Balancing (PRE), in order to estimate consumption and production and carry out efficient transactions on the wholesale electricity market. The

objectives of the project are correlated with the current needs of integrating a large volume of electricity produced from renewable energy sources (RES) and, at the same time, with the need to implement smart electricity metering systems (smart metering) for consumers by 2020.

The module, called EL- Supplier, aims to provide a solution to respond to consumer's electricity demand, by implementing not only consumers related data management but also some algorithms that will assist the supplier in making decisions: a consumption prediction models, a model for determining consumption profiles and models for consumption optimization. The analysis results are presented in a friendly and intuitive manner.

The paper is structured in four parts, as follows: section 2 - a brief presentation of the Romanian electricity market and the specific elements of electricity suppliers; section 3 - a presentation of the module for data management of electricity consumers; section 4 - a presentation of the module for electricity consumption management; section 5 - conclusions, advantages and future directions.



## 2 Electric power suppliers

The Wholesale Electricity Market is the organized framework in which electricity is purchased by suppliers from producers or other suppliers, in order to resell it or for their own consumption, as well as by network operators to cover their own technological consumption. The competitive wholesale market (free market) consists of:

(a) contracts for the purchase / sale of electricity, with quantities and prices negotiated between market participants (producers, wholesale suppliers, eligible consumers).

(b) the “a day-ahead” spot market, with marginal price transactions, for the balancing quantities of the forecasted consumption and the quantities of electricity contracted for each hour of the day.

The system of regulated and competitive markets operating in parallel has the advantage of allowing the development of bilateral relations between producers or wholesale suppliers, on the one hand, and eligible consumers, on the other hand, as the market is open to competition [2]. An eligible consumer is a consumer that is free to purchase electricity from any supplier and has access to the transmission and distribution networks [3].

All participants in the electricity market operate on the basis of accreditations granted by the Romanian Energy Regulatory Authority (ANRE) [4], and their activities are interdependent, the energy not being able to reach the final consumer if one of these actors does not work. In Romania, the meeting place between producers, large industries, suppliers or exporters is the Romanian Gas and Electricity Market Operator (OPCOM) [5], which has the role of managing the electricity market. It is an operator licensed by the National Energy Regulatory Authority (ANRE) and manages several markets, such as green certificates or the day-ahead market.

As an actor in the electricity market, the supplier is the one who ensures the connection with the final consumer, either domestic or non-domestic. The list provided by ANRE in October 2019 included 85 energy suppliers, the competition being very high. Electricity suppliers can have a wide portfolio of consumers of different types (industrial, commercial and residential). Customers have the option to choose a regulated electricity offer from a supplier that has been designated by ANRE as a Supplier of Last Instance or to be an eligible customer and benefit from a free market offer, with a price in a competitive regime.

In the case of tenders with regulated energy supply prices, it is the regulatory authority that determines whether an energy supplier can be a supplier of last resort, and the areas on which a supplier operates in this capacity, as well as the prices for active energy, for each area and for each voltage level. In this way, a supplier can operate in both the regulated market and the free market, having the possibility to offer customers all the variants. However, this option will disappear, by the gradual transition to an exclusive competitive market until 2022.

In the case of offers from the competitive market, the selling prices of active energy are established by each company, depending on the strategy it approaches and, of course, taking into account the price at which it purchases energy. The final value that the customer gets to pay on an electricity bill consists of the actual price of energy, expressed in the currency / MWh and the tariffs regulated by ANRE. They include the distribution tariff (different depending on the area where find out the customer), the transport tariff, the network extraction tariff and the system services, as well as excises, green certificates or the contribution for cogeneration. Thus, except for regulated tariffs which are mandatory and applied by each supplier, the difference between the offers on the market is determined only by the price of active energy and possibly by the extra services that a supplier can offer.

Considering the strong competition existing

on the electricity suppliers market, the efficient management of the data of the associated consumers, their analysis and the taking of informed business decisions becomes a particularly important advantage. This is the reason for developing the software prototype presented in this paper.

The module for managing electricity consumption from the perspective of electricity suppliers, called EL-Supplier, is developed in JDeveloper based on test data previously uploaded to the SMARTRADE prototype database. The module is implemented in the Cloud Computing architecture and can be accessed online through web browsers. The database, which runs on an Oracle Database 12c instance, maintains historical values of electricity demand and generation for more than 5 years.

The following sections detail the steps required to access the module and work with the functionalities implemented to profile consumers, forecast consumption and optimize consumption at the supplier level.

### 3 EL-Supplier: Data management module

It is a module that ensures the easy organization and retrieval of data on suppliers, affiliated consumers - with their places of consumption, meters, meter readings, tariff allocations, appliances and appliance readings, but also information about the locations and tariffs managed by that supplier.

The supplier can complete and update his personal data regarding name, CUI, address, bank account, email, phone and other contact details. It can also complete / update its data regarding its identification and authorization as a participant on the electricity market.

Through the web interfaces that the solution provides, the user can add or edit data on all consumers associated with that supplier, with all the details that they

involve. The software application is organized in several important sections, presented below.

#### 3.1. Supplier info

This option allows you to add / edit general consumer data in the system by filling in the information related to its name, type, address and contact details.

#### 3.2. Consumption place

The module allows to add / edit the details of a certain place of consumption of a consumer in order to achieve consumption profiles by filling in the information related to: type of place of consumption, facilities related to gas supply, existence of own generation sources, capacity and type their number of inhabitants and other details on the characteristics of the consumption place.

**Fig. 1.** Details about a consumer and his consumption places

#### 3.3. Meters

For each consumption location, the supplier

configures the operating parameters of the smart meters installed in the respective location: meter identifier, installation date, activation date and meter type. The supplier can later edit and update the meter details. Each smart meter will record the following values: reading date, active, reactive and apparent power consumed, active, reactive and apparent power generated,

meter status at the time of reading and recording status (valid or erroneous).

### 3.4. Meter readings

The data collected by the meters can be viewed in real time or aggregated, subsequently consulted by the supplier and the consumer through the interfaces of the computer system.

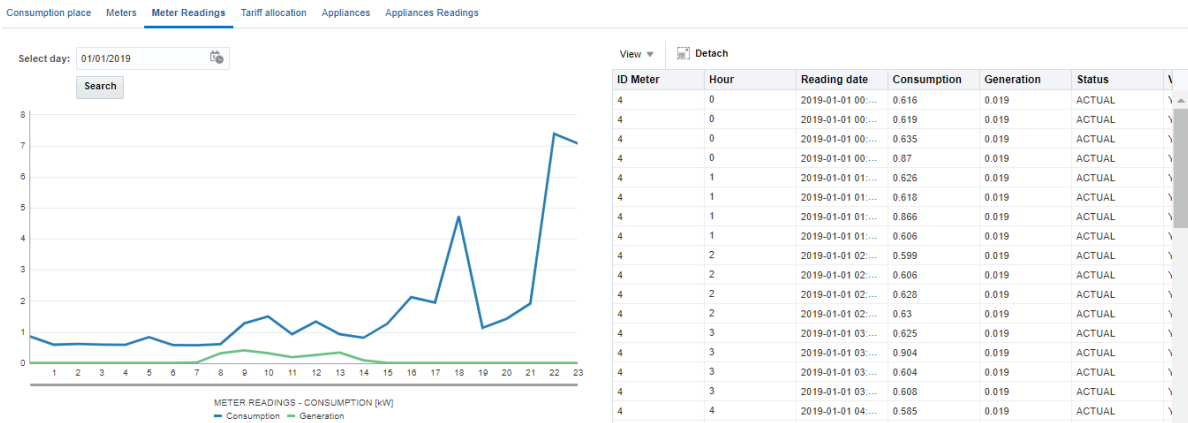


Fig. 2. Hourly consumption recorded by the meter readings for the selected day

### 3.5. Edit tariffs

Establishing consumer tariff plans is a strategic activity of the supplier and involves modelling consumer behaviour based on consumption profiles, but also considering strategies for participation in the electricity market [7]. The supplier establishes for each consumer's place of consumption a tariff plan according to the Edit information for consumers, consumption places, tariffs

consumption profile and the negotiations carried out with him. Thus, following the analysis of the cluster to which the consumer belongs, the supplier proposes a tariff plan for a place of consumption and informs the consumer. He may negotiate the proposed tariff plan and after negotiation the supplier shall associate the tariff plan with him.

ID tariff	Tariff type	Date start	Date end	Recommended hours	Consumption price	Generation price	A1	A2	A3	A4	A5
21	ToU	1/1/2015	12/31/2022	0-8	9	9	2	4	Tariff D	Residential	D
22	ToU	1/1/2015	12/31/2022	9-17	12.5	9	2	4	Tariff D	Residential	D
23	ToU	1/1/2015	12/31/2022	20-23	12.5	9	2	4	Tariff D	Residential	D

Fig. 3. Edit tariffs

## 4 EL-Supplier: Consume management module

This module is responsible for viewing consumer's profiles, forecasting and optimizing community consumption. It

includes these three functionalities that are going to be presented in detail in the next sub-sections.

### 4.1. Consumer profiles

In the View profiles tab, a group of

consumers affiliated to the selected supplier will be made according to the number of clusters desired for each quarter. A clustering method using k-means is run to group the electricity consumers into consumption groups with similar behaviour.

For example, select the number of profiles (or clusters) for quarter 1 to 3, then press the Confirm parameters button, which displays a message with the data that has just been selected. The next step is to select the number of profiles at the value 2 for the 2nd trimester (as in Fig. 4), then you can confirm and repeat the same steps for the 3rd and 4th trimesters.

Once the parameters have been set and verified, the Remake profiles button will be pressed, which will trigger the determination of the consumer profiles by calling some clustering algorithms.

The screenshot shows a web interface titled 'Management' with a sub-header 'View profiles, forecast and optimize community consumption'. Below this are three tabs: 'View profiles' (active), 'Forecast consumption', and 'Optimize consumption'. Under 'View profiles', there are two sliders: 'Select no of profiles' (set to 2) and 'Select season' (set to 2). Below the sliders, it says 'Supplier = 10 season = 2 and no profiles = 2'. At the bottom are two green buttons: 'Confirm parameters' and 'Remake profiles'.

**Fig. 4.** Selecting the clustering parameters

The result of the analysis will be displayed in tabular form on the same page, specifying for each of the identified profiles the following details: Profile ID, description, type of consumer, quarter (season), off-peak consumption, peak consumption (peak), average hourly consumption and vendor ID. By selecting one of the profiles, details about the consumers associated with that profile will be displayed in a table to the right of the first, as in Figure 5.

The screenshot shows the 'Management' interface with the 'View profiles' tab active. Below the sliders, there are buttons for 'Confirm parameters', 'Remake profiles', and 'Refresh'. The 'Profiles details' table is displayed below. A red box highlights a section titled 'List of consumers associated with the profile:' which shows a table of consumer details for profile 4310.

ID Profile	Description	Type	Season	Off peak consumption	Peak consumption	Average hourly consumption	ID Supplier
3110	residential	residential	3	0.6	1.348	1.028	10
3210	residential	residential	3	1.597	4.903	3.07	10
3310	residential	residential	3	0.442	5.973	2.178	10
4110	residential	residential	4	0.69	1.354	1.012	10
4210	residential	residential	4	3.494	6.959	5.44	10
1110	residential	residential	1	1.408	5.776	2.603	10
1210	residential	residential	1	6.729	13.079	10.232	10
1310	residential	residential	1	0.864	1.584	1.24	10
4310	residential	residential	4	1.057	4.565	1.983	10
2110	residential	residential	2	0.753	1.841	1.236	10
2210	residential	residential	2	1.664	5.642	2.933	10

ID Consumer place	ID Profile	Season
H11	4310	4
H4	4310	4
H5	4310	4
H6	4310	4

**Fig. 5.** The resulting profiles and a list of consumers associated with each profile

#### 4.2. Consumption forecast

The electricity forecast is influenced by the weather conditions, the time interval, the season, the type of day (working / weekend), but also by the consumption profile. The electricity consumption is

estimated daily for the next 24-hour period for each previously determined consumption profile. To do this, select the day and month for which you want to make the consumption prediction, select the profile and then run the prediction model. Hourly

estimates can be viewed and analyzed by the supplier in tabular and graphical form. The supplier may decide to resume the prediction process for the other consumption profiles. The power consumption prediction model is implemented in Python and can be called within the prototype in the form of a web

API [8]. For example, in Fig. 6 the profile with ID = 1112 was chosen and the supplier with ID = 12 was selected on 10/01/2019, then the data were confirmed and the prediction algorithm was run. The results obtained are displayed in tabular and graphic format (Fig. 6).

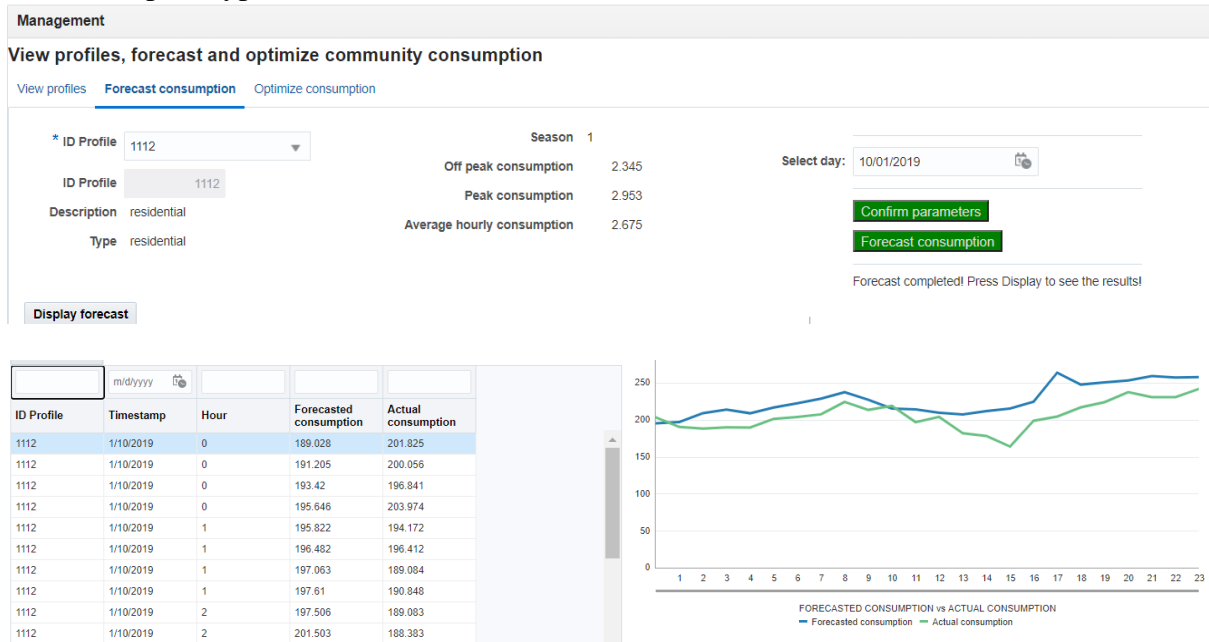


Fig. 6. Results of the forecast algorithm presented in parallel with Actual consumption

#### 4.3. Consumption optimization

In order to optimize the electricity consumption at the supplier level for the next day (day-ahead optimization), four algorithms were implemented, in Matlab and in Python respectively, which use different methods and approaches aiming at flattening the consumption curve at the aggregate level [9].

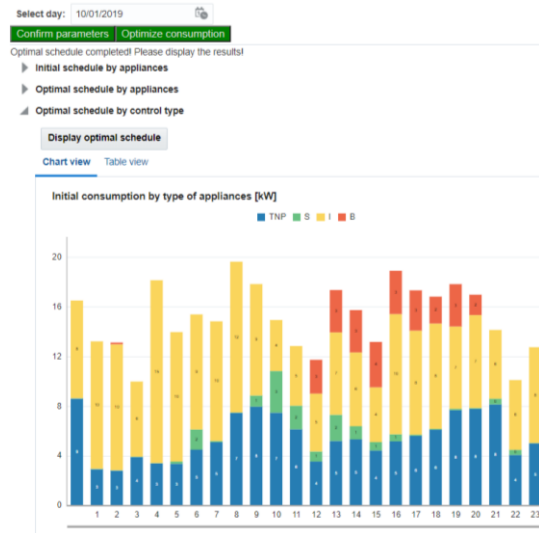
Each consumer submits for the next day an initial planning of the consumption of programmable devices. Based on the characteristics of the devices (type, maximum consumption, operating steps), electricity consumption estimation, programmable device planning and tariff plans applied to each place of consumption, the algorithms will determine an optimal next day consumption plan for each consumer. so that at the aggregate level the consumption curve is flattened. The

supplier analyzes and compares the schedule determined by each algorithm and chooses the optimal plan for the next day.

The Initial schedule is displayed first depending on the type of control, which highlights the initial consumption at each time interval (Fig. 7).

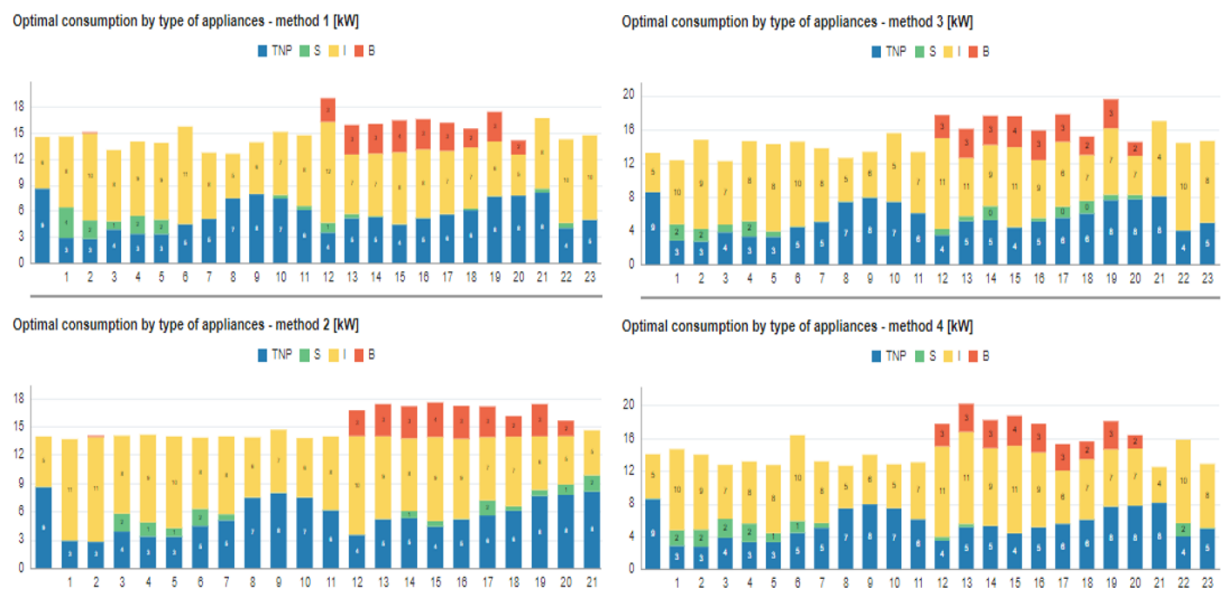
The optimization results are grouped into 3 categories, as seen in Fig. 7: Initial schedule by appliances, Optimal schedule by appliances, Optimal schedule by control type. The Optimal schedule by control type option is the one selected by default, where the control type can take the values:

- NPT - devices whose operation cannot be interrupted and cannot be shifted,
- S - shiftable devices,
- I - devices whose operation can be interrupted and can be shifted,
- B - batteries.



**Fig. 7.** Initial consumption by appliances type as a graph, and Table view - allows tabular display of data.

Since the optimization was performed by 4 methods, the results of each of them are presented in the form of a graph, as can be seen in Fig. 8.



**Fig. 8.** Optimal consumption by type of appliances by four methods

The Initial schedule by appliances option displays in tabular form the initial device scheduling data for the selected date, displaying for each device the control type, ID, estimated consumption, flexibility, start time, and end time of consumption.

The Optimal schedule by appliances option displays in tabular form for each device the time at which the consumption will take place, the initial consumption and the optimal consumption determined, also based on four optimization algorithms. Such an example is illustrated in Fig. 9.



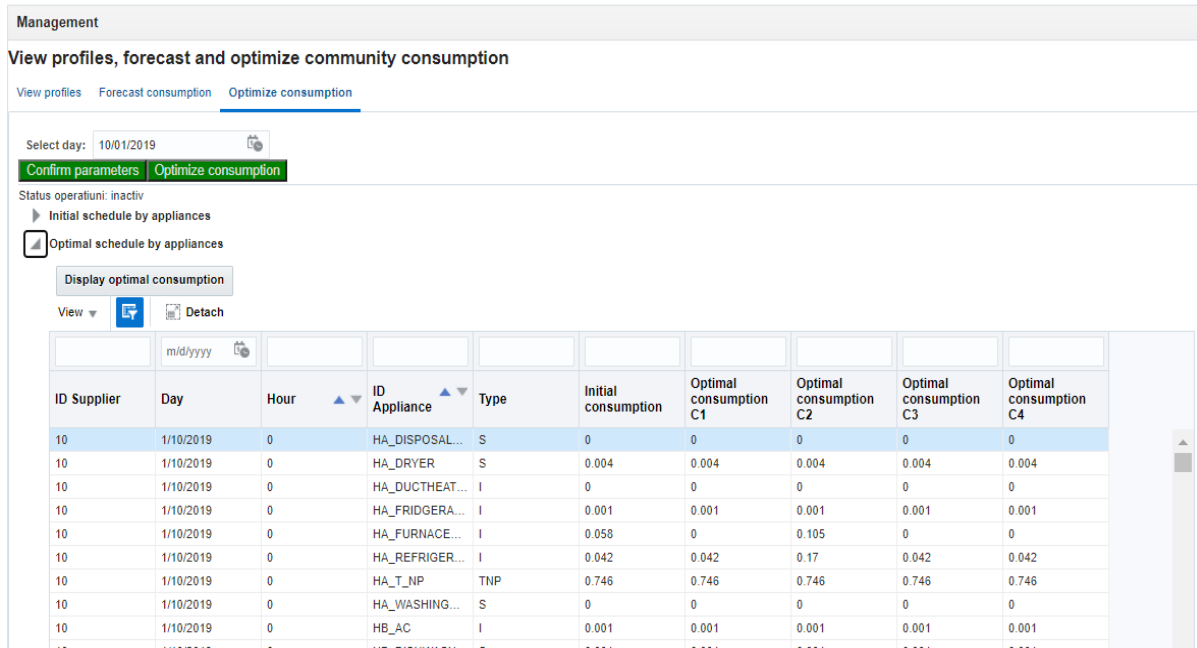


Fig. 9. Display optimal schedule by appliances

## 5 Conclusions

In order to meet the needs of power suppliers, the authors of this paper have developed a specialized software platform. The software product is designed to perform analysis of historical values, and to elaborate consumers' profile clustering, consumption forecasts and optimization, all for supporting the power suppliers in identifying the necessary information and take the right decisions.

The presented software solution contains the components necessary for the management of electricity consumption, the supplier performing the following activities:

- Manages consumer data based on supply contracts for each place of consumption and type of consumer;
- Carries out consumption profiles based on the clustering model;
- Establishes the tariff plans allocated for each place of consumption;
- Configures smart meters to measure electricity consumption;
- Monitors in real time and for different periods of time the readings recorded by

smart meters;

- Monitors in real time and for different periods of time the readings recorded by electrical devices depending on the access granted by consumers;
- Access the prediction model to estimate electricity consumption over different time periods.
- Access power consumption optimization models for optimal planning for the next 24 hours (day-ahead optimization);
- Accesses the electricity consumption optimization model for real-time flattening of peak consumption (dynamic and real-time optimization).

In addition to these elements, integration with an advanced analysis module was achieved.

The dashboards developed based on the data from the EL-Supplier module allow the visualization of the consumption history and the deviations between the forecasted values and the real consumption according to different criteria, and substantiate the strategies for applying the tariff plans according to the consumption profiles.

## 6 Acknowledgment

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## Electricity Consumption Management Software Tool for Consumers - MY SMART HOME

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*In the introductory part, this paper summarizes the main aspects related to smart homes and home energy management (HEM) technologies and presents several existing HEM solutions. The proposed Electricity consumption management software tool for consumers - MY SMART HOME allows the management of the types of devices that facilitate the monitoring and optimization of electricity consumption: meters, smart devices, and sensors. A process for optimal scheduling of the devices was implemented, through a series of seven steps to be followed by the user. Some reporting solutions, both in graphical and tabular form, for analyzing the initial and optimal consumption per device, consumption place and household are offered.*

**Keywords:** power sector, smart homes, software, energy consumption, optimization.

### 1 Introduction

Smart homes have been, over the last decade, a priority area related to strategic energy planning. In European Union's Strategic Energy Technology Plan, it is stated that "the Commission's vision for the electricity market aims to deliver a new deal for consumers, smart homes and network, data management and protection" [1].

Smart home technologies consist of a variety of devices such as sensors, monitors, interfaces, appliances that are networked together to enable automation along with localized and remote control of the domestic environment [2]. The results of a survey regarding the perceived benefits and risks of smart home technologies (SHTs) revealed that the survey respondents clearly perceive the main purpose of SHTs to be controlling energy, heating and appliances, indicating that the smart home is mostly seen through an energy management lens [3].

The emergence of electrical devices for end consumers, whose operation can be

programmed, has led to increased interest in IT solutions for consumer management at the household level. A study presented in [4] explored a vast range of home energy management (HEM) technologies on the market and identified how their functionalities may support energy reductions and load shifting opportunities. The aim of the study was to identify the technical capabilities and potential for HEM products to deliver savings, hence considerably increasing user's understanding on how HEM technologies could be, in fact, leveraged for energy savings.

As stated in [5], the popularity of HEMs has been substantially in recent years due to a series of advantages offered by smart phone and tablet connectivity, such as high accessibility, convenience, and affordability. Also, it presents an introduction and description for the overview of HEMs architecture, as well as a detailed investigation on the functions of renewable energy, home appliances and demand response in HEMs. It is shown that solar energy is a main contributor to home energy

consumption, while the wind, biomass and geo-thermal energy often contribute relatively less and limited due to urban geography and climate factors.

The approach presented in [6] uses price-based demand response (DR) programs, which pursue the involvement of end-user's participation in the distribution system operation. Since the residential demand is a significant portion of the total system load, residential DR programs are important from the system operator's perspective. The basis of DR programs is the intention of the system operator to create an electricity tariff or an incentive in order to encourage customers to voluntarily adjust their regular electrical consumption patterns. This method is based on prioritizing the operation of controllable appliances from the customer's perspective by considering the value of lost load of each appliance, electricity tariffs, and operational constraints of appliances. The output of the proposed HEM would be the optimum scheduling of household electrical demand. Furthermore, the research presented in [7], indicates that in controlling end-user assets, independently taken decisions can cause undesired effects such as rebound peaks, contingencies, and instabilities in the network. Also, it reviews, compares, and classifies approaches related to demand-side management and DR in a single household and concepts of coordinating mechanisms in a neighbourhood area. It is shown that recent research in the field reveal that the coordination of energy management in multiple households can bring benefits to both the customer and the system operator.

In the Energy Management System for smart homes proposed by [8] each home device is interfaced with a data acquisition module that is an IoT object with a unique IP address resulting in a large mesh wireless network of devices. There is a dedicated module which collects energy consumption data from

each device of each smart home. Further, data are transmitted to a centralized server for additional processing and analysis using off-the-shelf Business Intelligence (BI) and Big Data analytics software packages. In order to validate the proposed system, heating, ventilation and air conditioning units have been used as a case study.

## **2 Presentation of usage options**

The paper presents the main functionalities and characteristics of a proposed Electricity consumption management software tool for consumers - MY SMART HOME. The tool enables the management of various types of devices that facilitate the monitoring and optimization of electricity consumption in a smart home: meters, smart devices, and sensors.

Two sections are used in the main page of the prototype for general settings purposes (as in figure 1): a section for editing personal data and a section that allows the management of consumption places.

The personal data editing section allows the editing and updating of consumer data. Several details about a consumer can be entered: data regarding the type of consumer (which is chosen from a predefined list), the customer's name (required field), postal and email addresses, contact telephone number, bank account and location.

The second section of the first page allows the management of consumption places associated with a consumer. These are highlighted in the following figure. The user has the possibility to add, modify or delete information about a certain consumption place. This information includes: ID of the place of consumption, a suggestive name, the start date (which must be entered in the format highlighted when accessing the field), the period of validity of the contract, expressed in months, details of the type of consumption place, consumption location and energy supplier. For the last four fields, the user will be able to select the entered data via a list of values.

The user can add, update, or delete a

consumption place. Also, on this page, the user can view the consumption places that he has entered sorted according to the desired criteria. Thus, by placing the mouse over the name of a field in the list, two buttons will become visible that allow ascending data sorting or

descending sorting of data depending on the values of that field. To access the electrical devices associated with a consumption place, the user selects the desired consumption place of from the list and then clicks on the *View details* option on the left side of the window.

**Fig. 1. Home page – Section for consumption place management**

**Fig. 1.** Home page – Section for consumption place management

A window will be displayed in which the facilities offered by the module for managing a consumption place can be used. These facilities can be accessed via tabs a series of different tabs dedicated to a certain component of the module, as follows:

- Smart meters
- Smart devices
- Sensors
- Tariffs
- Optimal programming of devices
- Consumption distribution analysis
- Supplier recommendations
- Devices control

### 3 Smart meters management

The first tab, Smart meters offers, through the Meter administration section, the possibility to manage the meters

associated with a consumption place. For a meter, information about the installation date and installation start date is stored, type (is selected from a list of values), maximum rated power, current specification, model, ip, mac, and gateway. It is possible to add, update and delete information about a smart meter.

The user can access information on electricity consumption evolution and total generation over time in a graphical form. The user selects, by the means of a calendar, the start date, and the end date for which he wants to view the consumption information. A graph (shown in the figure 2) on the consumption evolution and total generation over time will be displayed.

The vertical axis of the graph shows the active power consumed and (if applicable) the active power generated, and the horizontal axis shows time intervals of 15 minutes for the previously selected period. By placing the mouse over the surface of the graph and using the scroll wheel of the

mouse, the user can view the evolution of consumption for the entire period previously selected.

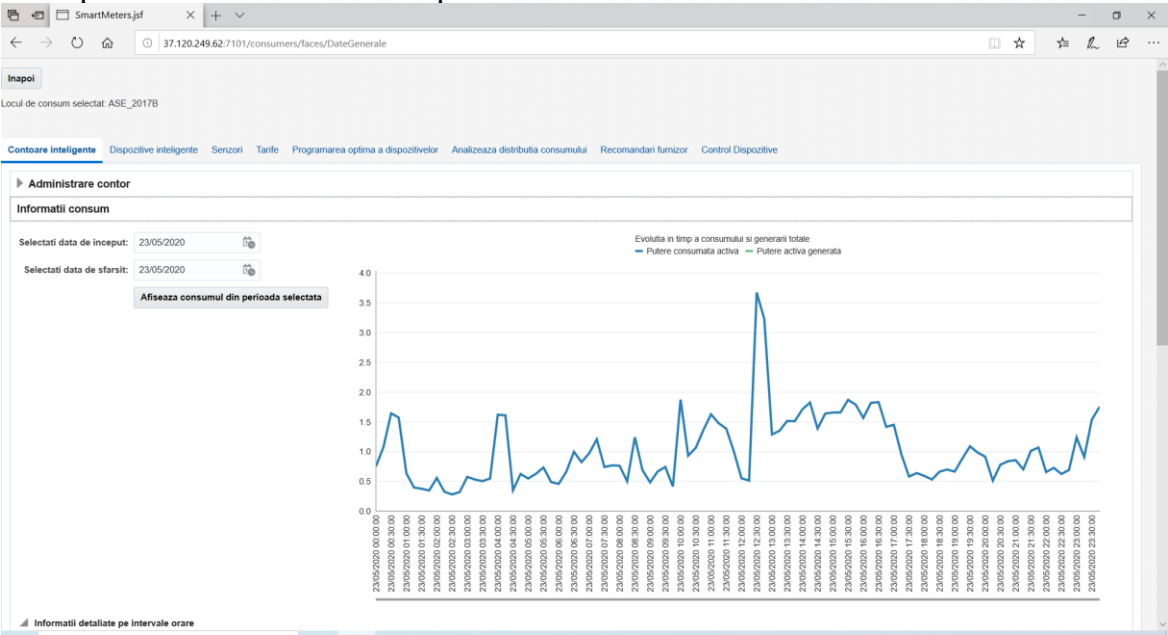


Fig. 2. Consumption information section from Smart Meters tab

Detailed information on consumption, are also presented in tabular form). In the table shown in figure 3, the user can view information on: day and time, meter ID that recorded the measurements, power consumed and generated, status, validity, measurements on voltage, current and total power, and possible error codes. The data in this table can be sorted by any of

its fields, except Day/Time. By placing the mouse over the name of a field in the list, two buttons become visible that allow ascending data sorting or descending sorting of data depending on the values of that field. Also, once data are sorted, their visual representation will be updated (as shown in figure 3).

Informatii detaliate pe intervale orare										
Ziua/Ora	ID Contor	Putere consumata activa	Putere activa generata	Status	Valid	Tensiune (Mv)	Curent (Ma)	Putere totala (Wh)	Cod eroare 1	Cod Eroare 2
23/05/2020 00:00:00	12	0.751		ACTUAL	YES					
23/05/2020 00:15:00	12	1.08		ACTUAL	YES					
23/05/2020 00:30:00	12	1.646		ACTUAL	YES					
23/05/2020 00:45:00	12	1.575		ACTUAL	YES					
23/05/2020 01:00:00	12	0.638		ACTUAL	YES					
23/05/2020 01:15:00	12	0.399		ACTUAL	YES					
23/05/2020 01:30:00	12	0.379		ACTUAL	YES					
23/05/2020 01:45:00	12	0.35		ACTUAL	YES					
23/05/2020 02:00:00	12	0.56		ACTUAL	YES					
23/05/2020 02:15:00	12	0.329		ACTUAL	YES					
23/05/2020 02:30:00	12	0.283		ACTUAL	YES					
23/05/2020 02:45:00	12	0.323		ACTUAL	YES					
23/05/2020 03:00:00	12	0.578		ACTUAL	YES					
23/05/2020 03:15:00	12	0.534		ACTUAL	YES					
23/05/2020 03:30:00	12	0.507		ACTUAL	YES					
23/05/2020 03:45:00	12	0.552		ACTUAL	YES					
23/05/2020 04:00:00	12	1.623		ACTUAL	YES					
23/05/2020 04:15:00	12	1.612		ACTUAL	YES					
23/05/2020 04:30:00	12	0.352		ACTUAL	YES					
23/05/2020 04:45:00	12	0.627		ACTUAL	YES					
23/05/2020 05:00:00	12	0.551		ACTUAL	YES					
23/05/2020 05:15:00	12	0.628		ACTUAL	YES					
23/05/2020 05:30:00	12	0.736		ACTUAL	YES					
23/05/2020 05:45:00	12	0.492		ACTUAL	YES					
23/05/2020 06:00:00	12	0.461		ACTUAL	YES					

Fig. 3. Table of detailed information by time intervals for a device (meter)

The text boxes placed above the table fields help to filter the data. Thus, the value



according to which you want to filter the data of a field will be placed in the corresponding text box and then Enter key will be pressed. Data can be filtered simultaneously by multi-field values.

#### 4 Smart devices management

The Smart devices tab allows the user to manage smart devices assigned to a

consumer location (section Device management) and is shown in the following figure. It should be noted that the consumption place was previously selected on the first page of the module. It is also possible to view information about the consumption of a smart device in section Device consumption information.

	Dispozitiv	Model	Descriere	Mac	Produsator	Status	ID loc consum	Serial No	Putere nominala consumata	Specificatii curent	Tip	Denumire	Alia
<a href="#">Detalii</a>	ASE_2017B_1	Microwave	Microwave				ASE_2017B		2		Microwave	Microwave 2017	Mic
<a href="#">Detalii</a>	ASE_2017B_2	Vacuum Cleaner	Vacuum Cleaner				ASE_2017B		0.024		Accumulator De	Vacuum Cleaner	Vac
<a href="#">Detalii</a>	ASE_2017B_3	Light1	Light1				ASE_2017B		2		Light	Light	Ligh
<a href="#">Detalii</a>	ASE_2017B_4	Light2	Light				ASE_2017B		2		Light	Light	Ligh
<a href="#">Detalii</a>	ASE_2017B_5	Light	Light				ASE_2017B		2		Light	Light	Ligh
<a href="#">Detalii</a>	ASE_2017B_T_...	Consum backgn	Consum backgn				ASE_2017B		5		Neprogramabil	Consum backgn	Cor

**Fig. 4.** Smart devices tab overview - Device management section

The following information about a smart device can be stored: device name (cannot be updated), model, description, Mac, manufacturer, status, consumption location ID, serial number, rated power consumption, current specifications, type, extended name, alias, control type (selected from a list), if controllable (selected from a list), under control type, power generated, device ID, IS Total.

In this window the user can add, modify, or delete smart devices associated with a consumption place.

Sorting is allowed according to any of the fields. At this level it is also possible to filter data, using the text boxes placed above the fields. By clicking the *Details* link on the left side of the smart device row, the user can add additional details

about a smart device.

#### 5 Sensors management

The Sensors tab, presented in the figure below, allows the management of the sensors associated with a consumption place.

It is possible to store the following sensor related information: name, description, current specifications, installation date and monitoring start date, device ID, MAC, model, maximum rated power, type, gateway.

The user can add, modify, or delete sensor devices associated with the selected consumption place.

At the same time, the data in the sensor records can be sorted according to any of its fields, using the buttons that appear next to the field names in the table header.

Denumire	Descriere	Specificatii curente	Data instalare	Data inceput	ID Dispozitiv	MAC	Model	Putere nominala maxima	Tip	Gateway	Salvați
HS110_1	Smart Wi-Fi Plus	16	1/1/2019	1/1/2019		0C-80-63-DD-5E	TP-LINK HS110	3500	IOT.SMARTPLU	RP2	Salvați
HS110_2	Smart Wi-Fi Plus	16	1/1/2019	1/1/2019		0C-80-63-DD-5E	TP-LINK HS110	3500	IOT.SMARTPLU	RP2	Salvați
HS110_3	Smart Wi-Fi Plus	16	1/1/2019	1/1/2019			TP-LINK HS110	3500	IOT.SMARTPLU	RP1	Salvați
HS110_4	Smart Wi-Fi Plus	16	1/1/2019	1/1/2019			TP-LINK HS110	3500	IOT.SMARTPLU	RP1	Salvați
HS100	Smart Wi-Fi Plus	16	1/1/2019	1/1/2019			TP-LINK HS100	3500	IOT.SMARTPLU	RP1	Salvați

Fig. 5. Sensors information management tab

## 6 Tariffs management

Figure 6a shows the Tariffs tab, having the role of allowing the visualization of the electricity tariffs that will be applied for the respective consumption place. The start date and end date for which a tariff plan applies are displayed, as well as the

applicable time slot.

By accessing the Plan details link on the left side of the information regarding a tariff plan, other details can be viewed, such as those related to the tariff applied for consumption or for generation (Figure 6b).

	DateStart	DateEnd	Hour	A1	A2	A3	A4	A5
Detalii plan	1/1/2015	12/31/2022	0-23	1	9	ToU	Standard	E

a)

Detalii ale tarifulor aplicate pentru locul de consum	
Tip Tarif	Standard
Data de la care se aplica	1/1/2015
Data pana la care se aplica	12/31/2022
Interval orar recomandat	0-23
Tarif consum	14.1
Tarif generare	9
A1	1
A2	1
A3	Tarif standard residential
A4	Residential
A5	E

b)

Fig. 6. Tariffs applied to a consumption place



## 7 Optimal scheduling of devices

The Optimal device scheduling tab allows the user to program smart devices as well as to optimize their operating schedule. The page also includes an information section showing the steps that must be followed to obtain an optimal device scheduling.

To display existing smart device schedules, the user must select the schedule day by directly entering a value in the specified format or using the calendar that appears. The scheduling of

smart devices for the selected place of consumption will be displayed, if any (figure 7).

The smart device view section presented in the next figure displays the following information about a device: the date it was scheduled, device ID, name, type, start time, stop time, vendor estimate, power generated estimated power, estimated power consumption, degree of flexibility, rated power, whether rated power is used and whether the program has been transmitted to the equipment.

Data programarii	ID Dispozitiv	Denumire	Tip	Ora de pornire	Ora de oprire	Estimat de furnizor	Putere generata estimata	Putere consumata estimata	Grad flexibilitate	Putere nominala	Utilizeaza puterea nominala	Transmis catre echipament
5/23/2020	ASE_2017B_1	Microwave 2017B	S	2020-05-23 18:00	2020-05-23 20:00	1		2	0	2		1
5/23/2020	ASE_2017B_2	Vacuum Clean...	I	2020-05-23 20:00	2020-05-23 23:00	1		0.024	1	0.024		1
5/23/2020	ASE_2017B_3	Light	I	2020-05-23 19:00	2020-05-23 22:00	1		2	1	2		1
5/23/2020	ASE_2017B_T_...	Consum backgr...	TNP	2020-05-23 00:00	2020-05-23 01:00	1		1.022	0	5		1
5/23/2020	ASE_2017B_T_...	Consum backgr...	TNP	2020-05-23 01:00	2020-05-23 02:00	1		0.627	0	5		1
5/23/2020	ASE_2017B_T_...	Consum backgr...	TNP	2020-05-23 02:00	2020-05-23 03:00	1		0.449	0	5		1
5/23/2020	ASE_2017B_T_...	Consum backgr...	TNP	2020-05-23 03:00	2020-05-23 04:00	1		0.462	0	5		1
5/23/2020	ASE_2017B_T_...	Consum backgr...	TNP	2020-05-23 04:00	2020-05-23 05:00	1		0.638	0	5		1
5/23/2020	ASE_2017B_T_...	Consum backgr...	TNP	2020-05-23 05:00	2020-05-23 06:00	1		0.96	0	5		1
5/23/2020	ASE_2017B_T_...	Consum backgr...	TNP	2020-05-23 06:00	2020-05-23 07:00	1		1.147	0	5		1
5/23/2020	ASE_2017B_T_...	Consum backgr...	TNP	2020-05-23 07:00	2020-05-23 08:00	1		1.406	0	5		1

Fig. 7. View the scheduling of the devices for a consumption place

The functionalities offered for the optimal scheduling of the devices will be described, following the seven steps specified in the information section.

### Step 1. Program the devices

Using the device scheduling section, presented in the figure 8, involves selecting the smart device for which the scheduling is done. It is followed by: selecting the scheduling date, start time and stop time, selecting options to use the rated or estimated power of the supplier, enter values for the estimated consumed and generated powers and select the degree of flexibility by choosing one of the available options (Fixed, Reprogrammable at home or Reprogrammable by the supplier).

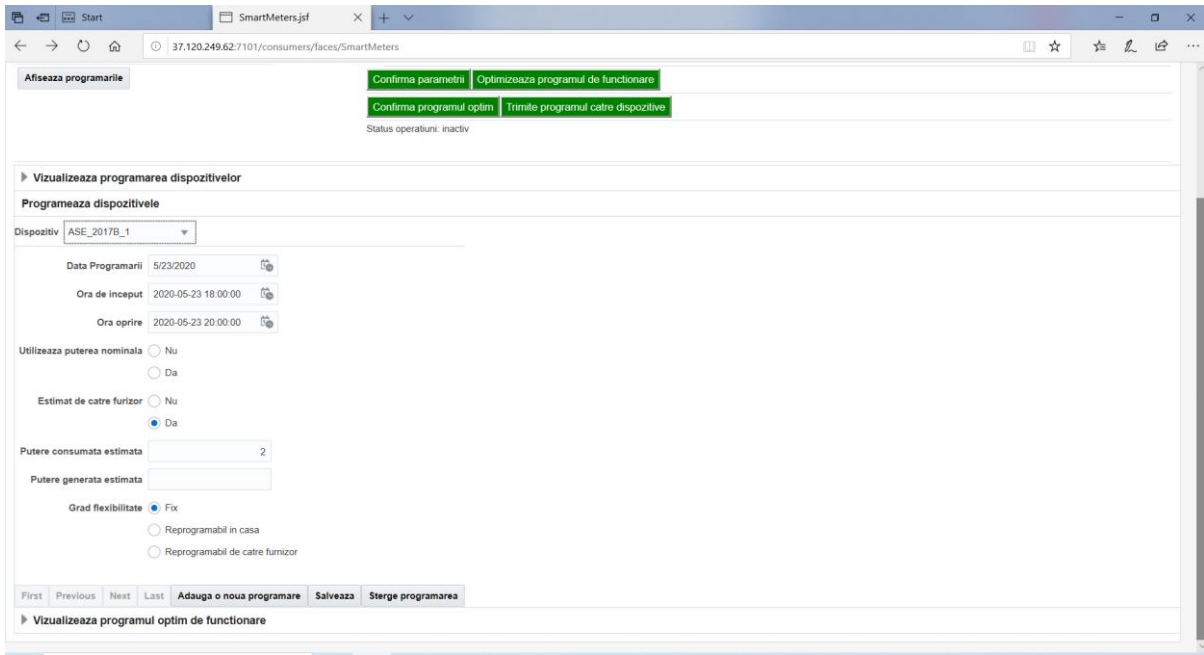
Also, the user may add a new schedule for a device, delete the currently displayed schedule, or browse existing schedules.

### Step 2. Confirm the parameters

The user confirms the required parameters for smart devices scheduling. After confirming the parameters, a message is displayed specifying the day and place of consumption for which the parameters have been confirmed.

### Step 3. Optimize the schedule

The user chooses the option to optimize the schedule. After this, a message is displayed stating that the optimization was successful and that the optimization results can be viewed in the corresponding section.



**Fig. 8.** Smart devices scheduling section

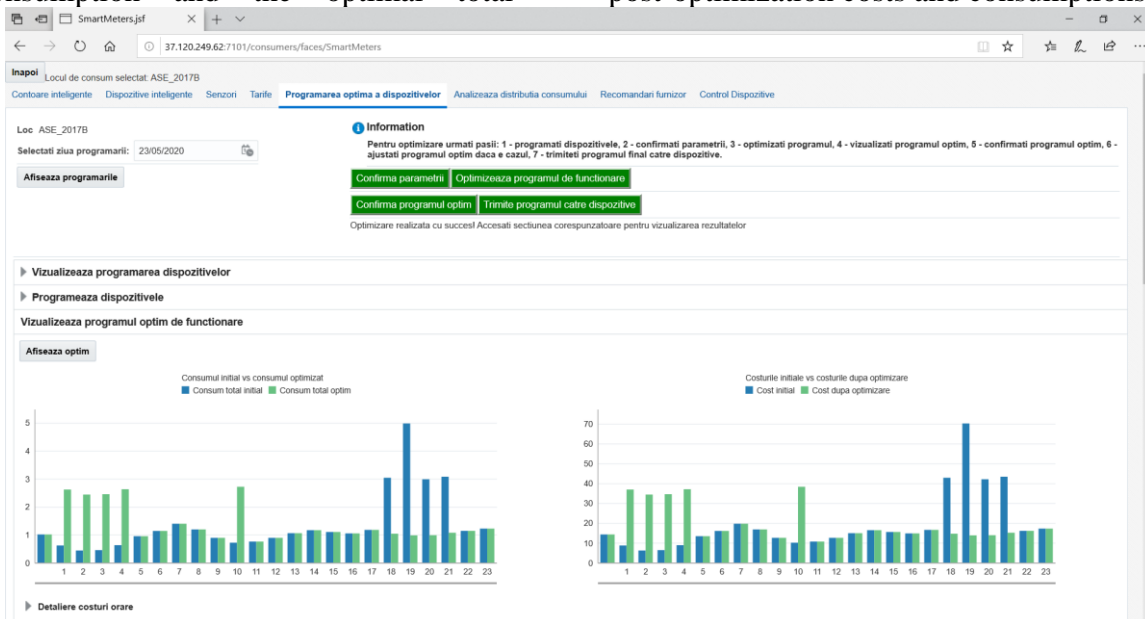
#### Step 4. View the optimal scheduling

The module offers the possibility to view the optimal schedule in either graphical or tabular form.

The graphical form (presented in figure 9) shows two graphs that reflect, for each of the 24 hours of the selected day, the comparative evolution of the total initial consumption and the optimal total

consumption, respectively the comparative evolution of the initial total costs and the optimal total costs.

The tabular form allows the user to view the day and time for which the direct costs are displayed, the name of the tariff, the tariff type, the consumption and generation tariff for each hour, as well as the total initial and post-optimization costs and consumptions.



**Fig. 9.** Graphical representations regarding the evolution of initial costs / consumptions versus optimized costs / consumptions

The module provides the facility to analyze the optimal operating schedule

for smart devices, in terms of consumption places of the house.

As seen in figure 10, presentations in graphical form and in tabular form are available in the corresponding section for optimal scheduling at house level.

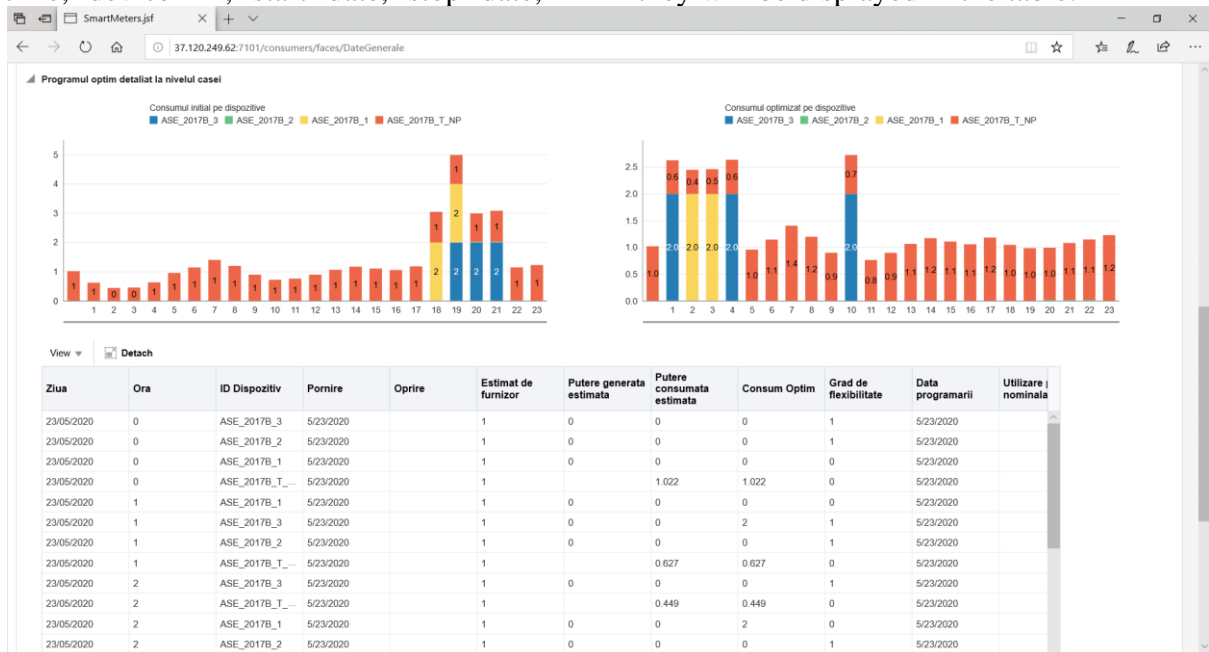
Two graphs allow the visualization of the initial consumption for each device and of the consumption optimized per device for every hour of the day for which the optimization was performed. The adjacent layout of the graphs offers the user the possibility to perform a comparative analysis between the initial situation and the one after optimization.

Also, the table in the same figure offers the possibility to view in detail the hourly consumption, from the analyzed day, for each smart device identified in the selected home. The following fields can be viewed in the table: analyzed day, time, device ID, start date, stop date,

estimated by the vendor, estimated and consumed overall power, optimal consumption, degree of flexibility, scheduling date, rated power usage and transmitted in fog.

The table provides some advanced viewing options via the *View* menu. Thus, by selecting the *Columns* option, the user can choose to display all the columns of the table (*Show All* option) or can check only certain columns.

There is also the option to arrange the columns of a table in the order you want, by clicking on the *View* button followed by selecting the *Reorder Columns...* option from the menu. A window containing all the visible columns of the table will be displayed. The order in which the columns appear in this list is also the order in which they will be displayed in the table.



**Fig. 10.** Graphical view of the initial and optimal consumption per device

#### Step 5. Confirm the optimal schedule

After the user confirms the optimal schedule, a message is displayed specifying that the optimal program for the previously selected day and place of consumption has been confirmed.

#### Step 6. Adjust the optimal schedule, if necessary

If the user wishes, he can return to Step 1. Program the devices to change the

optimal scheduling of the devices.

#### Step 7. Send the final schedule to the devices

The user sends the final schedule to the devices. After this action, a message is displayed stating that the devices have been scheduled for the previously selected day and consumption place.

After completing these seven steps, the result is an optimal consumption schedule at the household level, which can be customized.

## 8 Consumption distribution analysis

Consumption distribution analysis tab allows the visualization, in graphical and tabular form, of the initial and optimal consumption on types of smart devices. The user must select the day for which the consumption distribution is to be analyzed.

Two graphs (shown in figure 11) allow the visualization of the initial

consumption by types of devices and the optimal consumption by types of devices for each hour of the previously selected day.

Each type of device is highlighted with a distinct color in the bar graphs. The adjacent arrangement of the graphs offers the user the possibility to perform a comparative analysis between the initial and the optimal consumption by types of devices.



**Fig. 11.** Graphical view of initial and optimal consumption by device types

The tabular view from figure 12 below, offers the possibility to view in detail the initial and optimal hourly consumption for the analyzed day, aggregated on each

type of smart device identified in that home. The table can display the date of scheduling, time, device type, initial consumption, and optimal consumption.

Data programarii	Ora	Tip dispozitiv	Consum initial	Consum optim
5/23/2020	17	TNP	1.185	1.185
5/23/2020	18	TNP	1.048	1.048
5/23/2020	19	TNP	0.988	0.988
5/23/2020	20	TNP	0.971	0.971
5/23/2020	21	TNP	1.06	1.06
5/23/2020	22	TNP	1.125	1.125
5/23/2020	23	TNP	1.231	1.231
5/23/2020	0	S	0	0
5/23/2020	1	S	0	0
5/23/2020	2	S	0	2

**Fig. 12.** Visualization in tabular form of the initial and optimal consumption by types of devices

The meaning of the acronyms in figure 11 and figure 12 is as follows:

- TNP - total consumption of non-programmable devices (devices that cannot be optimized);
- S - total consumption of reprogrammable devices (shiftable), with the restriction that the operating cycle must be taken into account (for example, the washing machine can be moved to another time only by respecting its operating cycle);
- I - total consumption of devices that can be interrupted and resume their operating cycle at another time (for

example the charging vacuum cleaner).

## 9 Devices control

In the devices control tab presented in figure 13, the user can view the current schedules of a selected device for a certain day, in tabular form.

Information about scheduling a device includes scheduling date, device ID, start and stop time, estimated by the vendor, estimated power consumed and generated, degree of flexibility, if using nominal power, and SentToFog.

This section allows the user to add a new schedule for the device, to delete a schedule and to turn on or off the selected device.

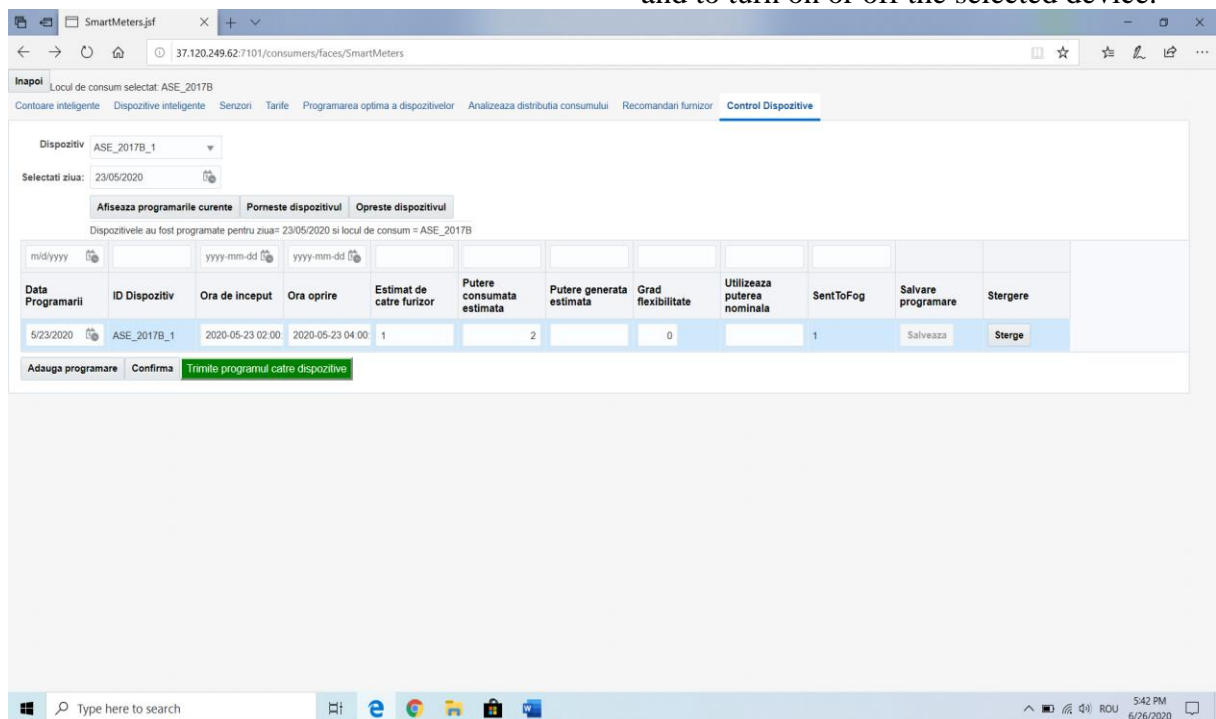


Fig. 13. Presentation of Devices control tab

## 10 Conclusions

Smart homes are a subject of great interest for research in the fields of information technology and smart devices. Efficiency of electricity consumption at the level of a household is an important component regarding the management of smart homes.

The proposed software solution, Electricity Consumption Management Module for Consumers - My Smart Home, offers an integrated approach that deals with the management of various

elements related to electricity consumption such as smart meters, smart devices, sensors, and tariffs.

One of the most important functionalities offered by the module is the optimal schedule of devices, allowing the user to program smart devices along with optimizing their functioning schedule.

For decision support proposes, the module provides various representations that illustrate initial costs/consumptions versus optimized costs/consumptions per device, consumption place or household.

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## Data Analytics for the Transmission System Operators

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*In the beginning the paper briefly presents the worldwide context determined by the global warming phenomenon evolution, and the foreseen impact on the power sector, with the focus on the massive integration of the RES powered electricity generators. Identifying the TSOs and grid operators as the main actors for implementing the necessary changes, the authors of the paper are proposing data analytics, designed to support the TSOs and grid operators in fulfilling their main functions and responsibilities.*

*The structure and the capabilities (analysis and reports) of the software product are presented, including practical examples for usage, and highlighting the potential usefulness of each analyze and/or report, from TSOs and grid operators' point of view.*

**Keywords:** power sector, Renewable Energy Sources, software, Transmission System Operators, grid operator, forecast.

### 1 Introduction

It has been more than a decade since the meteorological specialists sounded an alarm regarding the global warming phenomenon and its potential impact on human life.

Starting with that moment the countries around the world began to become aware about the risks and started to implement measures to prevent as soon as possible this unwanted outcome.

From the beginning, European Union (EU) was among the states that took determined action on the way to prevent the causes of global warming.

The most recent milestone is the approval by the European Commission (EC) of the European Green Deal, in 11<sup>th</sup> of December 2019.

“The European Green Deal is a response to these challenges. It is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is

decoupled from resource use”[1].

The measures proposed in the above-mentioned document [1] are targeting the following area of interest:

- Definition of new EU targets for achieving climate neutrality,
- Providing clean, affordable, and secure energy to its citizens,
- Implementation of clean and circular economy concepts,
- Building construction and energy efficiency,
- Development of sustainable smart mobility,
- Development of fair, healthy and environmentally friendly food system,
- Preservation and restoration of ecosystems and biodiversity,

and others.

In the energy sector, one of the most important measure is to continue the replacement of the electricity generation based on fossil and nuclear fuels with electricity generation based on Renewable Energy Sources (RES).

The route for achieving this challenging

objective started many years ago with the installation of RES powered generators in almost all EU member countries and will continue with the achievement of the new targets established by EC for 2021 – 2030.

The main barriers that need to be overcome are the funds for investments and the technical challenges of the integration into the power systems of large amounts of RES powered generators.

From the technical point of view the RES powered electricity generators (in case of the most significant technologies: wind and photovoltaic) are totally different to the steam or water powered electricity generators (conventional). The conventional electricity generators are rotating synchronous machines while the RES powered generators are convertor based.

Ensuring the compatibility of these two types of technologies, while maintaining the level of safety in operation of the power systems it is a challenging task.

The most important contribution to achieving this task is provided by the Transmission System Operators (TSOs).

## 2 Functions and Responsibilities of the TSOs in EU

According to the EU's law and regulations in force [2], [3] the TSOs have the following exclusive functions:

- to operate and ensure the maintenance of and, if necessary, develop a safe, secure, reliable, economical and efficient electricity transmission system, and to explore and develop opportunities for interconnection of its system with other systems, in all cases with a view to ensuring that all reasonable demands for electricity are met and having due regard for the environment;
- to ensure the availability of all ancillary services which are necessary for the transmission

system operator to carry out its duty outlined in previous paragraph.

- to operate a system of dispatch and use of interconnectors on objective, non-discriminatory, economical, and technical criteria, without prejudice to the supply of electricity based on existing contractual obligations.
- to provide to the operator of any other system with which its system is interconnected sufficient information to ensure the secure and efficient operation, coordinated development and inter-operability of the interconnected system.
- to offer terms and enter into agreements, where appropriate, for connection to and use of the transmission system with all those using and seeking to use the transmission system.

Supplementary to the exclusive functions the TSOs must also prepare a plan (in the following referred to as the “development plan”) for the development of the transmission system in order to guarantee security of supply, which shall relate to a period of 5 calendar years from the date on which the plan is prepared.

The TSOs must, at least once each year revise the development plan, and the revised plan, which shall relate to a period of 5 calendar years following the date on which the plan is revised.

In the context of the significant and continuous increase of the electricity generation based on RES and convertors, the operation of the power systems becomes more and more challenging, both from the complexity and speed of the phenomenon point of view.

The large volume of convertors operating in parallel creates technical conditions never encountered before and increase the complexity of the power systems operation. One of the most important consequence is the significant acceleration of the physical phenomenon that occur during the operation of the power systems.

Considering all the aspects mentioned

above, to support the TSOs to fulfill their functions and responsibilities it is necessary to develop modern software tools, suitable to the new technical environment.

According to [4] and [5] the main responsibilities of the TSOs are related to the following areas:

- electricity demand and generation structure and volume,
- electricity market,
- balancing the demand and generation.

In the following the authors will present the main features and capabilities of a modern software platform designed to support the activity of the TSOs. The platform provides useful tools for analyze and understand the operational situations, as a solid base for taking the right decisions in time.

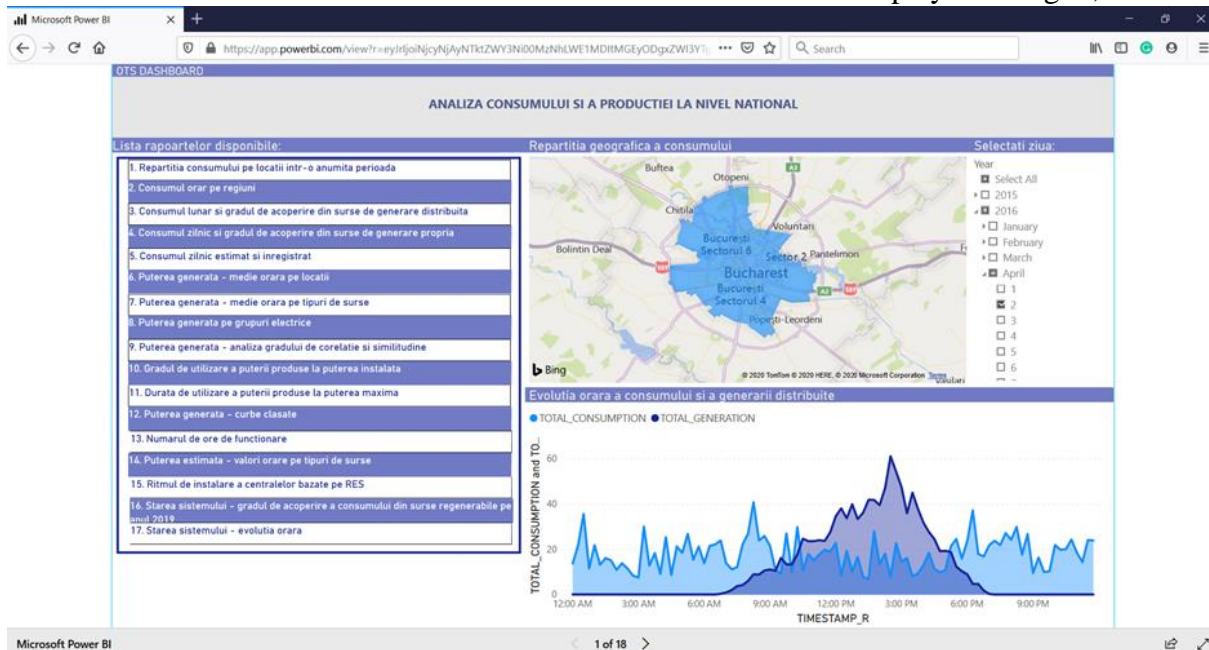
The software is designed to be user-friendly and to provide a large set of options, covering almost all the possible operational situations a TSO may be challenged with.

### 3 Module for demand and generation structure analyses

Understanding the electricity demand and generation structure and behavior is one of the most important pre-requisites for a TSO to properly fulfill its functions. The software platform developed by the authors of this paper [6] is equipped with a module specialized on analyzing and providing support for overcoming the main issues related to this topic.

The input data for this module are the historical values of the electricity demand and generation, for period more than five years.

The “home” window (OTS Dashboard) of this module it is displayed in Fig. 1, below.



**Fig. 1.** OTS Dashboard

Using this module, the user may generate seventeen types of reports regarding the electricity consumption and generation, including:

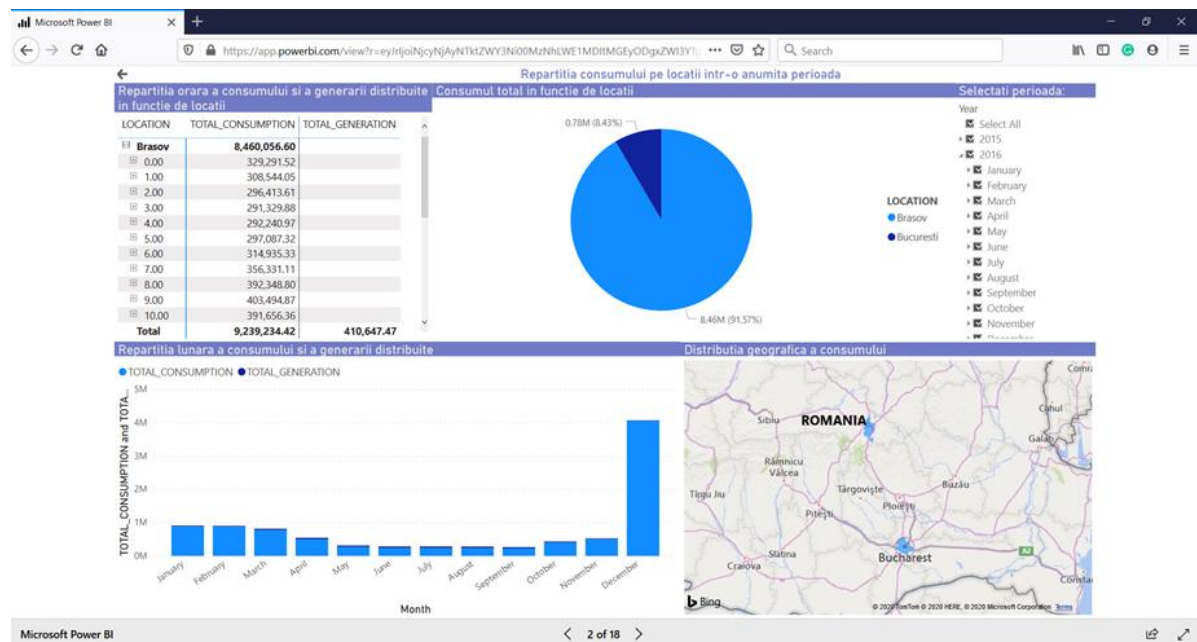
- Time periods: day, month, year.
- Geographical areas: cities, counties.
- Relevant information based on statistic calculations: ranked curves, duration of rated power utilization,

hourly percentage of RES based electricity generation and others.

Based on the analyses of the input data, the module may provide on request forecasts for both electricity consumption and generation. In case of electricity generation, the module focuses on the distributed generation because this type of generation poses the most difficult and complex problems from

the power systems operation point of view.  
Each of the reports are displayed in a

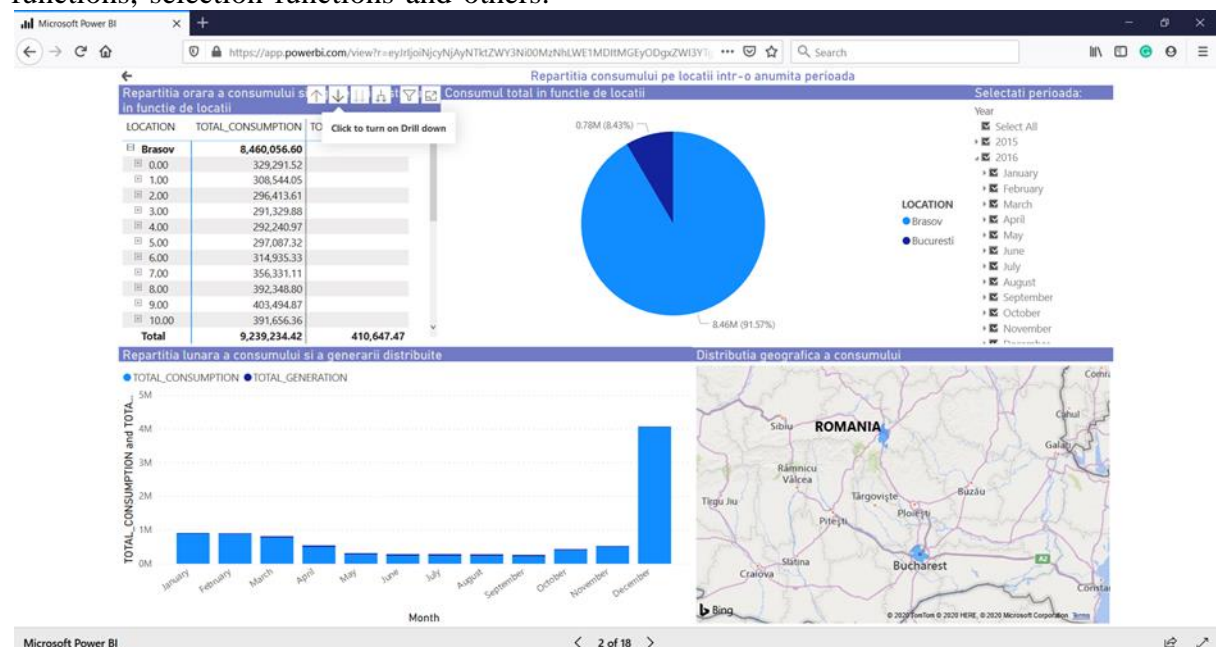
separate window including charts in pie and stacked columns format, and tables. In Fig. 2 below, it is presented an example report.



**Fig. 2.** Report for electricity consumption

Each report window includes editing facilities such as filters, navigation functions, selection functions and others.

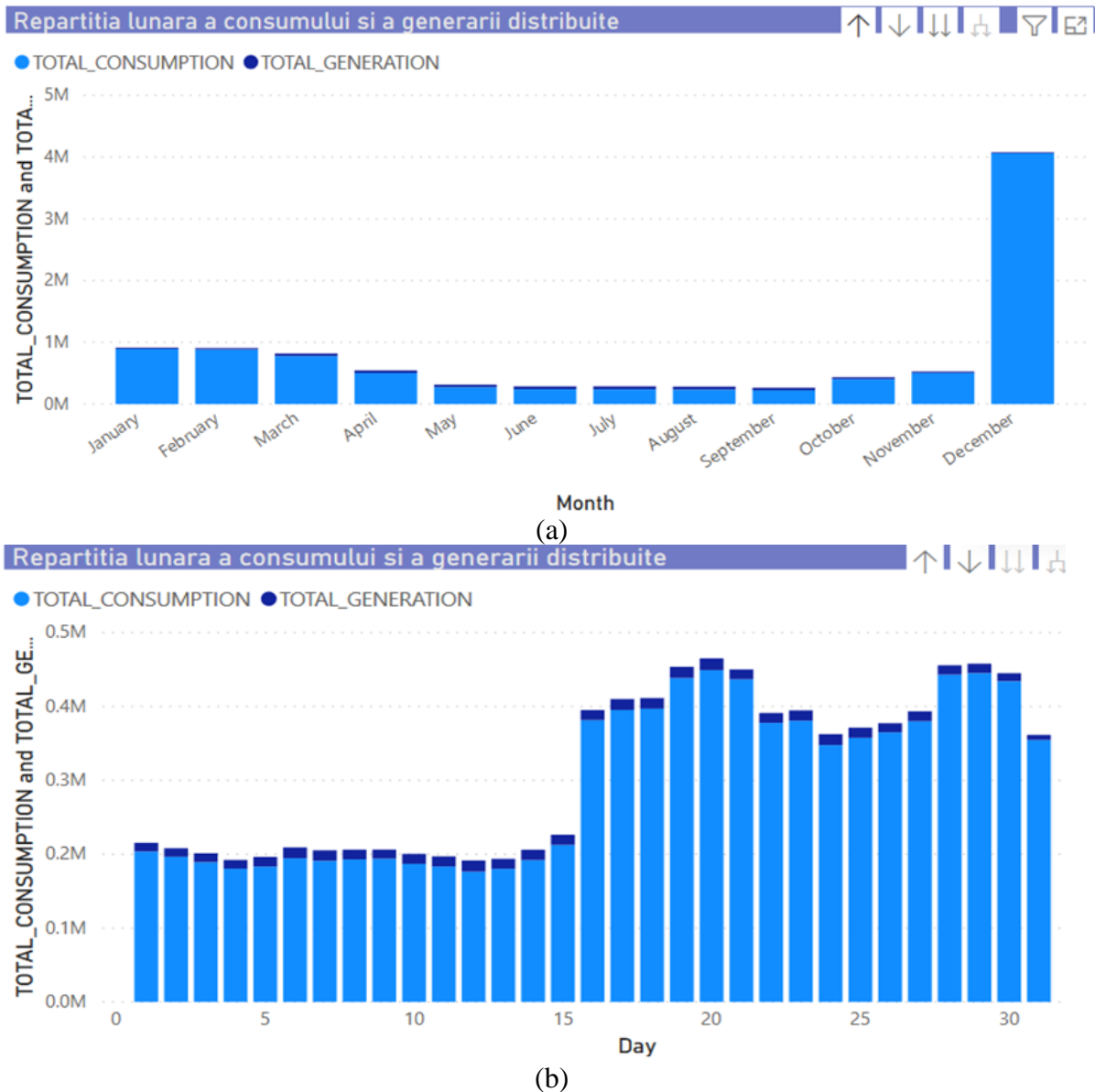
In Fig. 3 below, are presented the editing facilities and the activation commands.



**Fig. 3.** Activation of the editing facilities

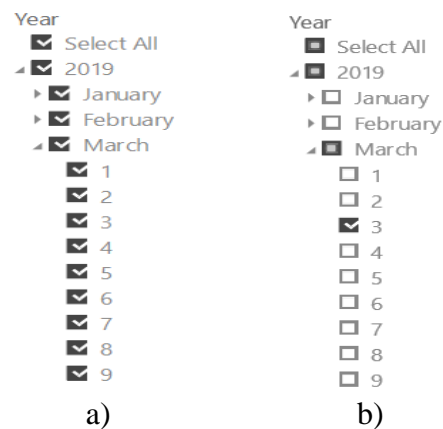
Utilizing the activation commands presented in Fig. 3, the user may change the data included in the tables and the charts format, according to its specific

needs, in a very convenient way. In Fig. 4 below, are presented two types of charts (monthly – a or daily – b) that may be selected by the user according to its needs.



**Fig. 4.** Different charts formats

The selection of the period to be included in the reports is also design in a user-friendly manner. Fig. 5 (selection of full parameters – a or selection of specific parameters – b) below, shows the large margin of possibilities and the respective controls to be used.



**Fig. 5.** Controls for selection of the duration in editing the reports

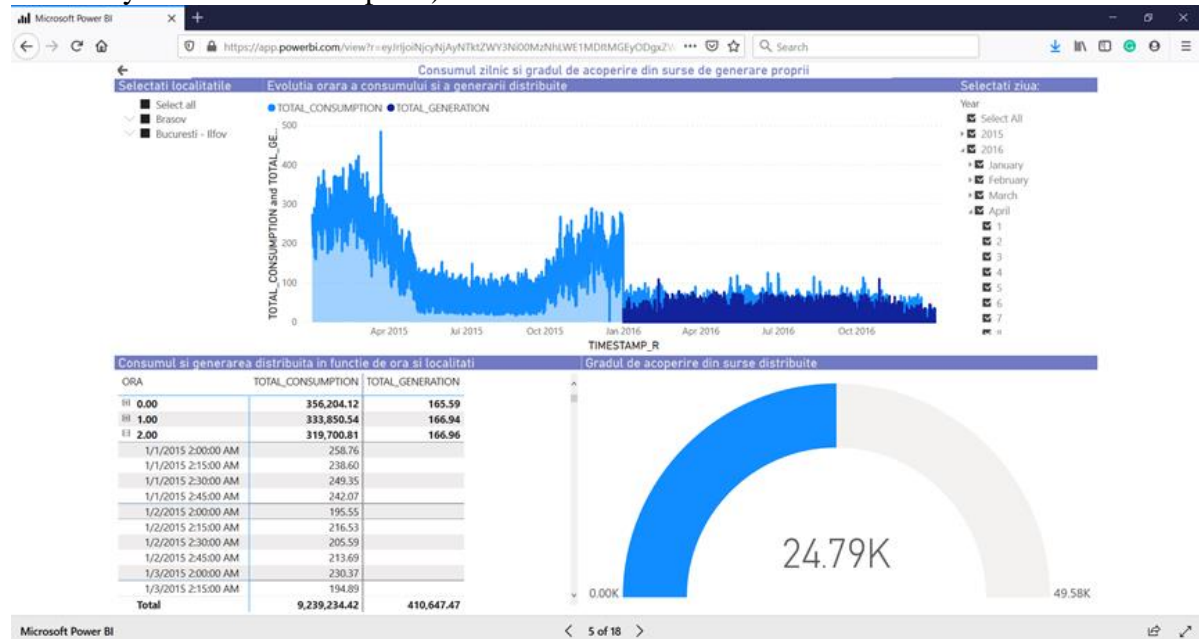
Up to seventeen different types of reports may be generated using the module for



electricity consumption and generation analyses. All the reports are useful for TSOs in fulfilling their functions and responsibilities. Besides, the authors have designed the structure of this model based on the feed-back received from several TSOs from South East Europe.

The electricity consumption and the distributed generation (including electricity self-consumption) are

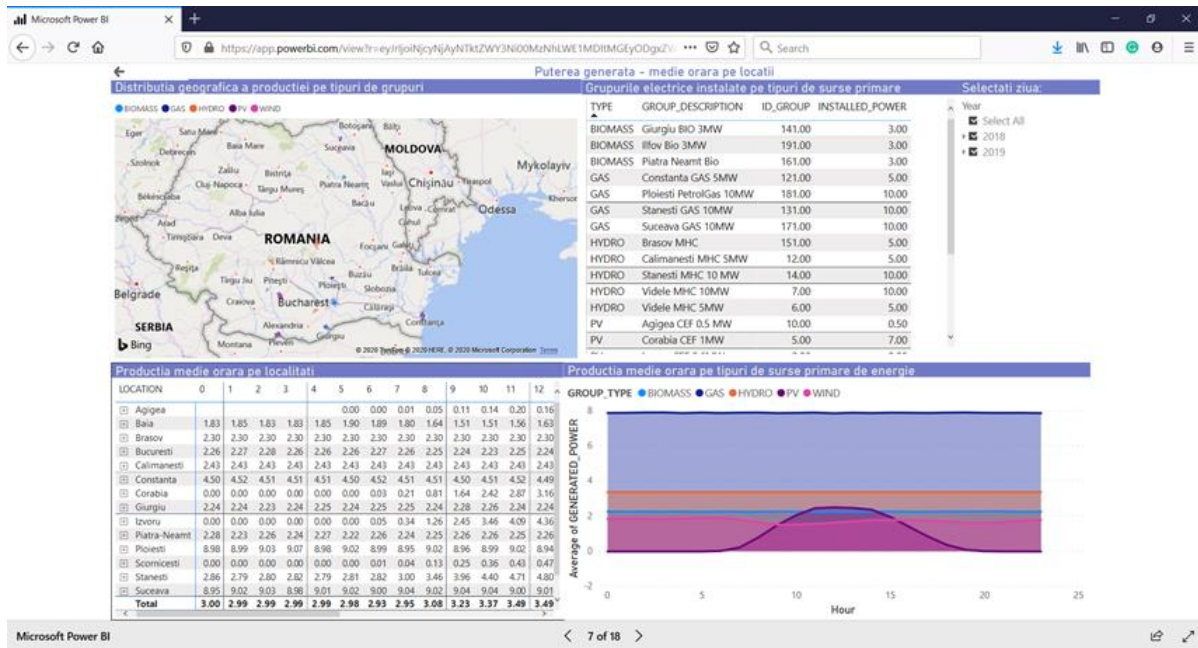
presented in the same reports because the obvious reason that electricity distributed generation is consumed locally (with very limited impact on the electricity distribution grid and practically no impact at all on the electricity transmission grid), in almost all cases. In Fig. 6 below, it is showed an example of the report for consumption and distributed generation, daily.



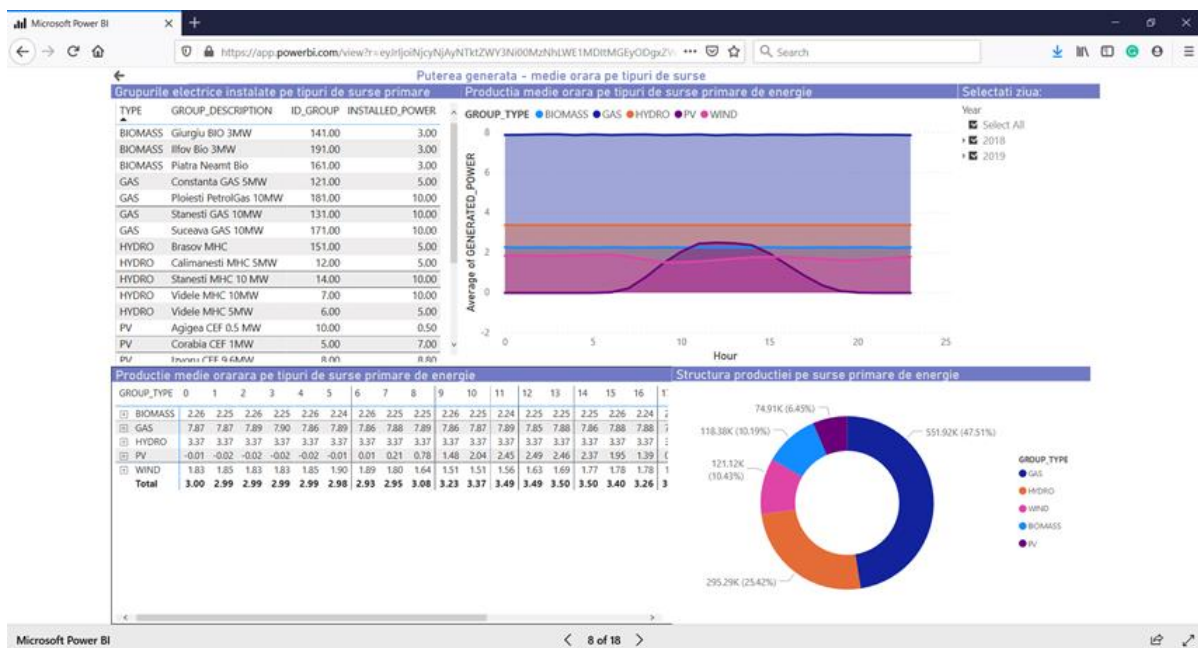
**Fig. 6.** Electricity consumption and distributed generation on daily basis

The electricity generation may be analyzed separately, and the results are displayed in several specialized reports. Of course, all the reports are equipped with the same editing facilities (filters, selection possibilities etc.) as the reports concerning the electricity consumption, presented above.

In the Fig. 7 below, are presented two examples of reports that may be generated to support TSOs in having a clear picture of the electricity generation structure. Fig. 7 – a) shows the geographical location, while Fig. 7 – b) shows the structure of the electricity generation based on technology (fossil fuels, hydro, RES etc.).



a)

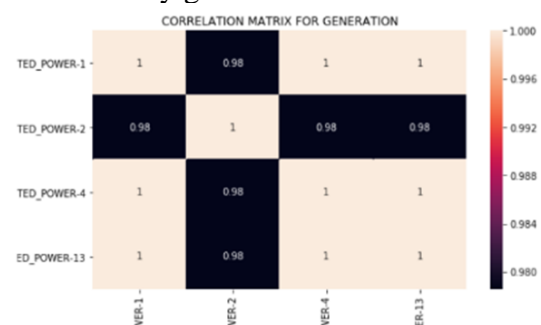


b)

**Fig. 7. Reports concerning the electricity generation**

A particularly useful report includes the level of simultaneity in electricity generation, in determined region, and in determined period. This information allows TSOs to identify timely the potential bottleneck points in the electricity grid, and to identify and implement the appropriate measures.

The simultaneity indices are computed by a Python script integrated in Power BI, and it is displayed in a matrix format, as presented in the Fig. 8 below.

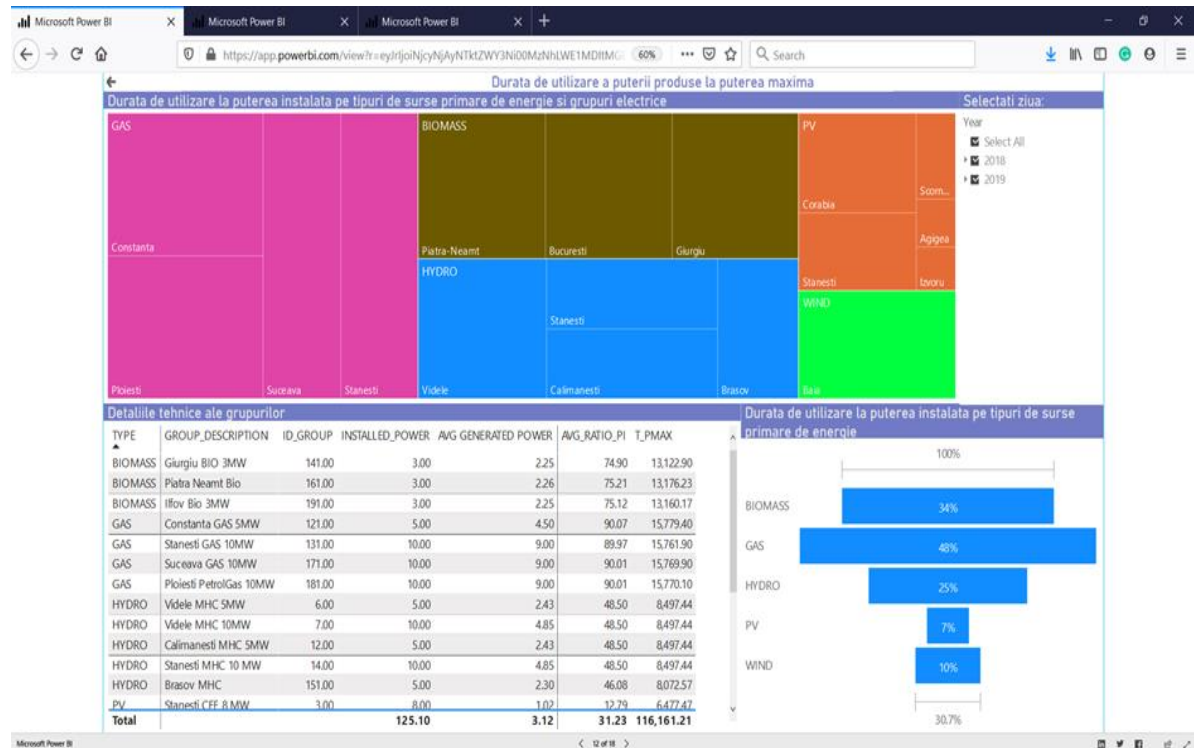


**Fig. 8. Simultaneity indices for electricity generation**



From the TSOs point of view, an especially useful information it is the charging level of the electricity generators. In this respect, the module

makes possible to generate a specialized report, that may be edited to fit the needs of the user. In Fig. 9 below, it is presented an example for this type of report.



**Fig. 9.** Average charging level of the electricity generators

The statistical analysis of the historical data concerning the electricity generation are used on one hand for a correct and detailed understanding of the power systems characteristics, and on the other hand for develop forecasts. Forecasting is a widely used tool for correctly and timely identify the potential operational problems in power systems operation. In this respect, the module makes available to the user a set of specialized reports

covering: forecasts of the electricity generation differentiated per technologies (fossil fuels, hydro, RES etc.), forecasts for evolution of the installed power in RES based generators, and the percentage of RES based generation of the total of electricity generation, for a determined period of time. The forecast for electricity generation may be reported for each generator unit, for groups of units or for groups of power plants, as it is shown in Fig. 10 below.

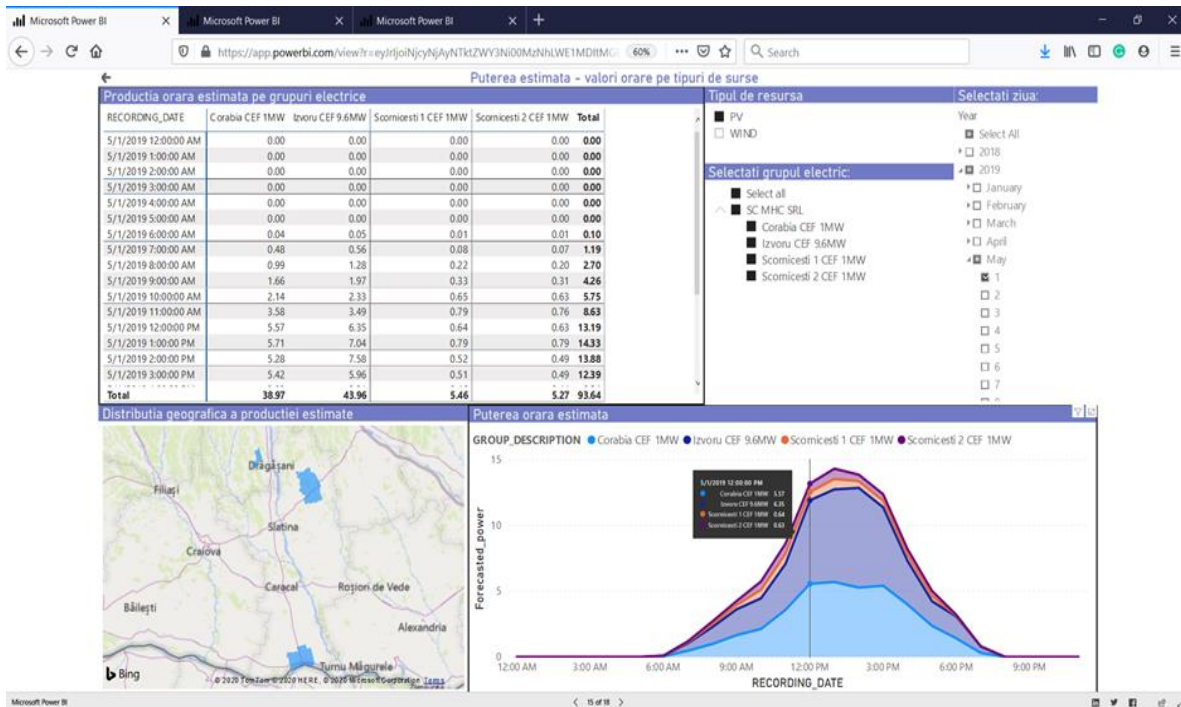


Fig. 10. Report including the electricity generation forecast

Based on the data and information available for the public [7] concerning the Romanian Power System, the authors have developed forecasts for RES based electricity generators, for the period 2020 ÷ 2022. The current databases will be updated at regular intervals to include all the relevant evolutions and thus to maintain the accuracy of the forecasts. In Fig. 11 below, it is presented the report including the forecast of RES based

electricity generation, in the Romanian Power System.

As it was mentioned before in this paper, the RES based generation is currently using (mostly) converters for connecting to the Power Systems. For the TSOs it is useful to be timely informed in this respect because this type of connection rises a lot of technical challenges in power systems operation.

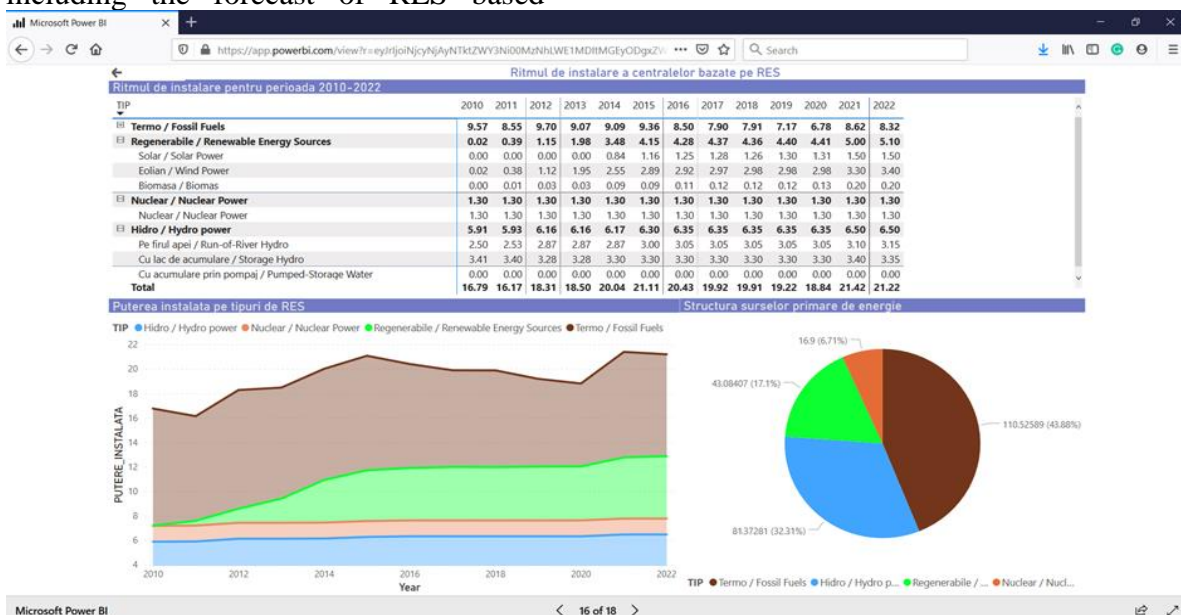


Fig. 11. Report including the forecast of RES based generation

#### 4 Module for analysis of the electricity engross market

The unbundling of the power sectors and the implementation of the electricity markets have been two process which took place practically simultaneously.

From the beginning the electricity market has been structured in layers, based on the timeframe, as follows:

- Long time – engross market,
- Short time – spot market,
- On-Line – balancing (including ancillary services) market.

Electricity engross market is the commercial framework with the largest volume (MWh) of transactions in all countries (power systems) where it was implemented the electricity market system.

TSOs are normally involved in the operation of the balancing and ancillary services market (also normally, they are the designated as operator of this type of markets). Nevertheless, the electricity volumes traded on the engross market makes it one of the most relevant parts of the commercial structure, with a direct and relevant impact on the technical and operational conditions.

The above-mentioned aspects determined

the authors to include this module in the software platform specialized for supporting the TSOs activity.

Similar with the previous module, the input data for the analysis are the historical values registered for last five years, in the Romanian Power System / Romanian Electricity Markets.

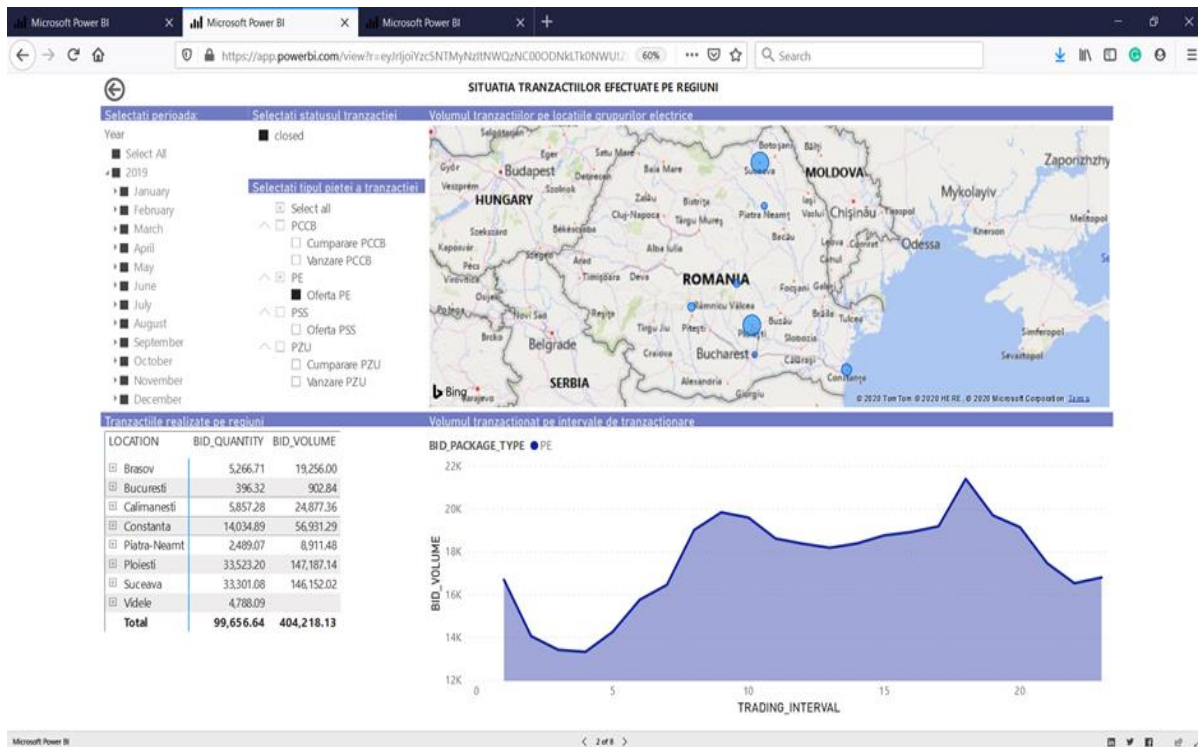
The module allows the user to perform analysis of the transactions according to different criteria, as follows:

- Geographical areas,
- Time periods (days, months, years),
- Primary energy sources used for electricity generation (fossil fuels, RES, hydro etc.),
- Market participants.

For a more complete understanding of the features and trends it was added the possibility to include the data and information concerning the Day Ahead Market (DAM) for electricity.

All the reports windows are designed in the same user-friendly manner with the module previously presented in this paper.

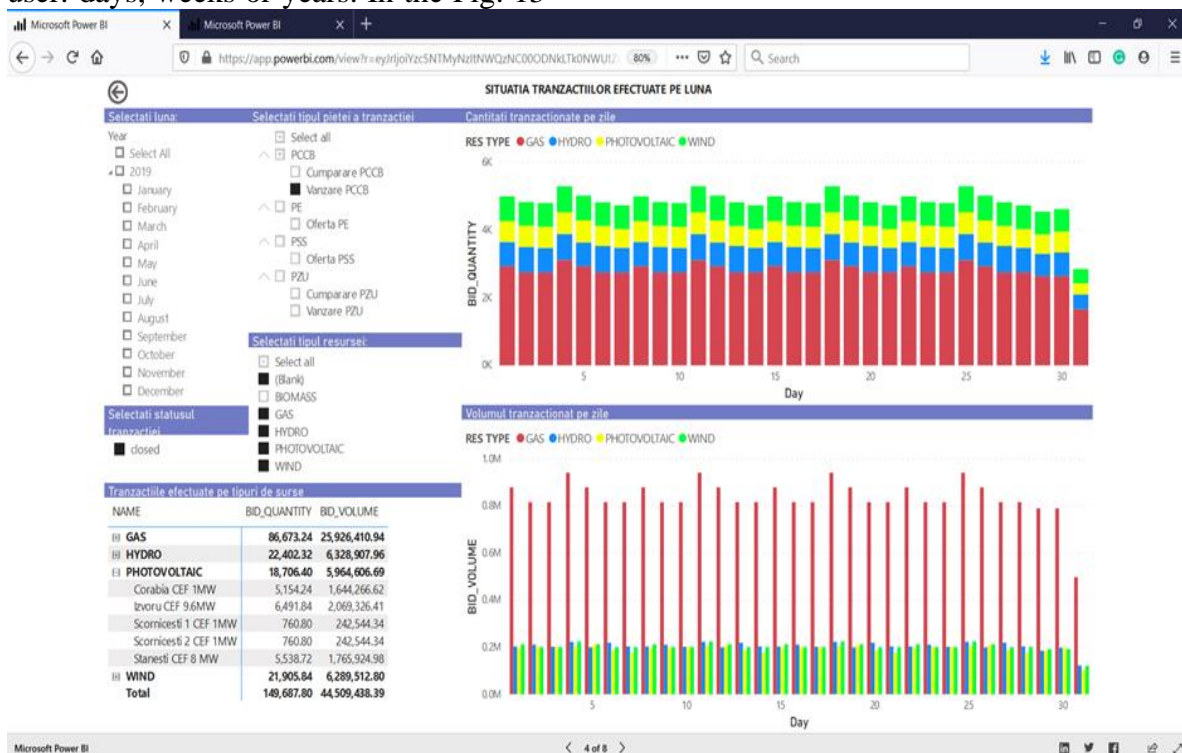
In Fig. 12 it is showed an example report including the aggregated traded volumes of electricity, for several selected cities (in alphabetical order): Brasov, Bucharest, Calimanesti, Constanta, Piatra-Neamt, Ploiesti, Suceava and Videle.



**Fig. 12.** Electricity traded volumes aggregated for several cities selected by user

Similar with the capabilities showed in the reports generated by the previous module presented in this paper, the reports concerning the volumes traded on the electricity markets may be generated for the time periods requested by the user: days, weeks or years. In the Fig. 13

below, it is presented an example report for a month period, including only the selling volumes traded, and the respective prices. The reports highlight the volumes traded for each type of primary energy source: fossil fuels, hydro, RES and nuclear.

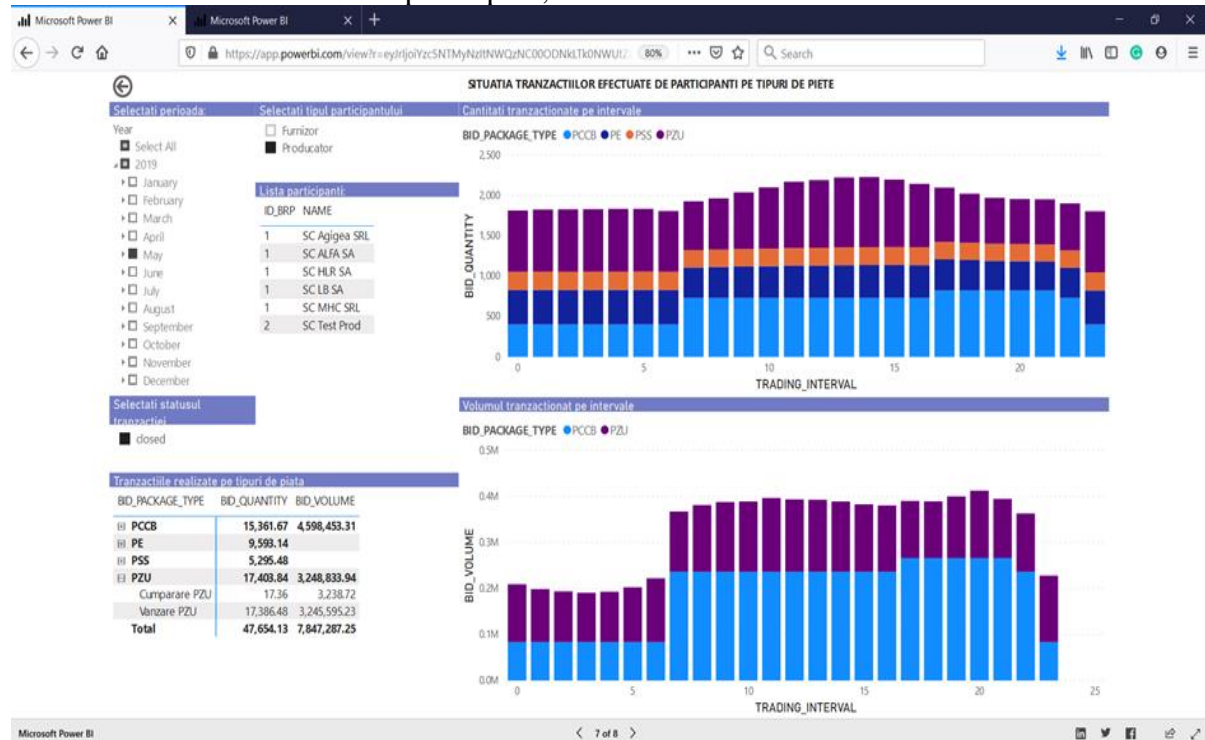


**Fig. 13.** Traded electricity volumes for one month, per primary energy source



For a more complete description of the electricity markets past evolution and identification of the future trends, the module has the capability to analyze and report the traded volumes of electricity differentiated for each market participant,

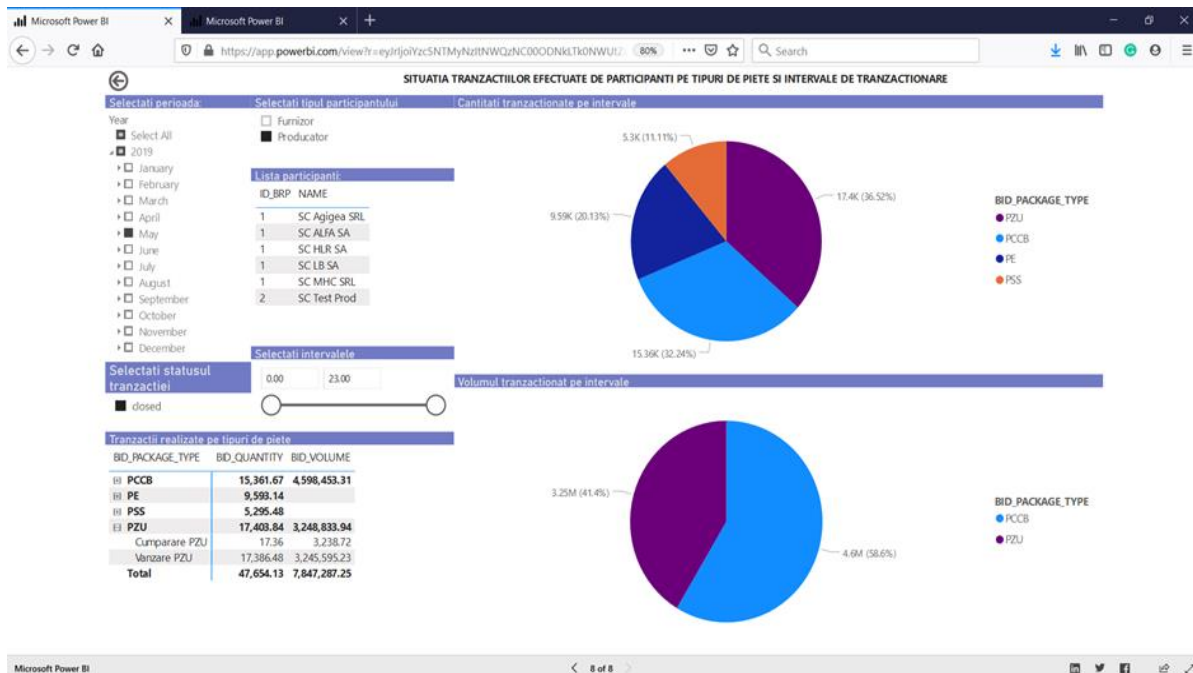
for selected time periods. The database includes only the transactions finalized (not the offers). In the Fig. 14 below, it is presented an example report for a randomly selected number of electricity generators.



**Fig. 14.** Finalized transactions with electricity, for a group of generators

The data and information included in the previous report may be useful to be structured in a different format, displaying the traded electricity volumes in percentages, for all the electricity markets. This change of perspective

highlights the impact of the selected group of market participants at the market level. In Fig. 15 below, it is presented an example report, in percentage format, for the same group of selected electricity generators, and the same period as in case of Fig. 14.



**Fig. 15.** Finalized transactions with electricity, for a group of generators, in percentage format

## 5 Module for analysis of the balance between consumption and generation of electricity

One of the most important function and responsibility of the TSOs is to take all the necessary measures to ensure the balance between electricity consumption and generation in each moment, continuously, and for indefinite period.

To fulfill this responsibility, the TSOs are carefully monitoring the electricity consumption and generation levels. In case an imbalance is detected the TSO is empowered to take timely all the necessary measures to restore the balance.

Reflecting the importance of this aspect in the power systems operation, a specialized electricity market has been created both at national and European level.

The European professional association of the TSOs: European Network of Transmission System Operators for Electricity (ENTSO-E) is the organization in charge with the elaboration and implementation of the regulatory framework concerning power systems operation and electricity markets design and operation, at European level.

According to ENTSO-E website [8] electricity balancing market is “a market where countries can share the resources used by their TSOs to make generation equal demand always. It is also about allowing new players such as demand response and renewables to take part in this market.”

For the same purpose of providing TSOs with the necessary tools to meet its responsibility, ENTSO-E has issued grid code specialized on electricity balancing: Guideline on Electricity Balancing [9].

According to ENTSO-E the balancing activity means: “all actions and processes, on all timelines, through which TSOs ensure, in a continuous way, the maintenance of system frequency within a predefined stability range as set out in Article 127 of Regulation (EU) 2017/1485, and compliance with the amount of reserves needed with respect to the required quality, as set out in Part IV Title V, Title VI and Title VII of Regulation (EU) 2017/1485” [9].

Balancing market means: “the entirety of institutional, commercial and operational arrangements that establish market-based management of balancing” [9].

One especially important characteristic of the electricity balancing market is the

noticeably short timeframe of the transactions, namely the dispatching interval [10].

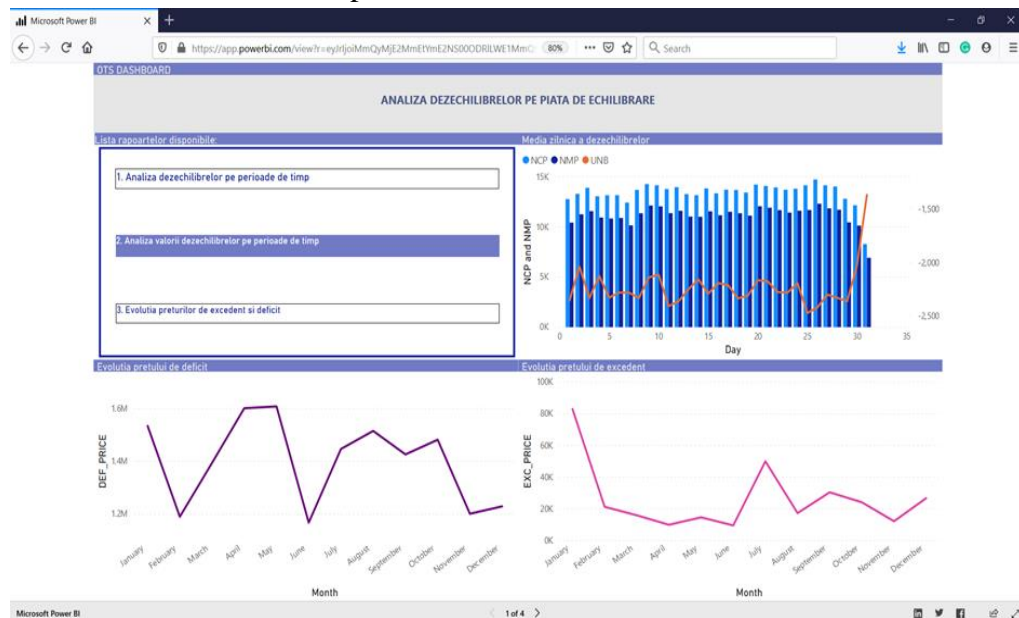
The duration of the dispatching interval was initially of one hour but in time the TSOs decided to reduce it step by step, to increase the accuracy of the balancing measures. Nowadays, the duration of the dispatching interval it is different in the EU member countries, ranging from 5 minutes to one hour, but the trend is to reduce it to 5 minutes all over the Europe. Considering all the above-mentioned aspects the authors of the software platform have been developed a

specialized module dealing with the following topics:

- Electricity balancing volumes,
- Electricity balancing costs,
- Electricity balancing prices.

In Fig. 15 below, it is shown the dashboard of the module for analysis concerning the electricity balancing market.

The databases used for statistics and computations include historical values registered in the operation of the electricity balancing market, in the Romanian power system, during the last five years [7]. In the Fig. 15 below, it is showed the dashboard of this module.



**Fig. 15** Dashboard of the module for electricity balancing analysis

The volumes of electricity traded for each dispatching interval, for a determined period is an especially important parameter for the TSOs on its way to optimize the operation of the power system while maintaining an adequate level quality and costs of services.

Ideally, the electricity consumption and generation should be balanced for the most part by means of the other electricity markets (bilateral, DAM and IDM), and the volumes traded on the balancing markets to be around 10 % of the total electricity consumption of the power system.

The larger is the volume of electricity traded on this market, the most difficult is

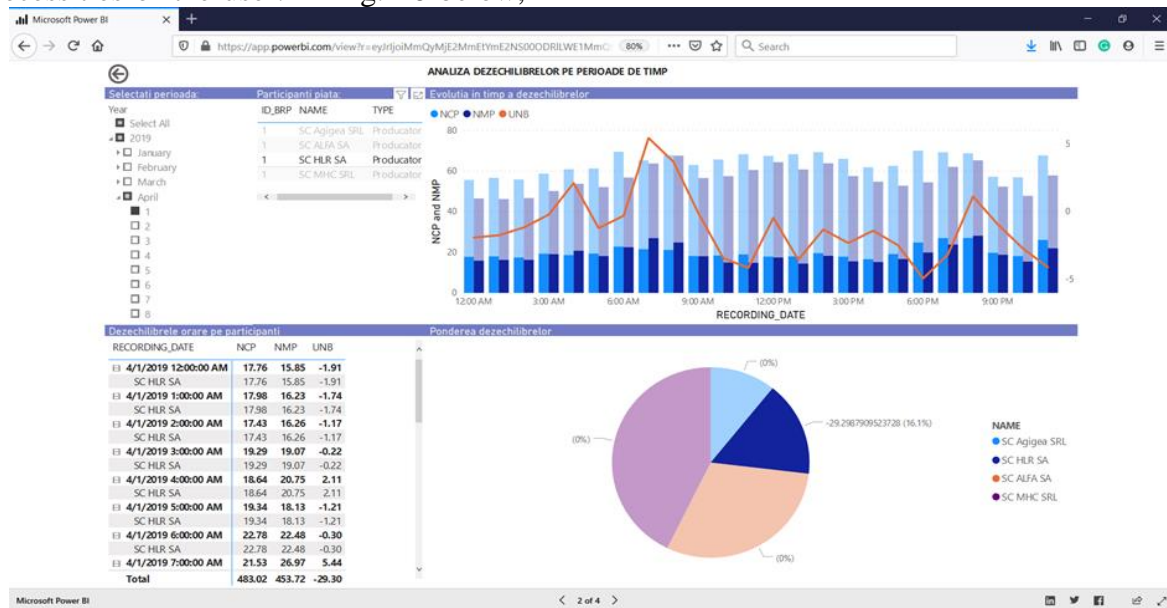
to operate the power system, and the most costly as well. On mention that the prices on the market in question are usually, on average about 40 % to 50 % higher than on any of the other markets.

In case the volumes traded on the electricity balancing market are exceeding 25 % it is strongly recommended to the TSO in charge to take active measures for improving the balancing activities at the level of each participant in the respective power system. The market price of electricity itself is such a measure but other supplementary levers may be implemented (incentives for forecasts improvement, incentives for storage facilities, incentives for demand side management actions, etc.).



The module may perform analysis for each market participant or for list of selected participants, according to the necessities of the user. In Fig. 16 below,

it is showed the results of the analysis for a user-selected market participant, and for a user-selected period.

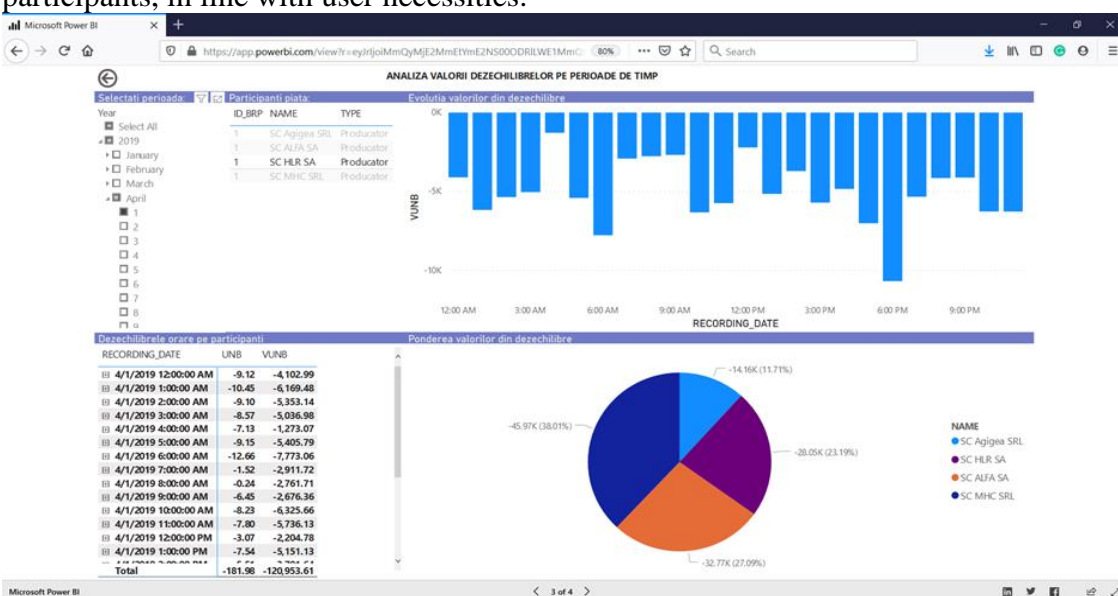


**Fig. 16.** Hourly volumes of electricity traded on the balancing market

Closely related to the volume of electricity traded are the associated costs. The next function of the module allow the user to generate reports displaying the statistical analysis of the costs evolution. Similar with the previous function, the reports may be generated for a single market or for a group of market participants, in line with user necessities.

The databases used in the calculations and statistical analysis include information related to transactions finalized on the electricity balancing market in Romanian power system, in the last five years [7].

In Fig. 17 below, it is showed the results of the costs analysis for a user-selected market participant, and for a user-selected period.



**Fig. 17.** Hourly costs of electricity traded on the balancing market

The transactions on the electricity balancing market are characterized by a

dual structure:

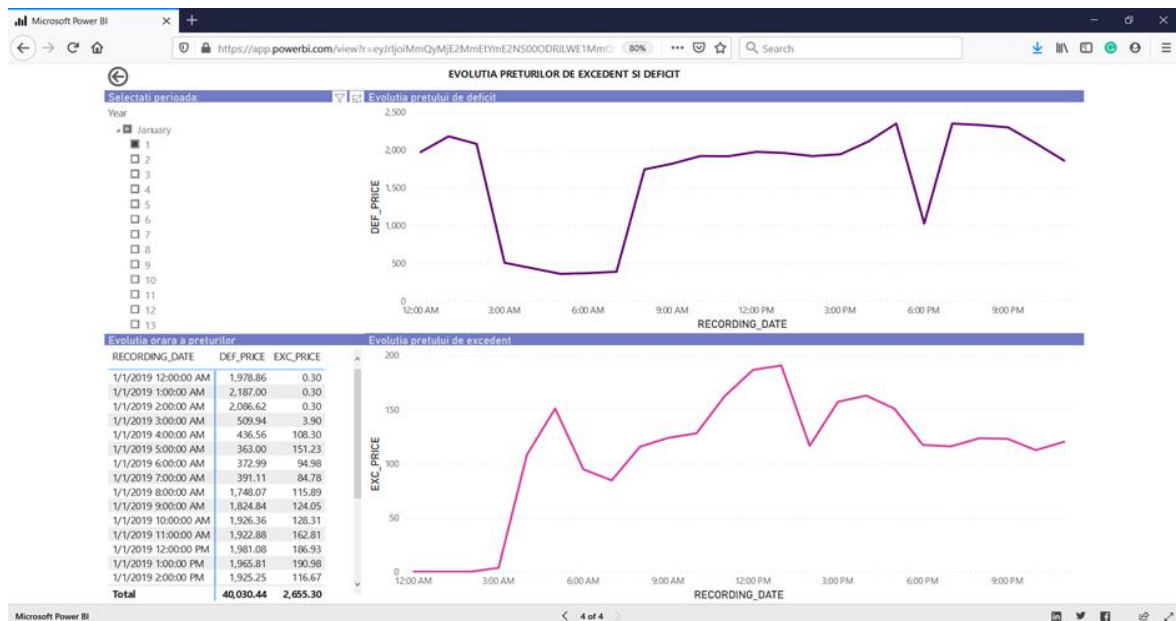
- Transactions for deficit settlement,

- Transactions for surplus settlement.

In a determined dispatching interval (the time frame of the transactions on the market in question) only one type of transaction is possible. TSOs are in charge to identify which type is necessary and to implement it in due time.

In these conditions, the actors and the prices are both different and independent, for each of the types, and requires differentiated analysis and computations.

In Fig. 18 below, it is showed the results of the deficit and surplus prices analysis for an user-selected period that may not be shorter than one day (24 hours).



**Fig. 18.** Electricity deficit and surplus prices for one day (24 hours)

The functions and statistical analysis capabilities provided by this module may be very useful for the TSOs in case they are using the levers of the electricity balancing market for congestion management and capacity allocation purposes.

According to ENTSO-E's regulations [11], the congestion management and capacity allocation are the responsibilities of the TSOs, and one of the main tools to fulfill them is the electricity balancing market. In line with the same regulation [11], the related costs will be supported by the TSO in charge for the respective power system.

It must be mentioned that utilization of the electricity balancing market mechanism it is not always necessary in the performance of the congestion management and especially in the capacity allocation activities but when the time comes it is useful to be able to

forecast the related costs.

## 6 Conclusions

The evolution of the global warming determined the countries worldwide to adopt more and more determined measures to fight against this phenomenon by reducing and even eliminating the main causes.

EU turned out to be, currently is and intend to be in the future one of the world leaders in this respect. The European Green Deal [1], elaborated by the European Commission and approved recently by the European Parliament, it is an undeniable proof of this statement.

In this environment, the power sector and the transportation sector are probably the most affected industries, facing a large variety of challenges: technical, financial, social, administrative and others.

Concerning the power sector, the main driver is the massive integration of the electricity generators powered by RES, replacing the electricity generators powered

by fossil fuels and nuclear fuel. The process has started at European level ten years ago and it is intended to continue for at least another decade.

The electricity generators powered by RES are using, in the vast majority convertors for connection to the electricity grid. This type of technology is totally different from the technical point of view, to the conventional synchronous rotating electricity generators.

The challenges are a direct result of the request to perform the process without reducing (increasing if possible) the quality level of supply service, while maintaining the affordability level of the electricity, at European level.

Considering the above-mentioned aspects, one may easily identify the TSOs as the main actors in charge to implement the changes, to monitor and assess the impact, to identify the necessary measures and the responsible parties.

In the desire to meet the needs of TSOs, the authors of this paper have developed a specialized software platform. The software product is designed to perform statistic analysis of historical values, and to elaborate forecasts, both for supporting the TSOs in identifying the sources of the problems and to timely take the right decisions.

The databases used for analysis and calculations include information collected in the last five years from the Romanian electricity markets: bilateral, DAM, IDM and balancing market.

The software product is structured in three modules, dealing with the following topics:

- electricity demand and generation structure and volume,
- electricity market,
- balancing the demand and generation.

Each of the modules is designed to be user-friendly and to provide a large set of editing options, covering almost all the possible operational situations a TSO may be challenged with.

In the frame of the module for demand and generation structure, the user may perform a set of seventeen analysis, and may generate reports for each of them. The topics addressed by this module are the following:

- Distribution of consumption by locations over a certain period,
- Hourly consumption by regions,
- Monthly consumption and coverage from distributed generation sources,
- Daily consumption and coverage from distributed generation sources,
- Estimated and recorded daily consumption,
- Generated power – hourly average per location,
- Generated power – hourly average by types of sources,
- Power generated by electrical groups,
- Power generated by the analysis of the degree of correlation and similarity,
- The degree of use of the power produced at the installed power,
- Duration of use of the power produced at maximum power,
- Generated power – ranked curves,
- Number of operating hours,
- Estimated power – hourly values by types of sources,
- The pace of installation of power plants based on RES,
- The state of the system – the degree of consumption coverage in RES,
- System status - hourly evolution.

In the frame of the module for analysis of the electricity engross market, the user may perform a set of seven analysis, and may generate reports for each of them. The topics addressed by this module are the following:

- Statement of the finalized transactions, by region,
- Statement of the finalized transactions, by types of resources,
- Statement of the finalized transactions per months,
- Statement of finalized daily transactions, by types of markets,
- Statement of transactions finalized per intervals, by types of markets,
- Statement of the transactions

finalized per participants, by types of markets,

- Statement of the transactions finalized per participants, by types of markets, and trading intervals.

In the frame of the module for analysis of the balance between consumption and generation of electricity, the user may perform a set of three analysis, and may generate reports for each of them. The topics addressed by this module are the following:

- Analysis of imbalances over time periods,
- Analysis of the value of imbalances over time periods,
- Evolution of surplus and deficit prices.

The paper includes a detailed presentation (practical examples for utilization) of each module with its functions / reports, highlighting the potential usefulness of them in the TSOs day to day activity.

## 7 Acknowledgment

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