AALBORG UNIVERSITY

DENMARK

Visualizing Complex Energy Planning Objects With Inherent Flexibilities

Siksnys, Laurynas; Kaulakiene, Dalia

Visualizing Complex Energy Planning Objects With Inherent Flexibilities

Laurynas Šikšnys, Dalia Kaulakienė
{siksnys, daliak}@cs.aau.dk
Department of Computer Science, Aalborg University

ABSTRACT

Energy distribution enterprises will face the challenge to plan and balance consumption and production in the electricity grid with the substantial amount of renewable energy sources (RES) [4]. To effectively plan and balance energy, a potential future energy enterprise will have to exploit flexibilities of individual energy consumers (and producers) to be able to delay certain loads of energy for some time interval. Such type of flexibility can be represented with a flex-offer from the MIRABEL project [1]. In this paper, we discuss energy planning and controlling activities within such future energy enterprise and, to support those activities, we propose a comprehensive visual analysis framework that provides detailed and generalized views over flex-offers, and offers a convenient OLAP-inspired approach to navigate and explore such data. Then, as the first step developing such framework, we focus on the detail view and present the implementation of the histogram-based approach to visualize a large number of individual flex-offers. Finally, we review the related work in the areas of the multidimensional, spatial, temporal, spatio-temporal, and energy data visualization, and present the future work.

1. INTRODUCTION

Today, more and more renewable energy sources (RES) are added to the European electricity production portfolio since they can offer sustainable energy with a much lower environmental impact compared to the conventional energy sources. However, due to the intermittent nature of the RES supply, balancing energy in an electricity grid with the substantial amount of RES (>30% of a total production) becomes a really challenging task [4] for energy enterprises (Balance Responsible Parties or entities responsible for energy generation and distribution). To address the challenge, the European electricity grid is being incrementally transformed into a *smart-grid* that utilizes a modern information and communication technology (ICT) to produce, supply, and consume energy in a more intelligent way.

MIRABEL (abbr. Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution) is an on-going EU FP7 research project [1] that develops and prototypes such ICT infrastructure [5] for the European smart-grid. The infrastructure enables millions of individual energy consumers to consume more energy at times when there is an excessive supply from RES and less energy when a RES supply is insufficient, while still providing a convenient way to balance the grid (see Figure 1). The MIRABEL relies on the concept of a *flex-offer* – an entity that explicitly captures a consumer's (or producer's) intent or capability to consume (or produce) certain amount of energy within a fixed future time interval.

A potential MIRABEL energy enterprise, MIRABEL enterprise for short, collects millions of such flex-offers from individual prosumers (entities that both consume and produce energy) and performs a complex planning activity in an online fashion to satisfy prosumer energy consumption (or production) needs (or offers) expressed in flex-offers. This planning activity involves large amounts of complex data such as flex-offers and time series collected from millions of individual energy prosumers. In this process, effective monitoring, accurate planning, and data analysis play a crucial role and raise the needs for effective flex-offer visualization. However, flex-offer visualization is challenging as (1) flex-offers are complex multi-dimensional objects with spatial, spatio-temporal attributes (as we show later), and (2) different (detailed, aggregated, map, and topological) views over sets of flex-offers are required.

In this paper, we present the implementation of a novel approach to visualize a large number of individual flex-offers. The approach employs the variation of the histogram plot where 2-dimensional (time and energy) subspaces are stacked onto each other. Although the approach is suitable to visualize individual flex-offers in detail, it addresses only the part of the flex-offer data visualization challenge when serving the needs of the MIRABEL enterprise. There is still a demand for a comprehensive visual flex-offer analysis framework offering different views over sets of flex-offers. Such framework is also elaborated in the paper.

The paper is structured as follows. In Section 2, we present energy planning and control activities within the MIRABEL enterprise and elaborate the importance of the visual flex-offer analysis. Then, in Section 3, we formulate high level requirements for the visual flex-offer analysis framework and,
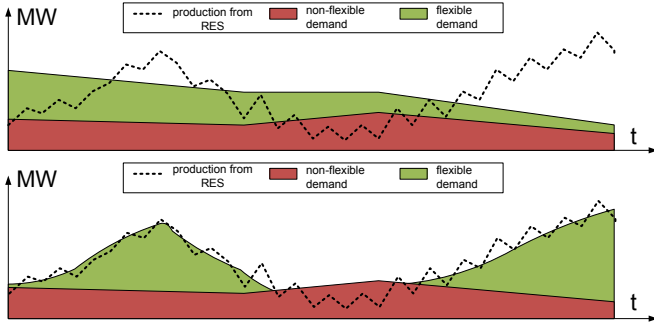
Figure 1: Examples of loads before and after the MIRABEL system balances demand and supply in the electricity grid

in Section 4, we present our initial work done implementing it. Finally, in Section 5, we review the related work on the visualization of multidimensional, spatial, temporal, spatio-temporal, and energy data, and we conclude the article in Section 6.

2. ENERGY PLANNING AND CONTROL IN MIRABEL ENTERPRISE

According to the MIRABEL project, an energy enterprise continuously perform complex energy planning and control activities [1, 5, 12] to achieve a multi-objective goal, which is to (1) satisfy all flex-offers, (2) utilize as much RES energy as possible, (3) balance the grid, and (4) maximize profit.

First, it collects millions of energy readings and flex-offers from individual prosumers (e.g., households) in a certain geographical region, e.g., Denmark. In this process, the overlaying ICT infrastructure automatically reads both momentary energy values from prosumers' smart-meters and their intents and capabilities to use certain electrical appliances (e.g., el. vehicle) in a flexible manner (e.g., charge a battery at any time over a night) in the form of flex-offers.

Then, the enterprise aggregates the collected measurements and flex-offers to forecast required demand (and the supply) of their customers for a certain time horizon (e.g., day ahead). Later, it produces a plan in which supply is equal to (balances) demand. For periods in which the balance cannot be met, the enterprise buys or (or sells) certain amounts of energy on a power exchange market (e.g., Nordpool Spot). When it buys (or sells), it has the responsibility to ensure that its customers collectively consume (or produce) amounts equal to those bought (or sold) on the market. For those time intervals when the balance is not met, the company is charged with an imbalance fee. The fee is substantially higher than a spot (market) price of electricity. This raises an incentive for the energy company to plan energy as accurately as possible and control it as good as possible.

Finally, appliance activation messages in the form of *flex-offer assignments* along with other settling information such as bills are distributed back to individual prosumers by disaggregating the plan.

To support planning and control of activities, specialized ICT systems are employed in the MIRABEL enterprise. In addition to the conventional SCADA (supervisory control and data acquisition) and ERP (Enterprise resource planning) systems, it employs a comprehensive energy data management system (EDMS) [5, 12] with the inherent support for flex-offers and offering flex-offer storage [23] and advanced analytic functionality such as aggregation[28], scheduling [27], and forecasting [11].

The EDMS is designed to automatically process a large number of flex-offers in the online fashion. In this process, the online monitoring and offline testing of the system, problem analysis, and long-term planning are very important, but they are not considered in the MIRABEL project. In all these activities, the visual analysis of flex-offer plays a crucial role. For example, to find out a reason behind the shortage of electricity, it is important to be able to see relevant geographical areas on a map with an option to drill down to the level of individual flex-offers. In the following two sections, we focus on individual flex-offers and their basic aggregates, and present requirements for, and our initial work done implementing, a comprehensive visual flex-offer analysis framework to support various visual flex-offer analysis activities.

3. REQUIREMENTS FOR VISUAL ANALYSIS FRAMEWORK

In this section, we focus on the flex-offer data visualization and present the essential types of views over flex-offer data in the form of requirements for the framework.

The framework must support an in-depth analysis on the individual flex-offer level (Req. 1) as well as a global analysis on the aggregated data level (Req. 2).

When visualizing individual flex-offers (Req. 1), the following elements of a flex-offer (see Figure 2) must be clearly visible:

Profile of flex-offer: Defines bounds (minimum and maximum energy) of energy required (or offered) by a prosumer at successive time intervals.

Start Time Flexibility: Defines a user-accepted flexibility in time to start a particular appliance to consume or produce energy.

Acceptance and Assignment Times: Define user-specified latest time moments for the enterprise to issue acceptance and assignment messages as a response for a particular flex-offer.

Scheduled Energy and Start Time: Define energy amount values and the starting time of a particular appliance, scheduled by the enterprise during the planning phase (see Section 2).

When visualizing aggregated flex-offer data (Req. 2), the following statistics are essential and must be supported:
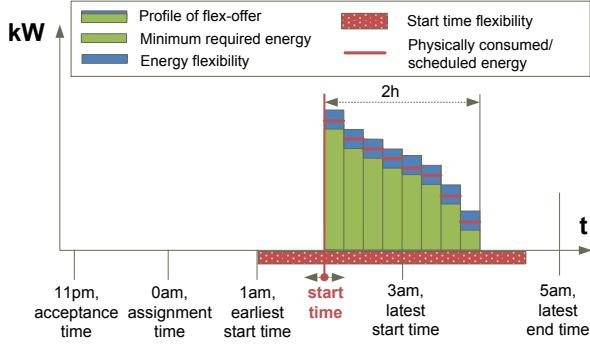
Figure 2: Structural elements of a flex-offer

Flex-offer Count: It is a total number of accepted, assigned, or rejected flex-offers in the plan or in the physical realization of the plan (numbers differ if prosumers do not follow the plan).

Flex-offer Attribute Value: It summarizes values of a particular flex-offer attribute, e.g., the minimum/maximum/average price, energy, or flexibility defined by flex-offers.

Scheduled Energy: It is the amount of energy that is planned utilizing flex-offers or physically used by prosumers.

Plan Deviations: It is a difference between the amounts of energy in the plan and in the physical realization of the plan.

Energy Balancing Potential: It is a measure on how well energy can be balanced utilizing flex-offers. The measure is computed from the total amount of energy and the flexibility prosumers offer with their flex-offers.

For all these elements and measures, the framework must support *filtering* and *grouping* on the following types of flex-offer attributes:

Temporal: To select data for a particular time interval and to analyse data at different time granularities.

Spatial Geographical: To select data for (or group on) a spacial object, e.g., country, city, or district. A user-friendly view (see an example in Figure 3) to explore and filter flex-offer data on a map must be provided.

Spatial Topological: To select data for (or group on) the topological or electrical structure the electricity grid, e.g., for a particular 110kV transmission line. A user-friendly view (see an example in Figure 4) to explore and filter flex-offer data on a topological map must be provided.

Energy Type: To select data associated with a particular energy type, e.g., renewable energy from hydro power plants.

Prosumer Type: To select data associated with a particular prosumer type, e.g., small industrial power plants.

Appliance Type: To select data associated with a particular appliance type, e.g., electric vehicles.

In addition, the nesting of multiple filtering and grouping operations must be supported. For example, the framework must be able to retrieve counts of accepted flex-offers in the west Denmark in the period from Jan-2013 to Feb-2013 grouped by cities and energy type. Moreover, to support filtering and grouping tasks, intuitive dimension hierarchies as those in OLAP has to be created for all these types of attributes. A convenient OLAP-based "pivot-table" view to explore flex-offer data must be provided (see an example in Figure 5). In the view, a user must be able to choose a preferred dimension hierarchy (e.g., prosumer type), navigate (drill up and down) hierarchy members from the most summarized (e.g., All prosumers) to the most detailed (e.g., household), and analyse the preferred elements or the measures (e.g., flex-offers., see above for more) on multiple swimlanes in the view. A possibility to manually formulate a query (e.g., in MDX) for the view must be provided.

Finally, a view to summarize the complete flex-offer data for the selected time interval (see an example in Figure 6) must be offered.

In the next section, we describe our initial results when implementing the flex-offer analysis framework.

Figure 3: Example of the map view of flex-offers

4. INITIAL RESULTS WHEN IMPLEMENTING VISUAL ANALYSIS FRAMEWORK

We have built a visualization tool offering only the subset of the described features (defined by Req. 1 in Section 3). The tool is capable of visualizing a large number of flex-offers on a computer screen and it allows interactively performing an in-depth analysis of individual flex-offers. It currently supports the flex-offer aggregation, the disaggregation, and
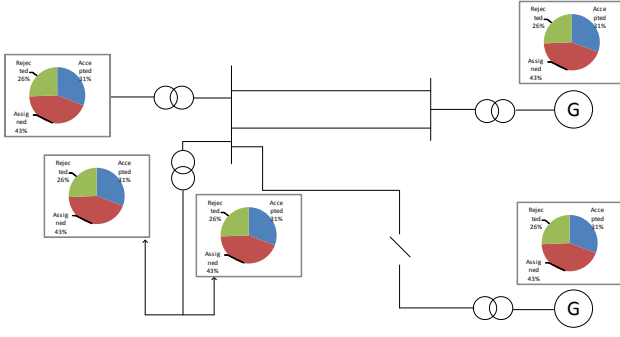
Figure 4: Example of the schematic view of flex-offers

Figure 6: Example of the dashboard view of flex-offers

Figure 5: Example of the pivot view of flex-offers

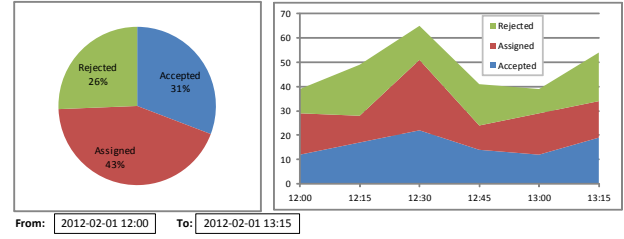the basic filtering functionality. In the rest of the section, we provide a walk-through of its functionality by starting with the data loading and ending with its useful graphical enhancements.

First, the tool reads flex-offers and related data from a database employing the MIRABEL DW schema [23]. When the tool connects to a database (PostgreSQL), a user can choose a specific legal entity (a prosumer), whose flex-offers he or she wishes to visualize (see Figure 7). The user can also select an absolute time interval, for which flex-offers needs to be selected.

When flex-offers are read, a new *flex-offer view* tab is created in the main application window (see additional tabs for two read operations in Figure 8). There are two flex-offer views currently supported: the basic and the profile view. Both these views show the set of flex-offers in a graph with the abscissa axis corresponding to time. Depending on the view, the ordinate axis in the graph is unit-less (see Figure 8) or shows energy (see Figure 9). As flex-offers are temporal object which may potentially overlap in time, boxes representing flex-offers (see Figures 8–9) are stacked on each other thus occupying one of several ordinate axes in the graph.

The basic view (see Figure 8) is used to show a large numbers

of flex-offers by visualizing only the most essential properties of a flex-offer: 1) duration of energy profile (light blue or red rectangles), 2) time flexibility interval (grey rectangles); 3) scheduled starting time of a respective appliance (red solid lines). Aggregated (light red rectangles) and non-aggregated (light blue rectangles) flex-offers are distinguished by a color. Such flex-offer view allows observing abnormalities in both individual flex-offers (e.g., unexpectedly long energy profiles) and large flex-offer sets (e.g., missing assignments in some time interval).

The profile view (see Figure 9) is used to provide the detailed flex-offer representation, specified by the requirement (see Req. 1 in Section 3). The view is effective for a smaller flex-offer set with less than few thousands of flex-offers. It allows exploring the actual (minimum and maximum) energy bounds at every profile interval (slice), and, thanks to the synchronized scales of all ordinate axes, compare them across multiple flex-offers. In addition to energy bounds, it shows the scheduled amounts for every profile interval (red solid lines).

Irrespectively for the selected view, the visualization tool provides additional information about flex-offers when pointing their representations with a mouse pointer (see Figure 10). This includes the markers (yellow lines) for user-specified *creation/acceptance/assignment times* of a flex-offer as well as indications (red dashed lines) on which flex-offers were aggregated to produce the pointed flex-offer. The mouse action can be changed to allow interactive selection of flex-offers. Flex-offers can be selected one-by-one or by drawing a rectangle (see dashed red rectangle in Figure 8). The selected flex-offers can be shown on different tab, removed from the current view, or processed with the tools from the main menu.

The visualization tool integrates the flex-offer aggregation and disaggregation functionalities [28]. This allows, for example, reducing the count of flex-offers shown on a screen by aggregation, as well as allows interactive tuning values of the aggregation parameters.

Finally, the tool offers useful graphical enhancements such as automatic selection of "pretty scales" of the axes, as well as the incremental rendering of flex-offers, which allows executing actions when a flex-offer rendering is in progress (rendering does not freeze the tool).

As mentioned before, the presented flex-offer visualization tool offers only the subset of the functionality of the complete the visual flex-offer analysis framework. As the next immediate enhancement, the basic and the detailed views will be integrated into the pivot view (see the description of Figure 5), where the flex-offer aggregation will be applied to produce inputs for the flex-offer visualization on swimlanes (see Figure 5). Later, the remaining functionality of the framework will be implemented.

In the next section, the related work is reviewed.
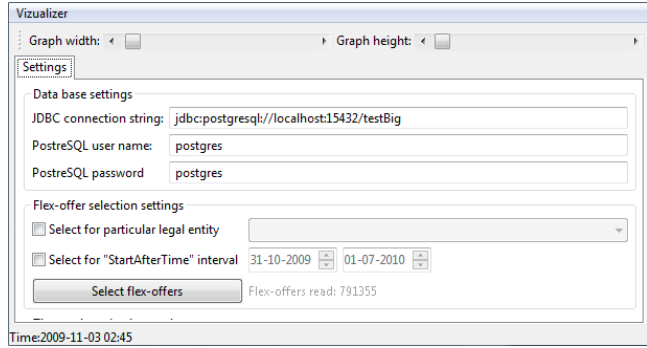
Figure 7: The flex-offer loading tab in the main window
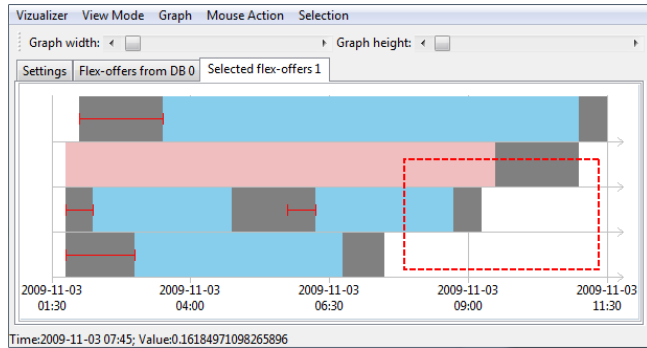
Figure 8: Basic view of flex-offers

5. RELATED WORK

The information visualization is an active and still emerging field offering approaches to see, explore, and understand large amounts of information in intuitive ways. Consequently, much work has been done in this broad discipline, and there is a number of publications surveying the accomplished results [6, 16, 9] as well as guides on how one should properly display [29] and visually analyse [10] information. In this context, a flex-offer is a novel concept and thus the visualization of flex-offers has not been addressed yet. Nevertheless, flex-offers can be seen as instances of multi-dimensional, spatial, temporal, spatio-temporal, and energy data (as it can be seen in Section 3) and methods for effectively visualizing such type of data has already been proposed.

First, the well-known OLAP (Online Analytical Processing) techniques to manage multidimensional data leaded to the
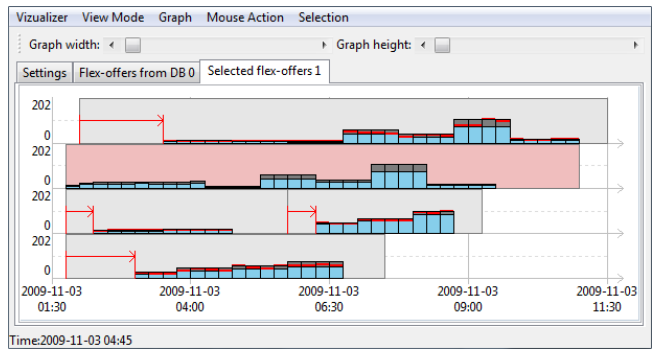
Figure 9: Profile view of flex-offers
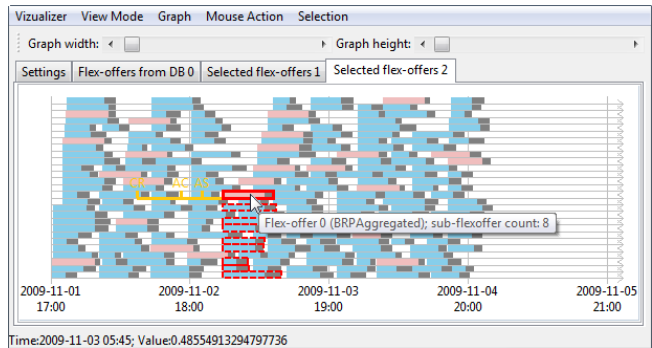
Figure 10: On-the-fly information about flex-offers

research field of Visual OLAP [17]. There, the traditional 2D interface for analysing multidimensional data is a pivot table (or cross-tab) view [8]. The current state-of-the-art (the survey [8] is available) enhances the pivot table view via providing the set of popular visualization techniques, such as bar-charts, pie-charts, and time series, as well as more sophisticated visualization layouts such as scatter plots, maps, tree-maps, cartograms, matrices, grids, and vendors's proprietary visualizations (e.g., decomposition trees and fractal maps). Recently, 3D interfaces for OLAP were explored [14].

Second, more general approaches to visualize multidimensional data exist [22, 7]. According to the survey [13], existing multidimensional visualization techniques are classified as pixel-oriented (map data value to a coloured pixel), geometric projection (e.g., parallel coordinates), iconography (map each data item to an icon), and hierarchical display techniques (e.g., dimensional stacking, tree-maps).

In addition, a variety of methods for visualizing time-oriented data have been proposed, and the survey [24] and the categorization [2] (systematic view) on the diversity of all these methods exist. According to the categorization, methods are classified according to the 1) characteristics of time axis (e.g., time points vs. intervals), 2) data type (e.g., univariate vs. multivariate), and 3) data representation (e.g., still images vs. animations). Time-series is the special case of a time-oriented data, and a number of visualization techniques were proposed [30, 25, 15].
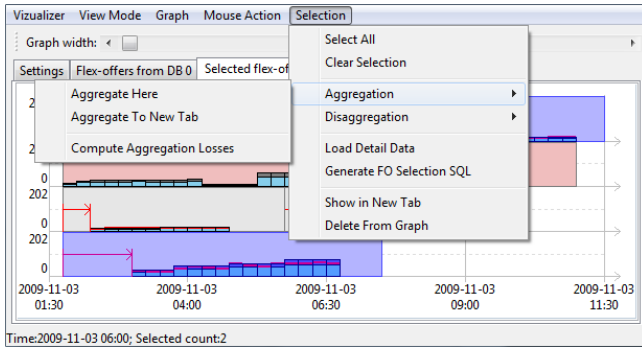
Figure 11: Aggregation tools of flex-offers

For spatial data, a number of cartography/geo-visualization [26], topology-based [20], and domain-specific [21] techniques were developed. In addition, techniques to visualize spatio-temporal data [3] are classified according to (1) the types of spatio-temporal data they are applicable to, and (2) the exploratory tasks they can potentially support. Finally, a number of techniques to visualize data of the regular [19, 18] as well as of the smart [31] electricity grid were proposed, but those - do not consider the visualization of flex-offer.

In the context of the surveyed work, our implemented flex-offer visualization tool employs the variation of histograms plot based on the dimensional stacking method [7], where 2-dimensional subspaces are stacked onto each other. For the complete visual flex-offer analysis framework, existing visualization techniques, particularly those for OLAP, geo-visualization, time series, and electricity data will have to carefully adapted and integrated to support flex-offers.

6. CONCLUSION

In this paper, we have introduced our initial work done to visualize complex energy planning objects, termed flex-offers. Such objects are employed by the MIRABEL system to facilitate the more efficient utilization of renewable energy sources while still providing a convenient approach for energy enterprises to balance energy consumption and production in the European electricity grid.

First, we have provided the insight into energy planning and control activities within a potential MIRABEL enterprise and elaborated on why the visualization of flex-offer data plays a crucial role. Then, we have formulated high level requirements for a comprehensive visual flex-offer analysis framework, which supports various visual analytic activities within the MIRABEL enterprise. Such framework is required to provide detail and generalized views over flex-offer datasets and to offer convenient OLAP-inspired approaches to navigate and explore the data. Then, we have presented the flex-offer visualization tool as our initial result implementing the complete framework. The flex-offer visualization tool meets only the subset of all requirements for the framework, but it offers a novel approach to visualize a large number of individual flex-offers. The approach employs the variation of the histogram plot where 2-dimensional (time and energy) subspaces are stacked onto each other. We have also discussed the immediate extensions of the tool as mile-

stones developing the full-featured visual flex-offer analysis framework. Finally, as flex-offers are instances of multidimensional, spatial, temporal, spatio-temporal, and energy data, we have reviewed the related work on visualization of those particular types of data.

The future work encompass the implementation of all the remaining functionality of the visualization framework with a sufficient quantitative evaluation on how well the functionality serves the end-user needs. Furthermore, an interesting future work is the development of the integrated energy planning and control platform offering high level qualitative information such as alerts about expected shortages or over-capacities and an option to drill down data to find out a reason behind this. The platform might couple the functionalities of the existing SCADA, ERP, planning and auction bidding systems, and, in addition to flex-offers, might integrate other types of data such as costs, prices, energy measurements and constraints as well as the forecasts of energy, weather, and the flexibility of different types.

7. ACKNOWLEDGEMENT

8. REFERENCES

[1] *The MIRABEL Project*, 2012.
    http://www.mirabel-project.eu.
[2] W. Aigner, S. Miksch, W. Müller, H. Schumann, and C. Tominski. Visualizing time-oriented data-A systematic view. *Comput. Graph.*, 31(3), 2007.
[3] N. Andrienko, G. Andrienko, and P. Gatalsky. Exploratory spatio-temporal visualization: an analytical review. *JVLC*, 14(6), 2003.
[4] E. W. E. Association. Creating the Internal Energy Market in Europe. Technical report, 2012.
[5] M. Boehm, L. Dannecker, A. Doms, E. Dovgan, B. Filipič, U. Fischer, W. Lehner, T. B. Pedersen, Y. Pitarch, L. Šikšnys, and T. Tušar. Data management in the MIRABEL smart grid system. In *Proc. of EnDM*, 2012.
[6] S. Card, J. Mackinlay, and B. Shneiderman. *Readings in Information Visualization: Using Vision to Think*. The Morgan Kaufmann Series in Interactive Technologies. 1999.
[7] W. W.-Y. Chan. A Survey on Multivariate Data Visualization. Technical report, 2006.
[8] A. Cuzzocrea and S. Mansmann. OLAP Visualization: Models, Issues, and Techniques. *Encyclopedia of Data Warehousing and Mining, 2nd ed.*, 2009.
[9] M. C. F. de Oliveira and H. Levkowitz. From Visual Data Exploration to Visual Data Mining: A Survey. *IEEE Trans. Vis. Comput. Graph.*, 9(3), 2003.
[10] S. Few. *Now You See It: Simple Visualization Techniques for Quantitative Analysis*. 1st edition, 2009.
[11] U. Fischer, M. Boehm, W. Lehner, and T. Pedersen. Optimizing Notifications of Subscription-Based Forecast Queries. In *Proc. of SSDBM*. 2012.
[12] U. Fischer, D. Kaulakienė, M. Khalefa, W. Lehner, T. B. Pedersen, L. Šikšnys, and C. Thomsen.

Real-time Business Intelligence in the MIRABEL Smart Grid System. In *Proc. of BIRTE*, 2012.

[13] D. Keim and H.-P. Kriegel. Visualization techniques for mining large databases: a comparison. *TKDE*, 8(6), 1996.

[14] S. Lafon, F. Bouali, C. Guinot, and G. Venturini. On studying a 3D user interface for OLAP. *Data Mining and Knowledge Discovery*, 2012.

[15] J. Lin, E. Keogh, and S. Lonardi. Visualizing and discovering non-trivial patterns in large time series databases. *Information Visualization*, 4(2), 2005.

[16] H. Ltifi, M. B. Ayed, A. M. Alimi, and S. Lepreux. Survey of information visualization techniques for exploitation in KDD. In *Proc. of AICCSA*, 2009.

[17] S. Mansmann and M. H. Scholl. Visual OLAP: A new paradigm for exploring multidimensional aggregates. In *Proc. of IADIS*, 2008.

[18] C. Mikkelsen, J. Johansson, and M. Rissanen. Interactive Information Visualization for Sensemaking in Power Grid Supervisory Systems. In *Proc. of IV*, 2011.

[19] T. Overbye and J. Weber. Visualization of power system data. In *Proc. of HICSS*, 2000.

[20] R. Peikert, H. Hauser, H. Carr, and R. Fuchs. *Topological Methods in Data Analysis and Visualization II: Theory, Algorithms, and Applications*. Springer, 2012.

[21] T. Ropinski, S. Oeltze, and B. Preim. Survey of glyph-based visualization techniques for spatial multivariate medical data. *Computers & Graphics*, 35(2), 2011.

[22] H. Siirtola. *Interactive Visualization of Multidimensional Data*. PhD thesis, University of Tampere, 2007.

[23] L. Siksnys, C. Thomsen, and T. Pedersen. MIRABEL DW: Managing Complex Energy Data in a Smart Grid. In *Proc. of DaWaK*. 2012.

[24] S. Silva and T. Catarci. Visualization of linear time-oriented data: a survey. In *Proc. of WISE*, volume 1, 2000.

[25] M. Sips, P. Köthur, A. Unger, H.-C. Hege, and D. Dransch. A Visual Analytics Approach to Multiscale Exploration of Environmental Time Series. *TVCG*, 18(12), 2012.

[26] T. A. Slocum, R. B. Mcmaster, F. C. Kessler, and H. H. Howard. *Thematic Cartography and Geovisualization*. Prentice Hall, 3 edition, 2008.

[27] T. Tušar, L. Šikšnys, T. B. Pedersen, E. Dovgan, and B. Filipič. Using Aggregation to Improve the Scheduling of Flexible Energy Offers. In *Proc. of BIOMA*, 2012.

[28] L. Šikšnys, M. E. Khalefa, and T. B. Pedersen. Aggregating and Disaggregating Flexibility Objects. In *Proc. of SSDBM*, 2012.

[29] C. Ware. *Information Visualization: Perception for Design*. Morgan Kaufmann Publishers Inc., 2004.

[30] M. Weber, M. Alexa, and W. Müller. Visualizing Time-Series on Spirals. In *Proc. of INFOVIS*, 2001.

[31] Z. Zhou, W. Wu, X. Dong, B. Zhang, and H. Sun. A preliminary investigation on smart grid Operation Cockpit. In *Proc. of ISGT Asia*, 2012.