Energy Forecasting and modelling in rural areas

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***Abstract*— Energy forecasting and modeling in rural areas is accomplished through NRG4Cast platform through which a set of real-time prediction and trend detection services are developed based on advanced machine learning, trend detection, prediction, optimisation and reasoning capabilities in order to provide to stakeholders unique service for energy consumption, network failure and energy prices prediction. In order to build up reliable services different type of information are assessed and combined from internal and external sources: historical and current information from the local energy distribution network (energy consumption and network devices status), information about the local environment (natural and social), energy prices (national and international).**

Keywords—component; Energy forecasting; analytics; data mining

I. INTRODUCTION

Rural communities are becoming the most important entities in the evolving green society. They understand local problems and needs, they personalize local governance, they are becoming financially independent, they care about citizen's wellbeing by understanding sustainable development and most important, they are economically stable.

This trend has been supported by NRG4Cast by developing and providing real-time management, real-time analytics and real-time forecasting services for energy distribution networks in rural communities. The services that are integrated in the pipeline and final prediction and decision support system include network monitoring, anomaly detection, route cause analysis, trend detection, planning and optimisation. These services use advanced knowledge technologies in particular machine learning, data and text mining, stream mining, link analysis, information extraction, knowledge formalisation and reasoning. The pipeline has been tested in the two orthogonal case studies energy efficiency in municipalities and energy efficiency in city districts. The two case studies will be complemented with the additional energy networks operated by project partners; electric vehicles network, public lighting system and energy positive buildings. This work concentrates on electric power networks through the development of a generic framework that will be able to control, manage, analyse and predict behaviour in an extensible manner on

other energy networks like gas distribution, heat water distribution and alternative energy distribution networks. For these reasons a generic toolkit with programmable data adapters has also been developed.

II. NRG4CAST PRINICIPLES

The aim of NRG4Cast is to develop advanced solutions for predicting the behavior of local energy networks for the following scenarios:

- Predicting energy demand on several network granularity levels,
- Predicting energy network failures on interlinked local network topologies and
- Detecting short term trends in energy prices and long term trends in national and local energy policies.

To achieve this, an energy management, analysis and forecast real-time service is developed. The software module pipeline includes prediction services and the decision support system is based on network monitoring, route cause analysis, trend detection, planning, as well as optimization. Advanced knowledge technologies is utilized, such as machine learning, data and text mining, stream mining, link analysis, information extraction, knowledge formalization and reasoning. The developed platform is tested against two pilot case studies.

III. METHODOLOGY

NRG4Cast tool developed and set out real-time monitoring and prediction services based on machine learning, trend detection, predictive analytics, optimisation and reasoning capabilities, in order to provide a unique service for energy planning, network failure and energy price prediction. The NRG4CAST tool has the ability to

- assess different types of information, combined from internal and external sources, i.e. historical and current information from the local energy distribution network (energy consumption and network devices status), information about the local environment (natural and social), energy prices (national and international), etc.
- cope with highly dynamic environment of energy distribution networks including emerging renewable energy sources, dynamic network topologies with electric vehicles, local energy storage, virtual plants and others.
- be applied in any type of energy distribution network (electricity, gas, heating etc.), and deal with mass amount of multimodal data in real-time.

In order to achieve its objectives, the concept of NRG4CAST toolkit architecture is to integrate a set of real-time energy monitoring and prediction software components so that it will enable their provision as services with specific APIs to external systems and applications. A crucial requirement for the specification of the toolkit architecture was the ability to combine different types of information provided by different information systems and databases. According to the above and taking into account the requirements of the pilot cases, the NRG4CAST toolkit architecture follows a multi-tiered Web Service Architecture approach. The layout of the toolkit architecture is depicted in Fig. 1.

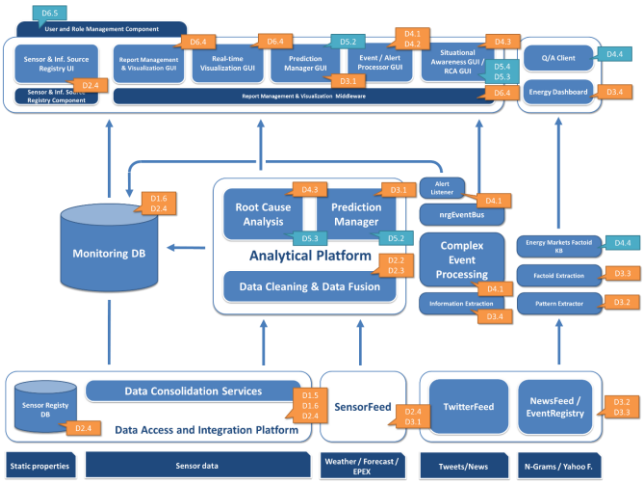

Fig. 1. NRG4CAST architectural diagram Example of a figure caption.

IV. NRG4CAST COMPONENTS

The NRG4CAST components, Data collection, Analytics, and Visualization, as well as authentication and authorization functions, the main challenges faced during their implementation to the tool are presented. Additionally, the Authentication and Authorization functions are also presented here.

A. Data Collection

Data Integration is the process of combining data coming from heterogeneous sources in order to provide a unique query interface to the systems and/or the users requiring access to the data. The main approaches for data integration are:

- The **data warehouse approach** according to which data are extracted from the separate data sources, are subsequently transformed and, in the final step, are loaded into a data warehouse with a single schema. This approach is usually referred to as ETL (Extract-Transform-Load) and it is characterized as tightly coupled.
- The **mediated schema approach** according to which data are retrieved directly from their original databases and only the query interface is provided in a unified way. The unified query interface necessitates a mapping between the original and the mediated schemas: in the "Global As View" (GAV) approach, through a mapping from entities in the mediated schema to entities in the original sources, in the "Local As View" (LAV) approach through a mapping from entities in the original sources to the mediated schema. This approach is characterized as loosely coupled and it is more feasible for datasets that are frequently updated since there is no need for explicit synchronization.

In the context of the NRG4CAST a software platform has been developed in order to integrate data coming from

hundreds of different sensors and other sources as well as necessary metadata.

B. Analytics

Complex event processing is a well known research area, where many possible solutions already exist. NRG4CAST project implemented an open-source solution on top of data layer and part of the application layer (mainly predictions) with the final goal to do some additional reasoning on top of this entire infrastructure. Additionally, CEP systems are able to perform some additional time-related operations on a stream, which can be useful in the simplification of the tasks within the pipeline. Prediction Manager Component in the NRG4CAST setting is essentially a stream-mining solution. The main challenge in such a setting is fusion of multi-modal data from various sources and various types, and preparing it for use in stream mining techniques.

Energy Market Factoid Extraction has also been implemented and tested within the NRG4CAST project. It was based on a statistical approach within a well-known, but not very much exploited dataset of Google N-grams, the most common n-grams, occurring in the web. The n-grams were to be connected with energy market companies from Yahoo Finance and the most common quotes should be extracted and out of them patterns should be created. As depicted in Fig.2, these patterns should be aligned with Cyc Knowledge Base and the extraction of factoids should be performed on a stream of news, being additionally enriched.

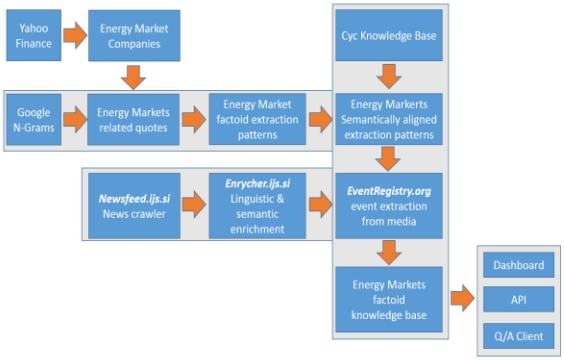

Fig. 2: Initial concept for fact extraction within NRG4CAST

C. Visualization

NRG4CAST visualization part consists of Real-time Visualization and Report Management & Visualization Components. Its responsible for the visualisation of the historical and real-time data coming from different sensors and visualisation of real time information related to NRG4CAST consumption centre, nodes and sensors, metadata and data related to external features.

Moreover, the real time alerting is available within the Real-Time Visualization GUI. The visualization part is responsible for the creation, management and visualisation of predefined and on the fly reports necessary for the NRG4CAST. The user can generate reports on different information and events from the sensor network logs, tasks, notifications, energy consumption and power usage.

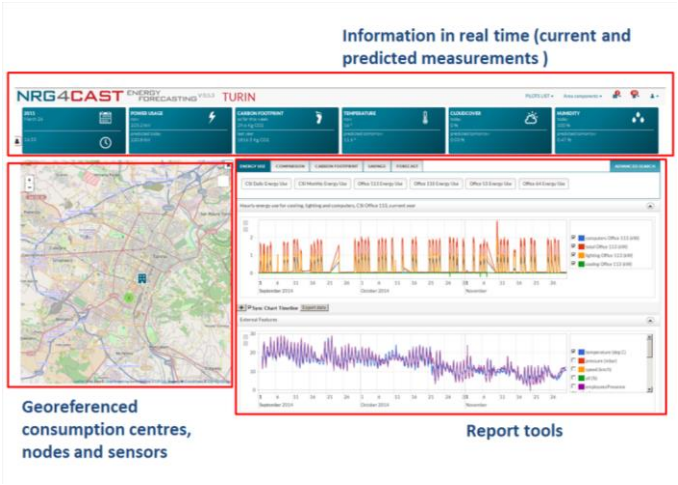

Fig. 3: NRG4CAST prototype GUI

NRG4CAST toolkit allows the user to visualize multiple data series and compare them to each other, navigate and select hierarchy of the consumption centres/nodes, visualize and compare aggregates for certain consumption centres or nodes for different time windows, create and export on the fly reports, visualize prediction vs. current and historical measurements, visualize prediction for different time windows (see Fig. 3). The user can visualise a set of predefined reports on energy usage, consumption, savings and prediction. It also provides the possibility to monitor pilot overall energy consumption and external features such as weather parameters, etc.

It also offers the possibility to visualize georeferenced objects on the map, and to effectuate zoom on the area of interest (chosen pilot site). By clicking on the object, the user visualises all the information related to the consumption centre, node and sensors installed (metadata, location, selected sensors last measurements). The alarm list is connected to the geo-referenced objects. An alarm icon appears on the object once an alerting notice is registered.

D. Authentication and authorization

Authentication is the act of confirming the truth of the identity of an entity, usually of the user of a system or of a specific data item. Authorization is the function of specifying access rights to resources for a specific entity, i.e. to control access of the users to the resources and the functionalities of an information system. A common scenario for access control is the aggregation of users into specific groups and roles and controlling access to system resources and functionalities according to the assignment of permissions to the role pertaining to a user.

V. Pilot Cases Implementation

A. National Technical University Campus (Greece)

Campus sustainability has become an issue of global concern for university Rectorate Authorities of NTUA as result of the realization of the impacts the activities and operations of universities have on the environment.

The National Technical University of Athens aims to monitor the energy consumption for heating, cooling and lighting of the entire campus, as well as to predict the energy demand. The campus monitoring included the electricity load and the thermal comfort level (temperature, humidity, illuminance) inside a typical office at the Campus. The collected data didn't only contribute to the energy demand prediction, but it also showed whether building and building services refurbishment is sensible, in terms of cost efficiency and energy saving potential. These actions enable new possibilities and new strategies for the energy management of the whole Campus.

The realization of the NTUA University Campus pilot case included:

- Installation of electricity sensors for all buildings in the Campus.
- Installation of sensors for measuring the thermal comfort level in a typical office in the Campus.
- Installation of other necessary electrical components: power inverters, analogue to digital converters for the connection of the electricity sensors to the Ethernet network, controllers, analogue to digital converter for the connection of the thermal comfort sensors to the Ethernet network.

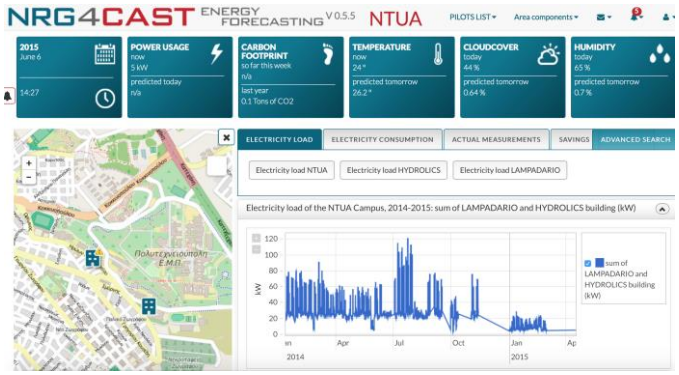

Fig. 4: NRG4Cast platform for NTUA pilot case.

Following energy efficiency strategies in NTUA campus, there has been a reduction in electricity consumption (ref. year 2012) by 12% in 2013 and by 13.9% in 2014.

B. Turin public owned Buildings and Iren Case – District heating in Reggio Emilia , Campus Nubi (Italy)

The Turin case aims to increase energy efficiency in public owned buildings, mainly public offices. Electrical energy and thermal energy consumption is monitored starting from 2011 in the CSI (ICT Consortia) historical building and the 34 public owned buildings in Turin.

According to the Directive 2012/27/EU transposed into Italian Decree 102/2014 in July 2014, starting from 2014 and until 2020 public bodies will have to progressively reduce the energy consumed on their own premises. Actions should be taken towards public owned buildings requalification and retrofit, widespread application of cost-effective technological innovations such as smart meters. An up-to-date information about customer energy consumption, and empowerment of final customers as regards access to information from the metering and billing of their individual energy consumption is needed.

NRG4CAST system meets these objectives by providing a possibility for streaming data integration and management and real time analysis and reasoning and network behavior prediction. Using this system public building owners can regulate their energy use. Moreover, NRG4CAST acts as an energy management system for CSI building (being a large energy-intensive Enterprise because of its Data Centre, CSI is obliged by this new low to implement an energy management system).

The main steps for Turin pilot implementation include:

- Improvement of the accuracy and quality of energy consumption measuring and monitoring.
- Detection of the anomalies in the measurements and sensors functionality plus energy, environmental and economic alerts.
- Monitoring of energy consumption in real time for a number of appliances.
- Possibility to compare energy consumption measurement with the external data stream.
- Possibility to estimate possible savings (see Fig. 5).
- Forecasting of energy demand and costs.
- Actions towards Green Data Centre and awareness

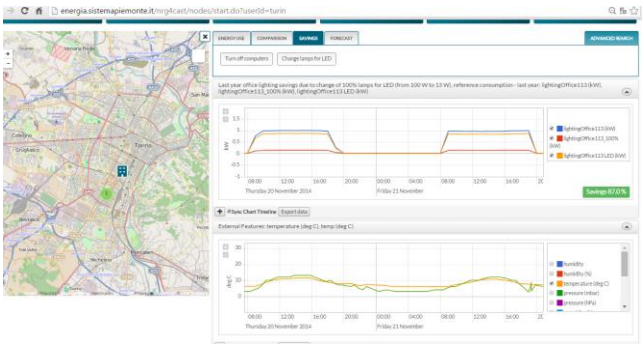

Fig. 5: Estimation of possible savings (what if situation, change old lamps with LED), CSI building

Following energy efficiency strategies in CSI building, there has been an estimated average reduction of electrical energy use due to the innovations developed in the project (ref. year 2013) 20% in 2014.

The main objective of the Iren case is to use the NRG4CAST model to improve the energy efficiency of the production of district heating in the city of Reggio Emilia. The NRG4CAST model foresees the total amount of thermal energy (MWh) requested by the district heating network of the city of Reggio Emilia 2 days in advance, hour per hour, with respect to the outdoor temperature. The aim is to reduce energy consumption and heat loss of the district heating network for the producers of District Heating in the Central thermal plant - at a network level.
The 2-3% of energy consumption savings in 2014 compared to the year 2013 energy consumption of DH network were achieved.

Another objective is a design of a forecasting model which is able to foresee and suggest the optimal water temperature of the secondary level to be provided to each substation within the Campus Nubi in order to keep a pre-defined indoor temperature. The aim is to infer the heating energy consumption, without equipping the network with extra-sensors. The main idea is to demonstrate the feasibility of a theoretical model for inferring the heating energy consumption

Miren (Slovenia)

C. FIR (Germany)

The FIR case aims to integrate the energy demand of electric vehicles into the NRG4CAST solution. Due to the increasing amount of electric vehicles in urban, areas, energy provider as well as the cities energy manager are facing new kinds of challenges, such as:

- How much energy is needed for charging the electric vehicles?
- At what place and time will be a high energy demand for charging vehicles?
- Will there be phases where the energy storages of the vehicles can be used to absorb load peaks?
- How can a network of profitable charging stations be offered?

NRG4Cast targets the to give solid foundation to the new challenges. Therefore, this pilot case predicts the energy demand at a certain time and place. This is done by taking the historical and current data of the charging stations in Aachen into account. In additional, external factors such as weather are considered. The city is energy-wise divided into certain sectors, where each sector is supplied by one transformer. Hence, the prediction is done for each sector. The result can forecast the energy demand for each sector. Deriving from that, the responsible energy manager can prepare for the predicted load at the certain time. In addition, it can be determined what would be a profitable space for another charging station as well as where the demand for charging stations is relatively low.

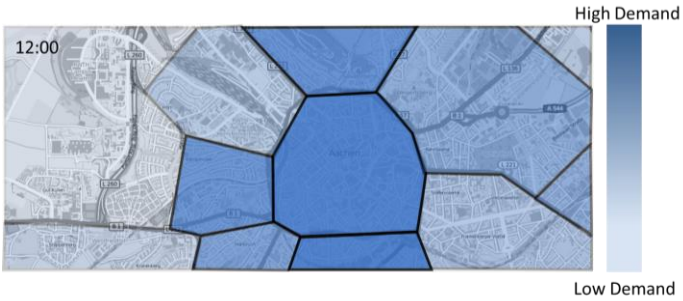

Fig.5:Example presentation of the energy demand in certain sectors in Aachen at 12:00

VI. Discussion And Future Directions

NRG4CAST brought together many different techniques, known in different areas of the data mining/ machine learning community and also among the Internet of Things community. Main research areas worth investing would be focused around: data cleaning (improved Kalman filtering), knowledge generation (on top of models), transition of the models and process modelling – namely for visualizations.

A lot of research on knowledge generation should be focused also on the area that was pioneered within the NRG4CAST projects (with collaboration with ProaSense project) and this area is Root Cause Analysis. This novel approach was introduced at the Discovery Science conference in 2014. As the results are still experimental and as it seems that this might be a wider research area, there are a lot of opportunities here. One might study the impact of different existing clustering algorithms, a lot of research is needed in the area of feature generation and there is also a lot of opportunities in developing a customized clustering algorithm like the one that was reported in NRG4CAST. As such a system is quite complex a lot needs to be done in the area of visualizing and discovering useful results.

The last area connected with modelling is the area of generalizing the models. It is a research area that would need a lot of data for testing, but the outcomes could be really useful. For example – with IREN proposition (see below) one would like to build a mathematical (process based) model of energy consumption for buildings. The current state of the model is rather simple, based on 2 measurable and 1 customizable parameter. Model could be expanded with relevant parameters (see below) and could use any of the known prediction methods. Such a model would be a general one and could be transferred to different buildings, places, areas where no sensor data is available otherwise.

Another important topic nowadays is energy and in fact there are two major fields of interest related to **energy markets**: the

first one regards to ESCO projects and performance contracting and the second is energy grids.

With respect to ESCOs and performance contracting there are two critical aspects to be solved. The first one regards future prediction of energy and financial success of the projects results. The second one is the verification of the project results (performance contracting) with respect to monitoring and verification utilizing the minimum number of sensors (reduction of M&V costs). For the first case it is of high importance to accurately analyse current project parameters yielding to specific energy consumptions and to estimate future energy consumption or energy savings (i.e. financial savings) with respect to certain technological interventions where their performance relies in a series of variables. A typical example of the above is the prediction of the buildings heating and cooling loads and performance of HVAC systems where, in return, they are influenced from system variables irrespective to building loads (such as aging of equipment, seasonal efficiencies, etc.). For the second case, namely M&V, the minimization of the number of sensors can be solved through the development of mathematical models which calculate energy consumption or energy savings with minimal monitored parameters (e.g. temperatures, time and electricity consumption).

With respect to energy grids and the emerging dynamic pricing markets, balancing supply and demand is of particular interest to be investigated. In order to achieve that, monitoring of energy consumption and information extraction of the energy production are of crucial importance. In order to take advantage of dynamic pricing markets and at the same time to sustain grids stability, demand and supply have to be accurately predicted. A major challenge for this particular case is to develop prediction models, particularly from the demand side, where loads are fluctuating in a dynamic manner and grids have to respond on this particular demand, often partially served by external unstable sources (such as on site installed RES), and all the above parameters, as economical and environmentally sound as possible.

In NRG4CAST project we decided to open a new research issue, investigating the possibility of predicting thermal energy consumption by calculation. This prediction model was applied to Campus Nubi pilot, in Reggio Emilia City. First results are encouraging, but a lot of work should still be done. What should be better investigated and refined is the variable affecting the energy rate coefficient. Since this research is very demanding, the experience gained with Campus Nubi pilot paves the way for a new big research project at European level.

VII. Conclusions

Quite a number of tools regarding energy monitoring, energy management, and future energy demand estimations exist in the market nowadays. The NRG4CAST concept was to develop a powerful tool able to deal with big amount of data, different data origin (web data, sensors data, etc), different data time series, and provide with a specific toolkit which integrates different solutions and information sources and a decision-making assistant for short-mid-long term planning of energy demand. The developed NRG4CAST tool provides with a variety of services which monitor energy consumption on different levels of interest, mechanisms that control energy demand, alert in case of anomalies or faults, accurate prediction features for energy demand and energy prices.

The NRG4CAST tool is a platform providing with complete energy services related to monitoring, alerting, reporting and forecasting. It is custom made so that the user gets exactly the information he needs. The tool has the ability to be extended to other important fields like water, environment, and industrial processes.

Acknowledgment *(Heading 5)*

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g.” Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

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