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Computer-Aided Local Energy Planning Using ALEP-PL Software

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Abstract. *The issue of energy system planning, including the planning of local energy systems, is critical, since it affects the security of energy supplies in communities, regions, and consequently the security of energy supply within the country. Energy planning is a complex process that requires integration of different goals i.e. improvement of energy efficiency, increase in the share of renewables in the energy balance and CO_2 emission reduction. Integration of the requirements and objectives may be supported by the computer system tailored to collect and to process the data on energy and fuels consumption. This paper presents the assumptions made during the ALEP-PL computer software development. Advanced local energy planning is presented and the role of information systems in energy planning is discussed. In addition, the paper presents the advantages and disadvantages of existing computer applications supporting energy planning. The paper presents the current version of the ALEP-PL, which consists of database and web application and compares the application with existing solutions. The entity relationship diagram of ALEP-PL database is discussed. The main application interfaces are presented. The paper defines the main actors of the system and discusses the use case diagram. Examples of the use case analysis enabled the demonstration of the software functionality.*

Keywords: *local energy planning, energy system, database, internet application.*

1. Introduction

This study was prepared within the scope of the project: TEWI Information Platform - Innovative Economy Operational Programme, Priority 2 - Action 2.3 - Action 2.3.1 "Projects for the development of information infrastructure for science" and Action 2.3.3, "Projects for the development of advanced communication services and applications "grant Agreement No. POIG.02.03.00-00-028/09-05.

Presented results of the study constitute a milestone on the way to build advanced applications and services for the development of IT infrastructure that will be applied in science. The computer software presented in this paper is innovative and original.

2. Description of the problem and the need to solve it

In the course of the research performed at the Department of Electrical Power Engineering (DEPE) within the structures of Faculty of Electrical and Control Engineering at Gdansk University of Technology (GUT FECE), it was noted that there is a need to build an advanced computer application for data collection and the analysis of trends in energy supply systems development.

Similar conclusions were drawn upon the implementation of the methodology applied in a European Commission sponsored project under the acronym: PATH-TO-RES [1]. That project demonstrated the need for the development of tools to perform the planning process more efficiently, including better identification of needs and opportunities.

In the past years, the DEPE team applied several computer applications, including PPP model [2] - describing the supply side, transmission system, and the demand side of district heating system, or the "Calculator" used to determine the cost of heat supply from different technologies. These models, however:

- Do not meet the criteria for advanced energy development planning [3, 4],
- Are dedicated to the selected energy sub-sector, for example to district heating,
- If applied in the analyzes, they do not include information from all the key actors involved in the planning process,
- Are not integrated with any web site, and therefore are not any part of the dissemination of research results.

For these reasons, most of the research studies performed at the DEPE is performed without the use of dedicated computer applications supporting the planning of energy systems, using temporarily created spreadsheets and local MS Access databases instead.

The solution to these problems is a dedicated computer software supporting the process of planning the development of energy systems in a community or a region. Key elements of this system are:

- Secure data collection system based on a database system,
- Internet service for data collection and the analysis of the results,
- Modules of business logic applications, mainly in the form of programs that use the .NET framework written in C♯.

Choosing a computer system in the form of web site was necessitated by the need for communication between the key stakeholders of the planning process and the need to collect data from smaller companies, cooperatives and condominiums, or even from the inhabitants. Municipalities and their inhabitants have a significant potential for energy savings and the selection of new energy sources. This may potentially be obtained by:

- Change in the energy consumption patterns,
- Implementing efficient lighting technology,
- Insulation of buildings,
- Better adjustment of supply to demand, or consumers own needs (changing tariffs, shifting consumption into zones of lower day rates of charges for energy),
- "Switching" to other energy carriers,
- Popularization of autonomous energy supply systems,
- Development of public transport and cycling.

The range of possible activities is much broader, but these mentioned above sufficiently justify the need to collect detailed data through the website.

The current scope of responsibilities of local governments in Poland and other European Union Member States include the planning of energy sector within local economy or region. City councils and municipalities are required to have a documented strategy with well-defined objectives of meeting the demand for electricity, heat and natural gas. Marshal Offices, in turn, are required to keep their energy policies in line with national and EU policies taking into account regional conditions. The regional policy is a set of strategies for each energy sub-sector and corresponding activities. For example, there are strategies for energy systems development based on renewable energy sources, strategies for improving energy efficiency in industry or household sector.

Urban or municipal offices, town halls, even in large cities, lack for the potential in the field of energy, having little competences to develop local energy policy. The situation is similar in most of the Marshal Offices in Poland. These offices employ specialists in the energy sector as consultants, but they do not have the potential of entire teams, which could develop a strategy for energy sector development in the region.

For these reasons, the tasks to develop energy policy objectives of the municipality or the regional energy development strategy are taken by energy conservation agencies and foundations, and particularly by research teams at universities.

An example of such a team is the Power Plants and Energy Economics (PPEE) team acting within the Department of Electrical Power Engineering (DEPE) at Gdańsk University of Technology (GUT).

Software employed by the team supports the performance of research studies devoted to the analysis of local energy systems and energy development planning. The ALEP-PL software fulfills relevant function in a set of tools used by the team.

3. Alternative computer programs for the analysis of energy consumption data

The following chapter briefly describes the existing sample applications supporting local energy planning.

3.1. SEC-BENCH - http://secbench.webcat.no/

Towns and municipalities conduct benchmarking of indicators of energy consumption, emissions, costs of modernization, failure, equipment life, performance,

Figure 1. Benchmarking system SEC-BENCH (source: secbench.webcat.no)

comfort through an Internet portal SEC-BENCH, which interface was presented in Fig. 1.

Comparison is relative to a certain standard e.g. standard energy demand (as defined in the Regulation on technical conditions to be met by buildings) or other industry standard, such as Best Available Technology (BAT).

3.2. REAM – Regional Energy Analysing Model

REAM is a multi-scenario tool for local and regional energy planning that is capable of analyzing the energy system in a municipality, region, selected sub-sector or geographic area. REAM has been developed within the 3-NITY project funded by the European Commission. The tool was implemented by consulting companies: Profu from Sweden and IFE / NEPAS from Norway. REAM has been developed in Microsoft.NET technology. As a result it can be installed on computers with Windows XP or newer operating system. REAM license is provided after passing the registration process and is available to municipalities, regional authorities, private companies and educational institutions.

REAM includes technical data and economic information on:

- Local production of energy in systems of both small and large scale,
- Transmission infrastructure for electricity and heat,
- End-use energy,
- Measures to improve energy efficiency.

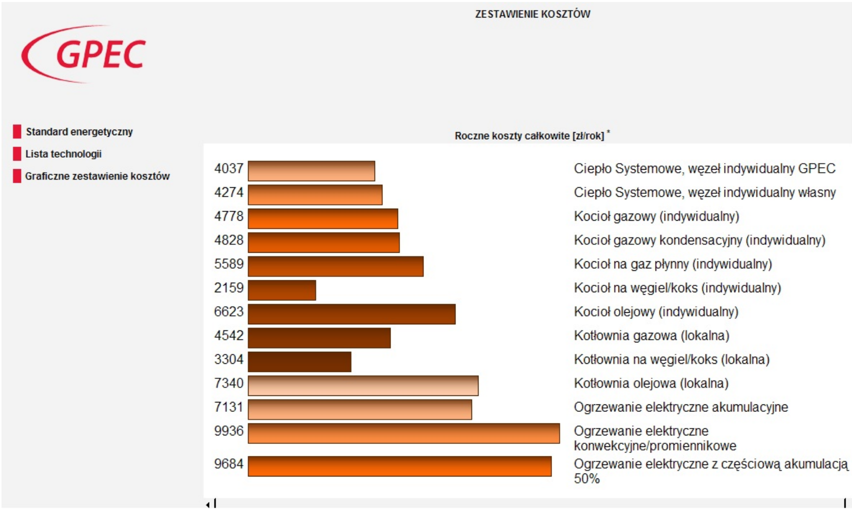

Figure 2. Kalkulator GPEC - Comparison of annual heating costs (source: own study)

This tool calculates the solution on the least-cost basis. REAM users can choose the level of detail, for easier handling, e.g. if they are insufficiently experienced to perform more complex analyses.

3.3. Calculator of heating costs

Approximately 6 years ago, the team from the Department of Electrical Power Engineering (DEPE) has developed a tool to determine the ranking position of district heating companies in the local heat market. The software has been implemented in the GPEC enterprise in Gdańsk and adopted the name “Kalkulator GPEC”. The interface of this application was presented in Fig. 2.

Basic values for the calculator are the demand for heat and thermal power for user-defined customers, broken down by various needs (heating, ventilation and hot water). The algorithm can alternatively define the customer using three different models for calculating the heat demand. In each model, the customer is described by the other input parameters, whereas calculations are performed according to different equations.

The system distinguishes between technologies: basic heating, additional heating and hot water technologies. In addition, each technology may consist of: heat source, transmission system and internal installations. Each technology is specified by advanced program user, who provides technical and economic data. Additionally, expert users predefine Investment. The term Investment means the list of technologies that provide comprehensive coverage of heat demand.

The program calculates the capital costs, annual fuel costs, and annual total costs divided into fixed and variable constituents. In the case of investment in facilities supplying energy to many users, the expenditure is divided by a number of users. As a result. the costs attributed to a single energy user are presented.

The end user of the computer application answers the questions of the survey, which allows the consumer to determine energy standard. After entering these data user can make evaluations and comparisons for selected investments (Fig. 2).

However, this tool rather compares technologies meeting the demand for heat than specific objects, and is limited to the indicators in the form of unit costs. Similar tools exist on the websites of electricity and gas suppliers.

This kind of tools however do not take into account any local or global energy policy goals.

3.3.1. RetScreen Software

The RETScreen software is distributed on behalf of the Government of Canada through Natural Resources Canada Agency (Fig. 3). The software consists of several modules in the form of spreadsheets. Each spreadsheet is dedicated to the selected type of renewable energy.

The RETScreen downloads weather database for a number of cities in many countries with given temperatures and the average degree-days for each month. Climate data related to building information enable the user to determine the annual demand for space heat and hot water.

This software enables the user to model heat transmission and distribution systems using the data embeded into the worksheet. Pipeline lengths and their loads are calculated on the worksheet Heating & Network load (Fig. 4).

The software analyzes the cost of heat sources and the cost of the connection to district heating system. RETScreen calculates economic indicators of investment and compares this investment with other options of heat and electricity supply.

Figure 3. Website of RetScreen project (source: retscreen.net/ang/home.php)

District Heating Network Design		Estimate /Total				
Design Criteria						
Design supply temperature	°C	95				
Design return temperature	°C	60				
Differential temperature	°C	35				
Main Distribution Line						
Main pipe network oversizing	%	20%				
Pipe sections	Load	Length	Pipe size	Is the Building cluster supplied by this pipe section? (yes/no)		
	(kW)	(m)	(mm)	1	2	3
Section 1	264	120	DN 65	Yes	Yes	No
Section 2	132	40	DN 50	Yes	No	No
Section 3	231	110	DN 65	No	No	Yes

Figure 4. The RetScreen Worksheet for District Heating Design (source: own)

Table 1 summarizes the characteristics of computer programs described above. It should be notified that existing applications are missing functionality. The ideal tool should include:

Table 1. Advantages and disadvantages of existing computer applications

	SEC-BENCH	**REAM**	**Kalkulator GPEC**	**RetScreen**
Presentation of local objectives against the objectives of the EU and the country	yes	yes	no	no
Web interface	yes	no	yes	no
Fuel and energy balance	no	yes	no	no
Creating scenarios	no	yes	no	no
Non-technical user interface	yes	yes	yes	yes
Expert interface	no	yes	yes	yes
Language	English /Polish	English	Polish	English /French

- Web interface for non-technical users to facilitate the collection of data on infrastructure in the municipality or region,
- Solver, which allows the preparation of energy balances and energy scenarios,
- Expert interface, which allows them to define indicators.

REAM model has many of these advantages. This model, however, does not have a suitable web interface. Additionally, the application of this model is related to a broad co-operation with consultants and experts from the companies that created the software. Arrivals of consultants from Norway and Sweden and their salaries may cost too much for the majority of Polish communities. Thus the creation and development of own computer application supporting energy planning is justified.

4. Design of the ALEP-PL computer software

The ALEP-PL computer software was designed as a web site with a relational database. The database of ALEP-PL system is shown by an entity relationship diagram (ERD) (Fig. 5) and the aggregated data model (Fig. 6).

The database consists of 37 tables in total. The above diagram shows the tables that model the relationship between the sectors of energy consumption. Another

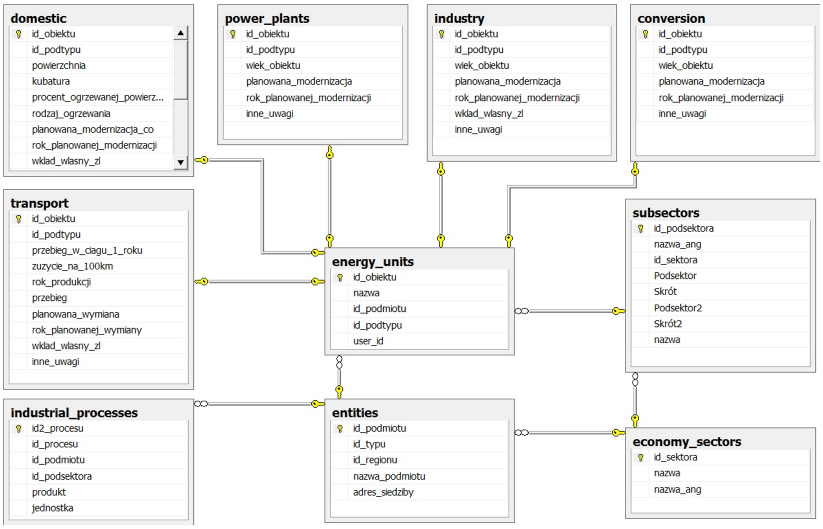

Figure 5. Part of entity relationship diagram – model of energy data (source: own)

group of tables describes the technologies to improve energy efficiency and investments that, in fact, are sets of technologies. Large group of tables provides data concerning program users and their privileges. The structure of data concerning program users and their privileges has been taken from the template user database in ASP.NET 4. [5]

Fig. 6 presents data aggregation in the ALEP-PL software. Aggregation of energy sectors was presented also in ERD (Fig. 5). The whole economy is divided to sectors and sub-sectors. Individual consumers and enterprises, including energy companies, belong to particular sector of economy. They consume fuel for end use or to electricity generation or to heat production. Some fuel and energy consumption is related to industry processes e.g.: production of cement, limestone, steel, non-ferrous metals, pulp and paper, sulfuric and nitric acid or oil refining. These industrial processes are treated in a special way since energy consumption is not limited to fuel combustion in boilers and because CO_2 emission coefficients differ from those for simple combustion.

Power units and energy facilities are assigned to particular region or municipality. Sometimes the geographic area should have more detailed description and the name of district within a town or name of housing estate are added to the

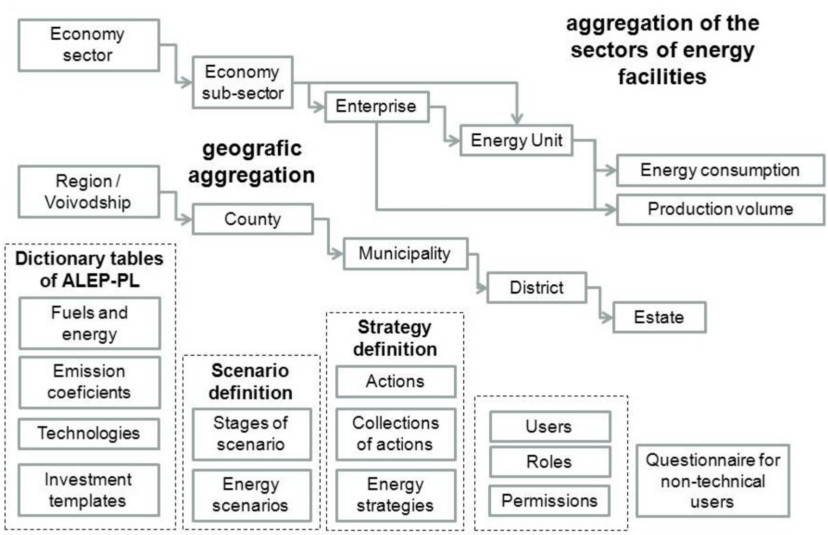

Figure 6. Data aggregation in the ALEP-PL computer system (source: own)

database. A detailed description of the location of objects enables the user to build scenarios for small communities.

In addition, Fig. 6 presents a group of entities characterized by essential attributes: fuel characteristics, air pollutant emission factors, technical and economic data of the technologies. At this stage, the ALEP-PL does not model neither the noise from power plants, nor water pollution. Investments, as in the "Calculator GPEC", are predefined in the form of exemplary sets of cooperating technologies.

The "Scenario definition" group in Fig. 6 contains the entity "Scenarios" with description of scenarios to improve energy efficiency, increase in the share of renewables in the energy balance and reduce CO_2 emission. Each scenario is identified by a number and a name and is valid for geographic location. Set of goals in particular period of time and geographic location creates the stage of the scenario. The sorted set of stages consist a scenario. The part of database of ALEP-PL system including scenario tables is shown by an ERD (Fig. 7).

The "Strategy definition" group in Fig. 6 contains the entity "Action" with description of actions to improve energy efficiency of particular energy unit. Set of actions in particular period of time and geographic location creates the collection if actions in the scenario. The strategy is identified by a number and a name and is

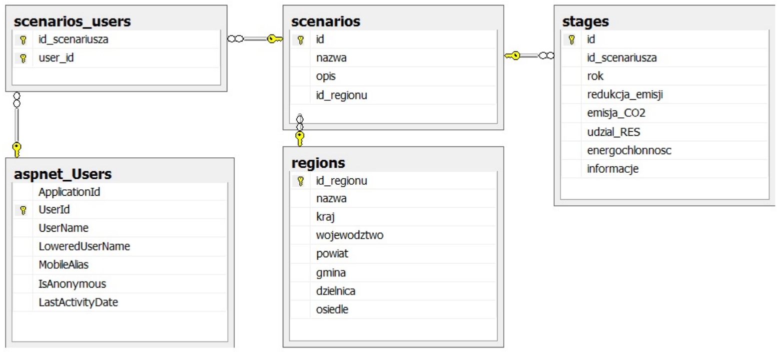

Figure 7. Part of entity relationship diagram – model of energy scenario (source: own)

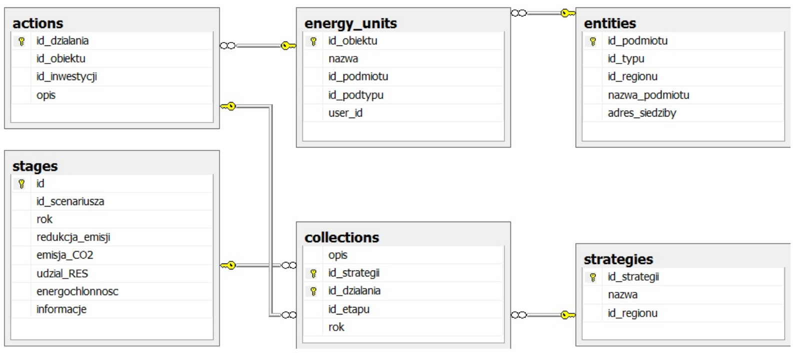

Figure 8. Part of entity relationship diagram – model of energy strategy (source: own)

valid for geographic location. The part of database of ALEP-PL system including strategy tables is shown by an ERD (Fig. 8).

Security mechanisms of the ALEP-PL computer system are based on the ASP.NET 4 template. In particular, the structure of data concerning users, their roles and privileges, the mechanism for assigning users to roles, and the personalization mechanism of the application functionality have been taken from the template user database in ASP.NET 4.

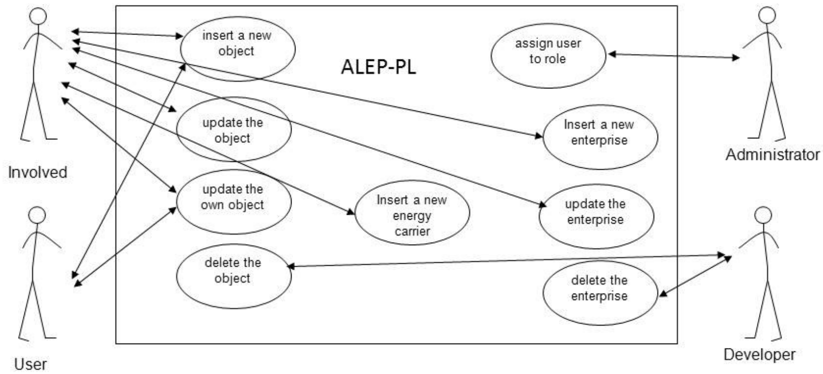

Figure 9. Examples of use cases (source: own)

The last mentioned entity in Fig. 6 is Questionnaire. The non-technical user of the computer application answers the questions of the survey, which allows the consumer to determine energy standard, e.g. annual heat demand in building or flat.

In Figure 9 a diagram of selected use cases was presented. Users with different roles operate on data stored in tables of energy facilities and industrial plants. Developer designs database objects and builds the application. It is a role for the users who is database owner, and who can create, drop and modify database objects. The Devloper role also authorizes user to delete rows of data, in circumstances where the tables are in restrictive relation. Developer is capable of interpretation of messages with regard to referential integrity violation. Developer has also an access to directories on the server hosting the ALEP-PL software. Involved users are those with broad privileges in the computer system and they understand the complexity of planning the development of energy systems. They are also capable of converting units of energy, power, mass, volume and other commonly used units for technical and economical parameters. Consultants and specialists in the field of energy, the officials responsible for energy management, employees of energy companies involved in planning the development of energy systems possess this kind of knowledge. Involved role permissions include the permissions of User role.

User is the role with the responsibility for the inserting data of a particular facility. Users in this simple role usually describe their own energy sources and

Figure 10. Example of ALEP-PL interface (source: own)

facilities. These data are usually more descriptive and do not need to be fully compatible with the semantics of the ALEP-PL software, for example, the energy consumption may not be presented in the proposed units. Before writing to the database these data will be processed by the ALEP-PL system. Alternatively; data will be corrected by the expert user assigned to the role Involved. In Figure 10 an example of an interface to view and edit fuel data has been shown. The entire application has been created in Polish language. However, data stored in the database have also definitions in English, which is to facilitate the use of the application in international projects. Presented interface enables the user to view data on fuels and their manipulation. Most interfaces for CRUD data manipulation are based on GridView control of ASP.NET 4 with nested drop-down lists. The DropDownList controls are filled with data from dictionary tables. Individual events are supported by methods developed in C♯ [6].

5. Summary

Developed version of ALEP-PL software does not integrate external modules containing e.g. linear programming procedures allowing optimization or modules implementing evolutionary algorithms. The direction of the software development includes integration of the application with external modules or direct implementation of the algorithms. One of the algorithms to be implemented directly is based on artificial neural network algorithm for the suggested values of missing data. The research team at the Department of Electrical Power Engineering uses GAMS software and MARKAL model [7] for optimization tasks. These tools could be integrated with ALEP-PL in the future. There is also a possibility of integration with other models developed in the country, e.g. a new evolutionary algorithm for routes generation in public transport or in district heating [8]. Despite these shortcomings, ALEP-PL software fits well with the requirements for energy efficiency, CO_2 emission reduction, increase in the share of renewables in the energy balance, including the Energy Efficiency Act of 15 April 2011. Currently, the ALEP-PL computer tool is attractive mainly for policy makers and key actors in the energy market or other institutional stakeholders. City councils and municipalities are required to have a document with well-defined objectives of meeting the demand for electricity, heat and gas. Voivodships (Polish regions) are required to have an energy policy in line with national and EU policies. Similar studies are also ordered by energy companies. Through such analyzes, the managers in energy companies and local authorities shall have:

- An ordered picture of the situation on local energy market,
- An inventory of their potentials, such as energy consumption in municipal buildings against the other owners of buildings,
- Estimation of operating cost savings that may be achieved in short term perspective,
- Identification of the most effective activities to improve the quality of life and enhance development potential of the community or region,
- Documentation that will be used in the application for funds for modernization activities (e.g. under the EU Covenant of Mayors or in other activities).

Additionally, the politicians and decision makers can shape the local or internal regulations taking into account the knowledge from ALEP analysis. Currently,

Figure 11. Example of a dynamically created drawing on the ALEP-PL website - investment unit costs (source: own)

ALEP-PL software is not attractive to ordinary citizens and consumers of energy. Experience with the implementation of the "Kalkulator GPEC" gained by the author of this paper proves that the presentation of diagrams with recalculated or aggregated data may encourage users to answer questions of a computer program in a reliable manner. Sample results from the system are presented in Figure 11. In next step the author chose to develop the following reports:

- Reference own energy to other customers in the neighborhood or region,
- An estimate of fuel consumption or CO_2 emissions for environmental report (which is mandatory for an increasing number of consumers),
- A review of possible solutions to meet energy demand and assessment of their popularity,
- Information on trends of choices done by other users.

The proposed tool will help research staff to perform tasks to develop local and regional policies by automating the communication between all key players in energy policy development process. Of great importance is the fact that the tool organizes the collection of data and provides the appropriate structure for data management and aggregation. As a result, the outcomes will be properly embedded in the data on energy consumption. Due to ALEP-PL, the verification and modification of the developed strategies will be easier in future iterations of the planning process. Periodic repetition of the planning process is consistent with the methodology of advanced planning and even enforced by it.

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