SOFTROL Advisory System for Agri-Energy Complexes

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Abstract. The article presents the general concept, key assumptions and a description of the SOFTROL advisory system. The system has been implemented online, and it is available to all potential users. It supports virtual design of agri-energy complexes and optimization calculations for maximize farms' ability to harness their energy potential and meet their energy needs based on renewable energy sources.

Keywords: advisory system, agri-energy complexes, database

1 Introduction

Every agricultural undertaking is a consumer and a producer of energy. Energy resources that have not been used up by a farm can be utilized productively. The energy generated by a farm can be harnessed to cover the farm's needs, and surplus energy can be used to generate additional income and improve the farm's economic performance. This strategy underlies the operations of agri-energy complexes. An agri-energy complex can be defined as an organization that utilizes all available resources to meet its energy demand or to generate surplus energy.

Regardless of its size, production profile and organizational model, every farm has specific energy needs and energy potential that can be utilized productively. Therefore, even the smallest farm fits the definition of an agri-energy complex.

This study describes an advisory system for decision-making support in an agri-energy complex with a specific production profile. The system has been designed and built as part of key project No. POIG.01.01.02-00-016/08 entitled "*Model agri-energy complexes for distributed cogeneration units based on local dispersed sources of energy*". The system can be implemented in the existing, currently

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developed and planned agricultural undertakings. In this study, the described system is referred to as a *potentially designed agri-energy complex* (*PDAC*).

2 An agri-energy complex as a producer and consumer of energy

The energy potential of an agricultural undertaking has to be estimated to guarantee the effectiveness of every polyoptimization system. The required infrastructure, type and volume of wastes and by-products, surplus production and agricultural acreage that can be dedicated to energy crops have to be described in detail.
A diagram of an agri-energy complex as a producer and consumer of energy is presented in Figure 1.

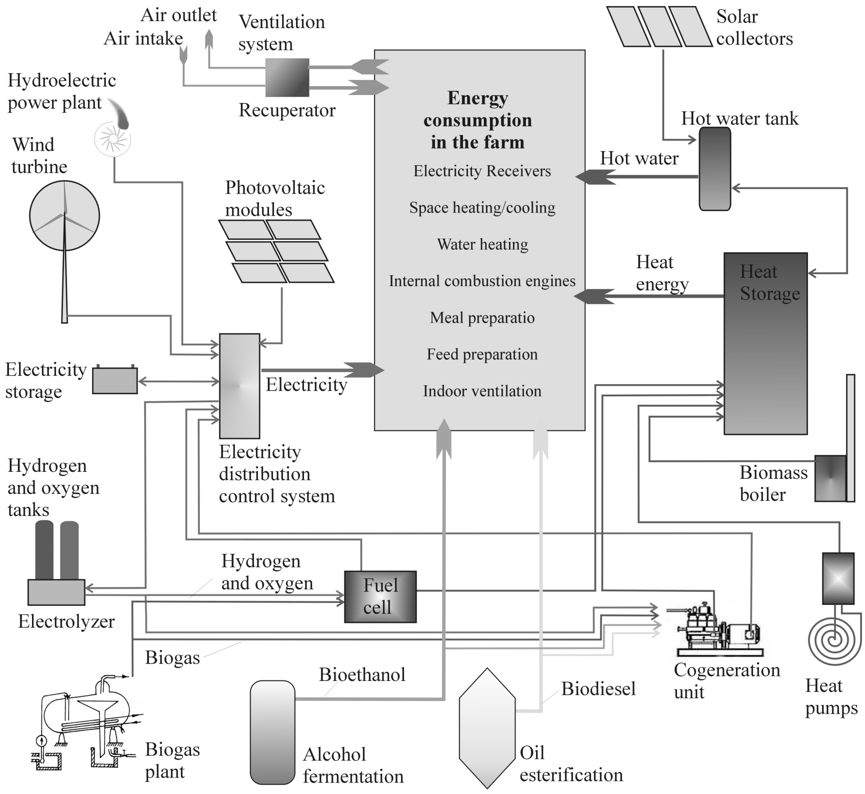

Fig. 1. PDAC as a consumer and producer of energy (Pietkiewicz et al. 2014).

An agri-energy complex consumes three types of energy:

- electrical energy (lighting, household equipment, production equipment, machines and electrical devices),

- heat (indoor heating, water heating, meal preparation, drying agricultural produce),
- mechanical energy (powering windmill pumps, conveyors, etc.).

In addition to conventional sources of energy (fossil fuels), an agri-energy complex can also rely on renewable sources of energy to cover its energy needs:

- solar energy (liquid and hot air solar collectors, photovoltaic modules, passive solar heating systems),
- wind energy (wind turbines for generating electricity and powering compressors and pumps),
- hydraulic energy (low-power hydroelectric turbines),
- biomass (direct combustion and pyrolysis of plant wastes, straw, wood, sawdust, energy crop residues; ethanol fermentation: cereal grain, wood, plant wastes; methane fermentation: farm manure, plant wastes),
- liquid fuels (for powering combustion engines in transport vehicles and machines, cogeneration units and fuel cells), fossil fuels.

The use of diverse energy sources and different methods for generating, converting and storing energy supports the development of modular solutions that rely on various combinations of the available technologies (Fig. 2).

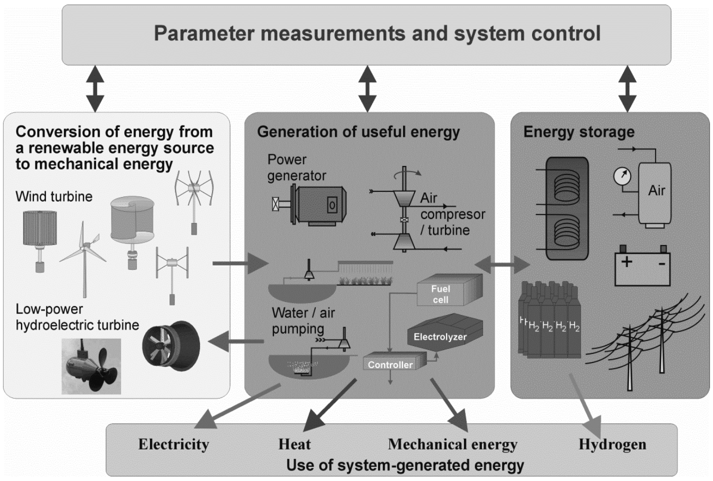

Fig. 2. Modular solution for converting, storing and conditioning energy from renewable sources (Nalepa et al. 2014)

3 Computer software advisory system for planning the operations of an agri-energy complex

Advisory systems consist of computer software that supports decision-making in various areas of activity. Dendral was the first artificial intelligence project, which led to the development of a computer software expert system in 1965. Dendral was originally designed for chemists, but many expert systems for medical diagnosis were derived from Dendral in successive decades. Medicine is the ideal field for an advisory system, which relies on rules of inference based on information about specific diseases that is gathered in databases. The system analyzes data input into the program by a user who requires expert advice (advisory system). Advisory systems are shells that are filled with knowledge by a user based on a set of rules. There are limitless possibilities for developing advisory systems based on unique data in a given area of interest.

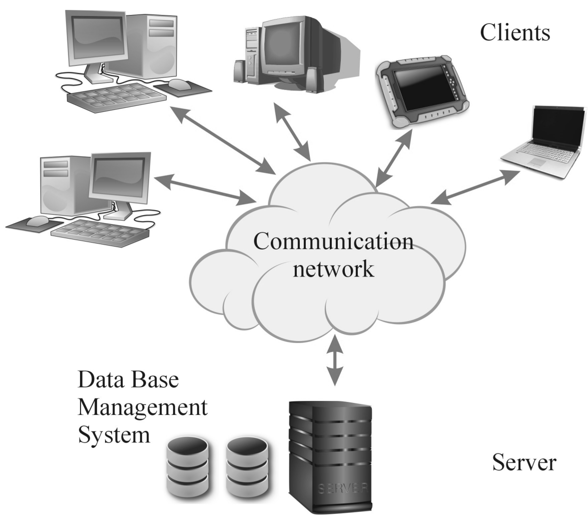

Fig. 3. Diagram of client-server architecture (Pietkiewicz et al. 2014)

Key assumptions in the process of developing the SOFTROL advisory system

The discussed advisory system was developed based on the following key assumptions:

- the designed system will have client-server architecture, and it will be accessed via a web browser (Fig. 3);
- the user is not expected to possess expert knowledge about crop production, materials or energy equipment,
- the system will be available to several groups of users with different levels of access. This hierarchy will be established to distinguish between users who have expert knowledge and users who require expert knowledge (results output by the system),

- inference rules have to guarantee that the system is flexible and suitable for a wide range of applications. The authors' role should be limited to designing the system framework.

Main system functionalities

The SOFTROL system will have the following main functionalities based on the key assumptions of the research project and the modular database concept:

- the system will collect data and provide users with information relating to optimal technologies for the production of crops, animals, energy sources and energy,
- the system will provide registered users with information relating to energy generation devices and optimal technologies for the generation of heat and electricity,
- the system will collect information about devices for the generation of heat and energy from renewable sources and will use the resulting data in the polyoptimization process,
- the system will assist users in selecting energy conversion devices based on multiple criteria.

System users and their role in the system

Several groups of users were defined in line with the expert system concept and the key assumptions for developing an advisory system for agri-energy complexes. A hierarchy of users with different access levels was created to distinguish between users who are providers of exert knowledge and users who request information from the SOFTROL system. The following groups of users were defined:

- farmers, independent producers, associations of producers and local governments who analyze and design agri-energy complexes, heat and electricity producers who use or plan to use the technologies described in the system,
- advisory organizations operating in the field of agriculture, power generation, regional and national energy development,
- equipment manufacturers and distributors,
- producers and distributors of energy resources and fuels,
- scientific organizations that require access to the database for research purposes.

Information collected in a relational database

The normalize the database, the process of collecting information will be governed by the following rules:

- the system will collect personal information about users in the database, including user identity, geographical location and administrative region. Users who input information into the system on behalf of other users will be placed in specific functional groups,

- information relating to a user's energy requirements will describe all elements of the infrastructure and devices that cater to the user's household needs (farms), operational needs (institutions), demand for energy that is sold (contracted) and generated from the existing resources,
- energy demand associated with the production and conversion of energy resources will be indicated in the description of the proposed technology, and it will not account for the user's energy needs,
- a user's energy potential is defined as natural resources and limitations. In crop production, a user's potential is determined by agricultural acreage; in animal production – by the number of buildings and facilities for animal rearing (based on the number of animals per unit area) which are owned or have been contracted for energy generation purposes. In the above approach, a user's energy potential is evaluated based on the existing output as well as potential outputs in the future. A user's energy potential is determined based on the area of farmland in different soil quality classes and the area of production facilities.

In the process of developing the database, the information that can be directly input into the system and the data associated with other types of information in the user's possession was identified in the modeled agri-energy complex. An analysis of the modeled agri-energy complex revealed that most elements of the model are indirectly linked with the norms, standards and average values applicable to agricultural production. An individual farmer is not expected to be familiar with all parameters relating to his farm or the production process. As regards large agri-energy complexes and prospective farmers who are in the process of planning the production of energy crops and/or energy generation, the values of most modeled elements will be the expected system outputs.

The information stored in the database should be available and comprehensible for an average user. Some of that information constitutes single-use data embedded in the PDAC. Data entries can also relate to specific attributes describing various users (potential crop production), which requires the creation of several subsets of multiple-use data.

Modules of the SOFTROL advisory system

The database of the SOFTROL advisory system consists of several modules that are closely linked with the user interface. The entities in the database have been defined. The network connecting three database modules and their links with different entities in the database are presented in Figure 4. The presented diagram was used in the database normalization process.

In the user interface, the *species* and *materials and carriers* entities are separate structures that are not allocated to any module. The *devices* entity overlaps the data acquisition module on energy conversion devices. In view of the required quantity and quality of data relating to energy generation devices and equipment used in the production of energy resources, the database system has to be provided with extensive mechanisms that control data access and the quality of input data. The information about producers, equipment efficiency and fuel is an integral part of the module marked in green, but it is not an interface between the remaining database modules.

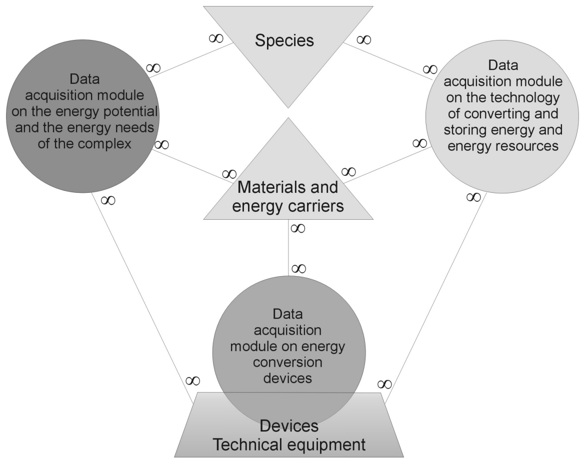

Fig. 4. Diagram of connections between database modules in the *SOFTROL* advisory system (Pietkiewicz et al. 2014).

4 Development of the SOFTROL advisory system

The database and the user interface were designed based on the described concept. Information was stored in a MySQL database, and the user interface was written in PHP, a popular object-oriented language for developing web applications. PHP is used mainly for server-side scripting (Hilton et al. 1999)

Data acquisition model on the technology of converting and storing energy resources

The designed system contains a data acquisition model on the technology of converting and storing energy resources. We will use this module to describe various stages in the process of designing and implementing the advisory system.

In a software system, technology is defined as a chain of operations, which represent successive stages in the process of achieving a specific goal, such as the production of fuel or an energy resource. In a farm, different technologies are used to produce crops and animals, but similar stages can be identified in every production technology. The designed system should contain a universal technology for designing any process in an agri-energy complex. The universal technology should also support the design of other technologies that are not directly linked with crop or animal production, such as biogas production technology for biogas plants in sewage treatment facilities. The universal technology was developed in a series of steps:

- significant similarities between the modeled crop and animal production technologies were identified,
- significant differences between the modeled crop and animal production technologies were identified
- parameters for minimizing differences between the modeled crop and animal production technologies were determined,
- data sets and parameters were expanded to account for the needs of other technologies.

Table 1. A comparison of the main stages in typical crop, animal and universal production technologies (Pietkiewicz et al. 2014)

Crop production	**Animal production**	**Universal production technology**
Selection of species and variety	Selection of species and breed	Selection of species
Land cultivation	Preparation of animal facilities	Preparation of production area
Production or purchase of seeds, pre-sowing fertilization, sowing and planting	Selection of breeding stock, preparation for mating, mating / purchase of animals	Beginning of breeding
Cultivation: fertilization	Nutrition	Nutrition
Cultivation: crop protection	Disease prevention and treatment	Pest and disease control
Harvest	Slaughter or sale	Harvest

Similarities between crop and animal production systems were identified to standardize their description in the advisory system. The simplest technological model is composed of a series of successive stages, where selected stages are obligatory and other stages are optional. Different stages in crop and animal production technologies were compared. The results of the comparison are presented in Table 1. Similar stages were identified in all of the compared technologies. Despite significant differences in treatments, the conditions under which they are applied and the time of their application, every stage of the production process involves a specific number of operations. A given set of materials, devices and workers necessary for the described operations can be allocated to every stage of the production process. This approach has been adopted to evaluate the energy consumption, cost and duration of every operation. In each technology, the end product can serve as a resource in another technology or as an energy carrier for the generation of electricity, heat or mechanical energy. End products can also be sold.

The correlations between data sets relating to technologies for the generation of energy or the production of energy resources are presented in a diagram in Figure 5.

A specific technology is used to produce one or more products, including energy resources. The entire technological process is a chain of many technological operations. Specific materials, resources and devices can be allocated to each operation. Complex technologies that can be developed based on the processes listed in the database are also indicated in the diagram.

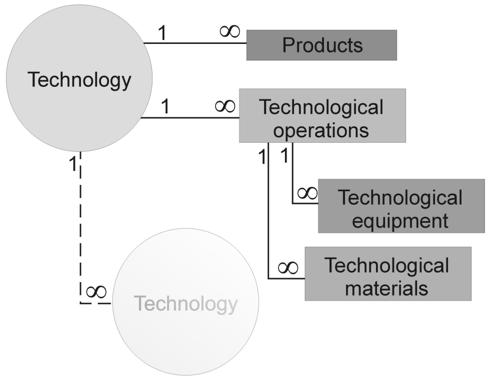

Fig. 5. Correlations between data sets describing individual components of technologies for the generation of energy and production of energy resources (Pietkiewicz et al. 2011)

Several correlated tables were developed to design the database of production technologies. The structure and correlations between the tables are presented in Figure 6.

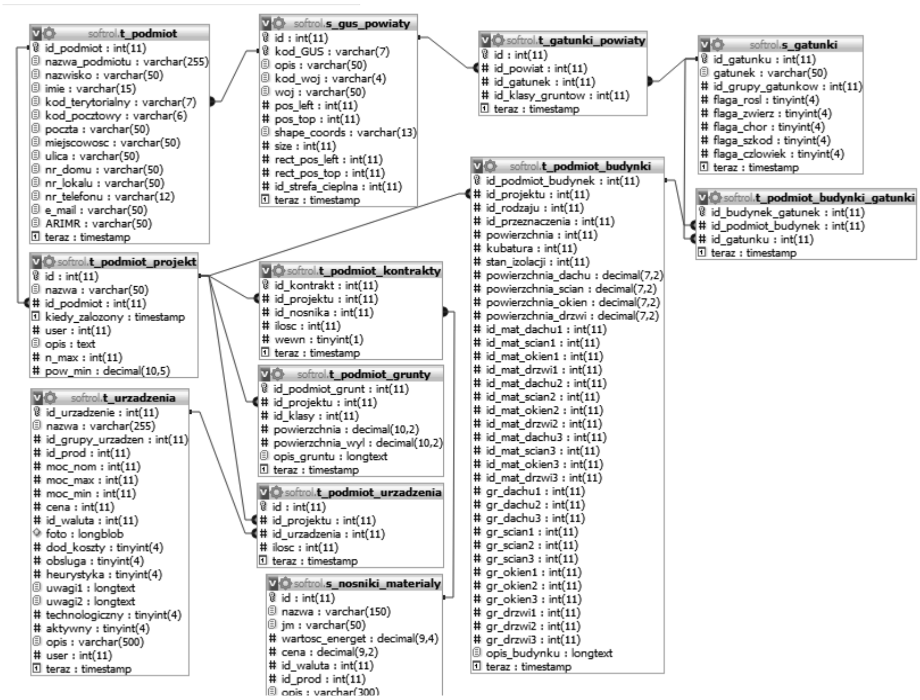

Fig. 6. Structure of the database relating to the data acquisition module on the energy potential and the energy needs of the PDAC (Pietkiewicz et al. 2014)

A similar approach was used to develop the remaining database modules. The design and implementation of database modules in the advisory system was described in a previous study ("SOFTROL – Energy directly from nature", Pietkiewicz et al. 2014).

Simulation module

The main element of the advisory system is a simulation module which supports the development of other technological systems based on the adopted parameters of energy potential, energy demand, energy consumption during fuel production, and energy conversion to electricity and heat. Due to copyright and trade secrets regarding the system as a product for implementation, detailed algorithms have not been described.

The user interface enables a user to design an agri-energy complex based on information relating to a farm's geographical location, natural resources (acreage, soil class), the existing or planned buildings. Based on the information collected in database modules, the system develops a subset of technologies that can be applied in the designed complex. Selected technologies, including those that meet boundary conditions, can be eliminated by the SOFTROL system based on PDAC preferences (Pietkiewicz et al. 2012).

Selecting a simulation module is a collection of PPKA energy efficiency variants. By default, the system is presented in the order of the most cost-effective. The user has the possibility to change the criteria, such as the criterion of covering the PPKA energy demand.

The described system is an advisory system. The user decides on the optimization criterion alone, and in no way should it coincide with the criteria established in the system.

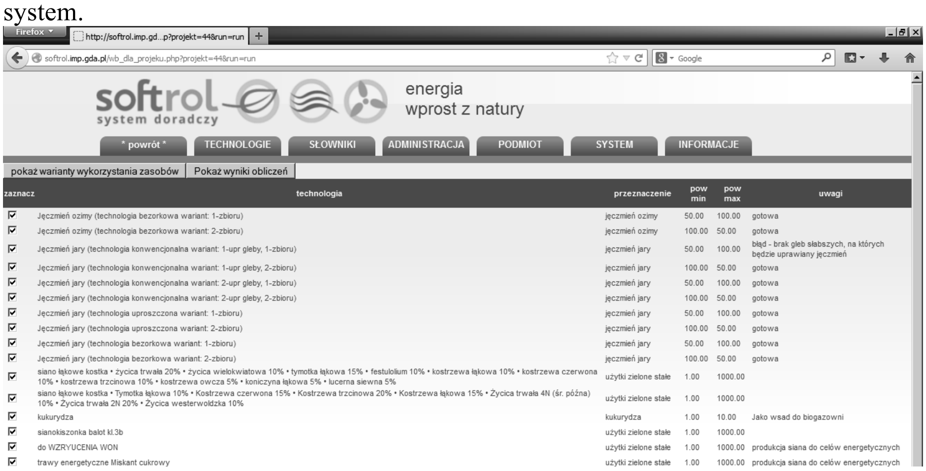

Fig. 7. Subset of technologies that meet boundary conditions in the defined PDAC (Pietkiewicz et al. 2014)

A list of technologies that meet boundary conditions in the defined PDAC and can be eliminated from further analyses is presented in Figure 7. Logical fields in *Yes/No* format for eliminating selected technologies are shown on the left. When the list of technologies defined in the PDAC is closed, the user can begin to design variant solutions for harnessing the energy potential of the PDAC. This operation lasts from several seconds to several dozen minutes, depending on the number of variables in the energy potential of the PDAC and the size of data sets containing technologies that meet boundary conditions and can be used in further analyses.

The calculated results are presented by the system (Fig. 7). The user can access detailed information about the variant solution for harnessing the energy potential of the PDAC by clicking on the *Variant details* link.

5 Conclusions

The *SOFTROL* system has been designed for a wide range of applications. The system contains dedicated algorithms, and it is a complete product that is ready for commercial implementation. According to the authors, the system can be used for the following purposes:

- to provide access to information about energy equipment available on the market,
- to update the database of devices based on the data supplied by the manufacturers of energy equipment,
- to select the optimal energy generation system based the system's ability to rapidly process the variables input by the user,
- to support decision making in the production of energy crops,
- to collect and analyze information about the use of renewable energy sources in various regions of the country,
- to popularize information about renewable energy sources,
- to lower the costs of systems that harness the energy potential of farms,
- to maximize farms' ability to harness their energy potential and meet their energy needs based on renewable energy sources.

The discussed advisory system has been implemented for educational purposes at the Faculty of Technical Sciences of the University of Warmia and Mazury in Olsztyn, Poland. The system has been designed and built as part of key project No. POIG.01.01.02-00-016/08 entitled "*Model agro-energy complexes as an example of distributed cogeneration based on local renewable energy sources*", and it is ready for commercial implementation.

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