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Developing an Industry 4.0 Tool Based on a Decision Support System for the Electricity Sector

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Abstract:

Industry 4.0 brings together disruptive technologies and methods such as Big Data, Advanced Analytics, Cloud Computing and Internet of Things IoT and means connecting devices, machines and equipment to the internet, interacting with each other and transforming static objects into dynamic elements of an integrated network. The basic foundation of Industry 4.0 in the electrical sector is that through the interconnection of machines, production systems and equipment, companies will have the ability to create intelligent networks along the entire value chain, and thus control and command the production processes independently. The Decision Support System (DSS) described in the present paper simulates an electric system regarding the technical, environmental, social and economical aspects. The DSS is based on a conceptual model that could be adapted for most Countries. The DSS helps to understand the effect of consumer practices, production technology and Government measures on the electricity sector. Computer-based systems are useful to deal with great amount of information. Also, computer-based systems are adequate to organize disperse information. The author developed a DSS based on informatics technologies and applied to showcases and scenarios that can be used for better decision-making.

Keywords:

Industry 4.0, Decision Support System, Business Intelligence, Key Performance Indicators, Agent Reaction, Simulation Scenarios, Decision Making, Systems Modeling, Methodologies and Technologies

1. Introduction

There are about three key aspects of system design: decision making under uncertainty, trade-off studies and formal risk analyses. [1] The mathematical treatment of these topics is complex and mathematical techniques are interactive, in order to produce results coherent to reality. Common to these topics are importance weights, combining functions, scoring functions, quantitative metrics, prioritization and sensitivity analyses. Furthermore, human decision-making activities and problems use these same tools. [2] Therefore, these problems are also treated uniformly and modelled using prospect theory. [3] An in-depth discussion of the major decisions in production planning, scheduling, and inventory management faced by organizations, both private and public, is made from several authors. [4] However, individual decisions from agents in a whole system that combines energy both as a commodity (a valuable and imperative thing of life) and as product (to be traded in market) is challenging. One must not forget that every decision an agent does affects his self-performance and other agent's decision. Some authors provided already comprehensive, up-to-date guide to today's revolutionary management support system technologies, and showcases how they can be used for better decision-making. [5] Modeling and Analysis, Data Mining for Business Intelligence, Artificial Neural Networks for Data Mining, Text and Web Mining, Data Warehousing, Collaborative Computer-Supported Technologies and Group Support Systems, Knowledge Management, Artificial Intelligence and Expert Systems, Advanced Intelligent Systems, Management Support Systems are background and alternative methods and approaches, which has been already explored by some authors. [5] However, it is also important to have biological decision system manages the way in which individual organisms decide "what to do now" by maximizing the value of available information to avoid chance events from the environment. The discovery of the biological decision system leads to a new scientific discipline, decision biology, which embraces key platforms in many scientific disciplines: biology, neuroscience, psychiatry, psychology, economics and many more, and integrates them on a shared foundation: the biological decision system, opening many new scientific opportunities. [6] Computer-based systems play a vital role in helping professionals across various fields of practice understand what information is needed, when it is needed, and in what form in order to make smart and valuable business decisions. By addressing all topics on three levels, general theory, implications for DSS design, and code development, [9] presents an integrated analysis of what every DSS designer needs to know.

These themes are being under study for more than 3 decades. Relevant studies have been made. Table 1 shows the first key research. It is presented the method, objectives and topic of study. [2] emphasized that the best way to begin a risk evaluation would to be use qualitative techniques and later gradually increase the complexity of the techniques until one has achieved the best cost-profit ratio for each type of firm and project. He stated that the selection of risk analysis techniques would be affected by the following factors:

- In cases where a certain degree of maturity is involved, whether or not the organization is, for the first time, in the transition from applying the process in small and well-managed projects to its application in more problematic and larger ones;

- The motivation and attitudes of personnel involved in the implementation of the risk management process;

- Whether or not the risk management process is applied from the project's inception;

- The way in which risk management is carried out in the program that includes the present project;

- The available resources (internal and external) and time;

- The type of contracting system;

- The prioritization of objectives.

Table 1. *Key research and their models.*

Method/Model used	Objectives	Researchers & Year	Topic of study
Influence diagram	Risk identification	Ashley and Bonner (1987)	Identification of political risks in international project
	Brain storming and Delphi technique	Yingsutthipun (1998)	Identification of risks in transportation project in Thailand
Monte Carlo simulation (MCS)	Distribution form	Songer et al. (1997)	Debt cover ratio (project cash flow) in a toll way project
	Variables' correlation	Chau (1995)	Distribution form for cost estimate
		Wall (1997)	Distribution form and correlation between variables in building costs
		Dey and Ogunlana (2001)	Project time risk analysis through simulation
		Yeo and Tiong (2000)	Evaluation of investment decision in infrastructure project
Programme Evaluation Review Technique (PERT)	Network scheduling	Hatush and Skitmore (1997)	Contractor's performance estimate for contractual purpose
Sensitivity analysis	Deterministic Variables' correlation	Yeo (1990)	Probabilistic element in sensitivity analysis for cost estimate
		Woodward (1995)	Survey on use of sensitivity analysis in BOT project in UK
Multi Criteria Decision Making (MCDM)	Multi-objective Subjectivity	Moselhi and Deb (1993)	Project alternative selection under risk
		Dozzi et al. (1996)	Bid mark-up decision making
Analytical Hierarchy Process (AHP)	Systematic approach to incorporate subjectivity Consistency of judgment	Dey et al. (1994)	Risk analysis for contingency allocation
		Mustafa and Al-Bahar (1991)	Risk analysis for international construction project
		Zhi (1995)	Risk analysis for overseas construction project
		Nadeem (1998)	Risk analysis for BOT project in Pakistan
		Hastak and Shaked (2000)	Risk assessment of international projects (ICRAM-1)
Fuzzy set approach (FSA)	Vagueness of subjective judgment	Kangari and Riggs (1989)	Risk assessment by linguistic analysis
		Diekmann (1992)	Combination of influence diagram with fuzzy set approach
		Lorterapong and Moselhi (1996)	Network scheduling by fuzzy set approach
		Paek et al. (1993)	Risk pricing in construction

			project through fuzzy set approach
Neural network approach (NNA)	Implicit relationship of variables	Chua et al. (1997)	Development of budget performance model
		Boussabaine and Kaka (1998)	Cost flow prediction in construction project
Decision tree	Expected value	Haimes et al. (1990)	Multi-objective decision tree
Fault tree analysis	Accident analysis Safety management	Tulsiani et al. (1990)	Risk evaluator
Risk checklist	From experiences	Perry and Hayes (1985)	Risk and its management in construction project
Risk mapping	Two dimensionality of risk	Williams (1996)	Two dimensionality of project risk
Cause/effect diagram	Risk identification	Dey, 1997	Symbiosis of organizational reengineering and project risk management for effective implementation of projects
Delphi technique	Subjectivity	Dey (1997)	Same as above
Combined AHP and decision tree	Probability, severity and expected monitory value	Dey, 2001	Decision support system for risk management

System Dynamics was introduced by Forrester in mid 1950s as a method for modelling and analyzing the behaviour of complex social systems in an industrial context. It has been used to understand various social, economic and environmental systems, where a holistic view is important [11]. In recent years, this approach has also attracted the attention of project managers [7,8,9,10,11,12,13,14].

System Dynamic approach is primarily based on cause-effect relationship. This cause-effect relationship is explained with the help of stock, flow and feedback loops. Stocks and flows are used to model the flow of work and resources through the project. Feedback loops are used to model decisions and project management policies. System Dynamics can be used to model processes with two major characteristics [15]:

- those involving change over time,

- those that involve feedback.

The central concept of System Dynamics is to understand how the parts in a system interact with one another, and how a change in one variable affects the other variable over time, which in turn affects the original variable. Systems can be modelled in a qualitative and quantitative manner. In Systems Dynamics, verbal descriptions and causal loop diagrams are more qualitative; stock and flow diagrams and model equations are more quantitative ways to describe a dynamic situation. As systems Dynamics is largely based on the soft systems thinking, i.e. the “learning” paradigm it is well suited to those managerial problems which are ambiguous and require better conceptualization and insight [16,17,19].

SD modeling has been extensively applied to construction research. A summary of past application is available in [11,18] has advocated the use of System Dynamics to construction projects on account of the following reasons:

- Construction projects are extremely complex, consisting of multiple interdependent components;
- highly dynamic;
- involve multiple feedback processes;
- involve non linear relationships; and
- involve both "hard" (quantitative) and "soft" (qualitative) data

[8] used SD to model the client-project relationships in construction projects. [17] demonstrated how SD can be used to improve civil contracting work. [10] used System Dynamics to identify and understand the major factors influencing construction project performance. [14] used SD for modeling the performance of a construction organisation.

2. Description

2.1. Theoretical DSS

It is assumed that the electric system to be modelled consists of a set of components and agents that interact. The relations in the model are represented by the model. The model is part of a tool that helps decision makers to gather information and analyse it: a Decision Support System (DSS). The block diagram of the DSS of the present paper is illustrated on Figure 1.

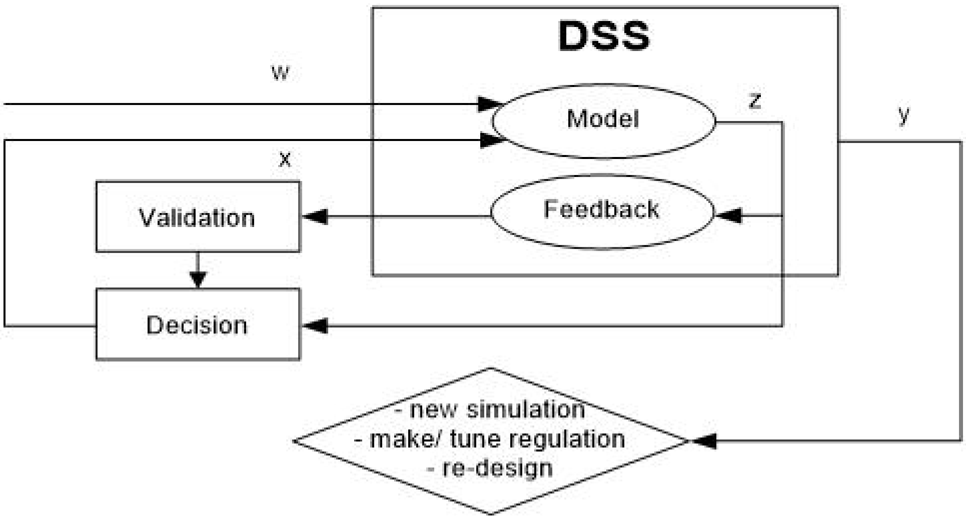

Figure 1. *General Block Diagram.*

Once the decision, fundamental objectives, uncertainties, and consequences have been identified, and the decision context has been understood, the next step in the decision analysis process is to create a conceptual model of the decision. Influence diagrams provide simple graphical representations of decision situations, where the elements appear as different shapes. These shapes are then linked with arrows in specific ways to show the relationships among the elements.

An influence diagram is a snapshot of the decision situation at a particular time, which must account for all the decision elements that play a part in the decision. In an influence diagram, rectangles represent decisions, and ovals represent uncertainties or state variables. The rectangles with rounded corners represent calculated variables or constant values and have a variety of uses, but the most important is to represent consequences. The three shapes are referred to as nodes: decision nodes, uncertainty nodes, and consequences or calculation nodes. Uncertainty nodes mean that although the decision-maker is not completely sure of what will happen, he or she has some idea of the likelihood of the different possible outcomes. Nodes are put together in a diagram, connected by arrows. The node at the beginning of an arrow is called a predecessor and the node at the end of the arrow is called a successor. The arrows can represent either relevance or sequence between the decision elements through link.

The approach to structure an influence diagram is first to put together a simple version of the diagram and then add details as necessary until the diagram captures all the relevant aspects of the problem. To this DSS, the decision context hasn't been set for incorporating and key performance indicators are presented. For some agents it could be profitability, for others it could be environmental impact, for others it could be continuity of supply, and so on: every agent has its own individual or group of criteria. Hence agents influence each other and influence the system: all the decision elements affect the objective function had to be identified represented by the performance indicators. The diagram is said to be appropriate or requisite, when it contains everything that the decision-maker considers important in making the decision. Identifying all its basic elements was achieved by working through the problem based on the background information available.

The influence diagram graphically depicts the decision problem, whether to incorporate real options in the concession agreement, the decisions embedded within this one, and the state variables or uncertainties that affect these decisions. It also depicts the constant variables and the calculated variables that result from the interaction between state variables and decisions, and finally the objective function that serves to evaluate the extent of deficit which is required to be bridged. The influence diagram illustrates the interactions among all these elements, allowing the assessment of the information needed to make the decision. The elements in the influence diagram can be grouped as follows.

2.2. Equipment

No special equipment is required to run the simulator; however it was not tested in mobile devices.

2.3. What this DSS Helps the User to Accomplish

There is a usual predisposition to stakeholders and decision makers/ takers to support an opinion or suggestion based on international practices rather than on their own country's conjuncture. However, this can lead countries to solutions not appropriate to the country or to a strange hybrid of different approaches. The present simulator is a decision support system that helps the user to gather information to accomplish a number of important tasks regarding to his interest.

2.4. Who the Target Groups Are

- Civil society groups (non-governmental organisations, academics etc.)

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- Households consumers

- Poor and vulnerable groups representants

- The private sector (industry, services, power plant owners, etc)

- Sector specialists, specially working in electricity, energy, environment and economics

- Anyone who would like to understand how incentives could be used to encourage more sustainable resource use in their sector

- Politicians and bureaucrats at all levels of government

- Development agencies and international actors

- Media.

3. How It Is Organized

The simulator is built based on two tabs for the input data and five tabs for the output data.

The input tabs are divided in production and consumption areas and they have predefined values that can be changed by the user, partially or totally. The items in those two input tabs are technical, environmental and economical associated.

The production input tab is represented in Figure 2.

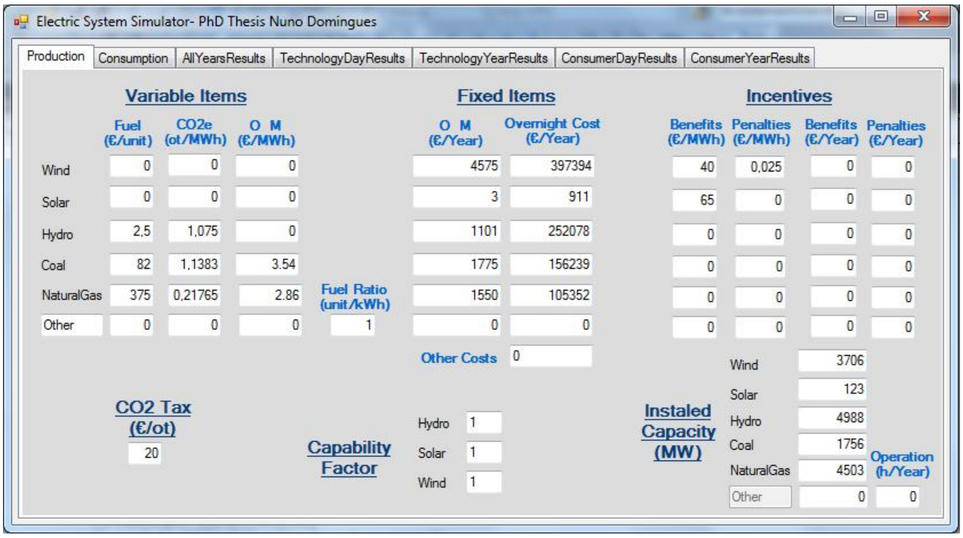

Figure 2. Production Input Tab.

It is divided in economical and technical items, per technology. It is considered 5 technologies: wind, solar, hydro, coal and natural gas. There is also a possibility to add other technology with the aim to exercise the impact of a new technology or an existing one with different characteristics.

For the economical items, there are the variable (the unit fuel cost, de CO_2e emissions per unit produced, the associated CO_2 tax and the variable O&M), the constant costs (constant O&M and constant costs per year), the incentives (the benefits and the penalties, variable per unit produced and constant per year) and also other constant costs per year as global. There is also other costs where the user can introduce the system management costs and the ancillary services costs, for instance.

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For the technical items, there is the capability factor for the renewable energy and the installed capacity for all technologies.

The consumption input tab is represented in Figure 3.

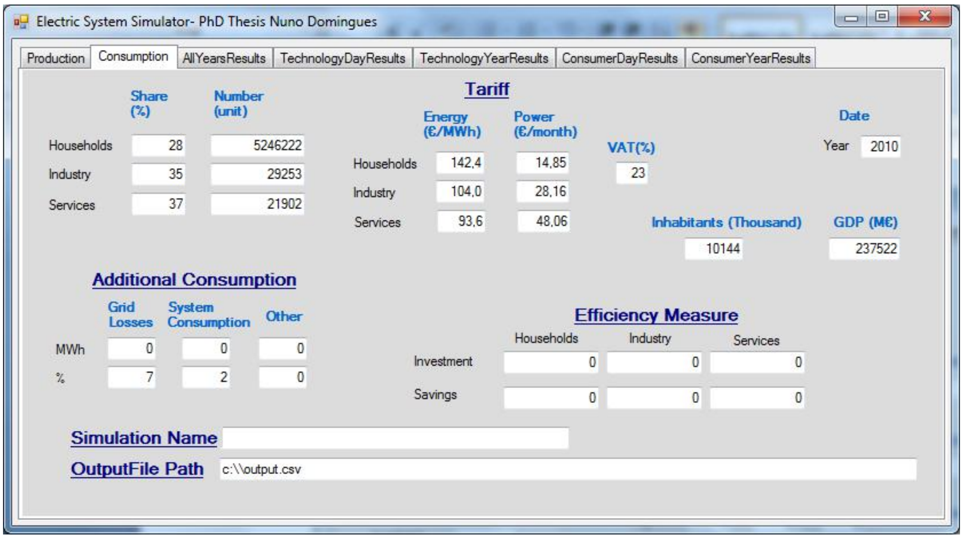

Figure 3. *Consumption Input Tab.*

It is divided in the share of consumption and the number of consumers per three different sectors: households, industry and services. For the same different sectors, there is also the variable term (by energy consumed) and the constant term (per month) of the tariff; and for the system there is the VAT. There are also the items that influence the consumption: the efficiency measure to study (divided in the savings percentage, the sector(s) affected and the necessary investment) and the GDP. The date field is related to the data introduced in both input tabs. Finally, there is the path [1] of the output file that will be filled automatically with the relevant data package generated by the simulation. The items "additional consumption" allows accounting for losses in the network, the self-consumption and other consumption. It can be in percentage or in units of energy or both. The other consumption may serve, for example, to reserve power for export to an abnormal condition (such as a sporting or cultural event that has significant impact on the electric field) for a counterpart (e.g. ensure minimum of water in reservoirs for agriculture or tourism, requiring extra boost) or other situation (as an item energy intensive during that year).

To start the simulation, one should click the «Run Simulator» bottom to simulate the year-by-year study. The forecast and the Graphic zoom bottoms are inactive in the simulation for the first year. The output tabs are divided in total years overview and the production and consumption, by year and by day.

The day results by technology are represented in Figure 4. and Figure 5.

It is divided in economical items (variable costs, constant costs and total costs) and technological items (consumption, production mix, energy deficit and load diagram). The data is for a day in a year. The days are divided in the following typical days: Summer Week, Summer Weekend, Summer Week Holidays, Summer Weekend Holidays, Winter Week, Winter Weekend, Winter Week Holidays, Winter Weekend Holidays and Higher Energy Consumption. The data and the graphics change automatically when the user chooses the type of day to simulate.

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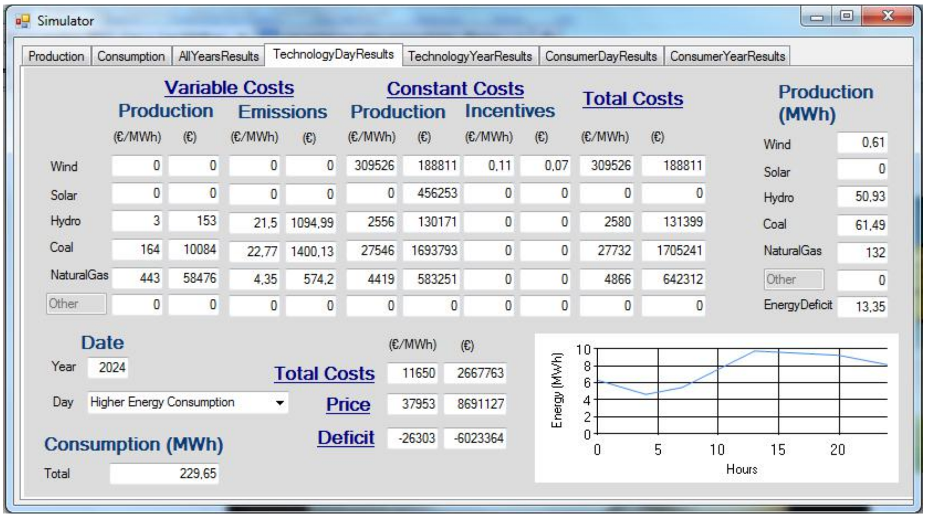

Figure 4. *Technology Output (by day) Tab: example 1.*

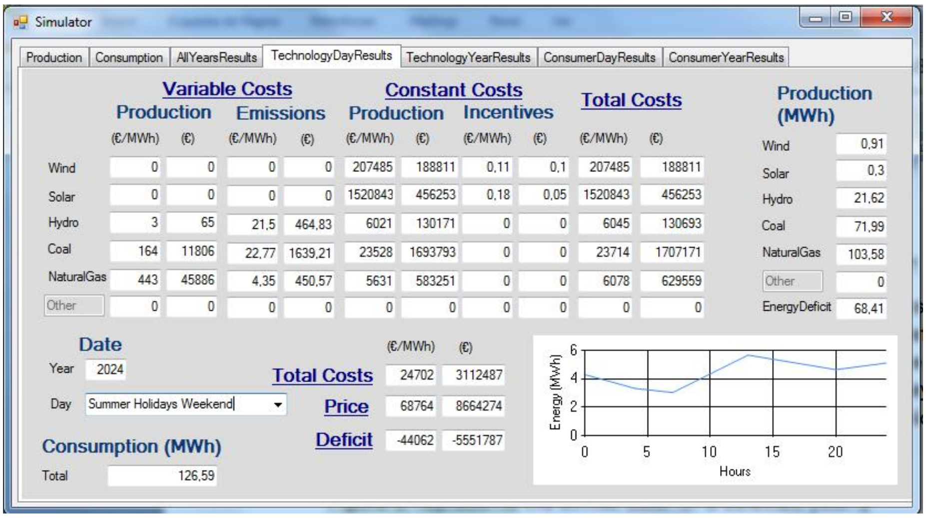

Figure 5. *Technology Output (by day) Tab: example 2.*

Figure 6. represents the similar data for a selected year. Instead of a load diagram, there is a load duration diagram.

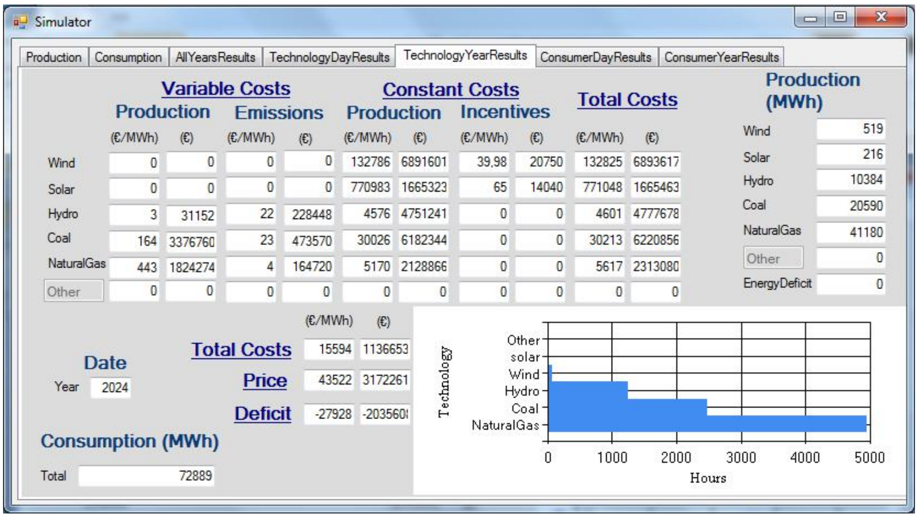

Figure 6. *Technology Output (by year) Tab.*

The consumer tab for a day is represented in Figure 7.

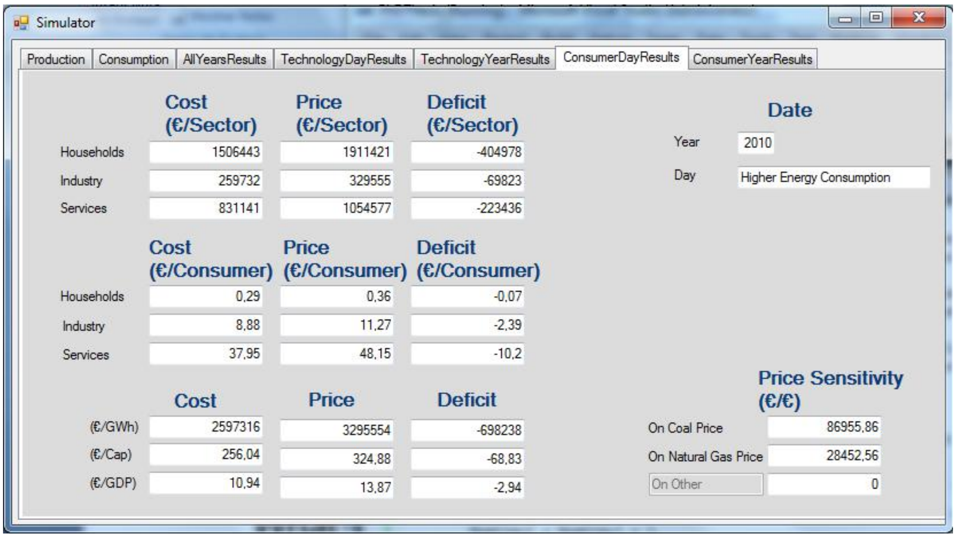

Figure 7. *Consumer data (by day) Tab.*

For the three different sectors in study (households, industry and services) it is shown the total and unit cost, price and deficit. Also, there is the cost per GWh, per capita and per GDP, as well as the price sensitivity to the price of coal and to the price of natural gas. The Consumer data (by year) Tab has similar data for a selected year and is represented in Figure 8.

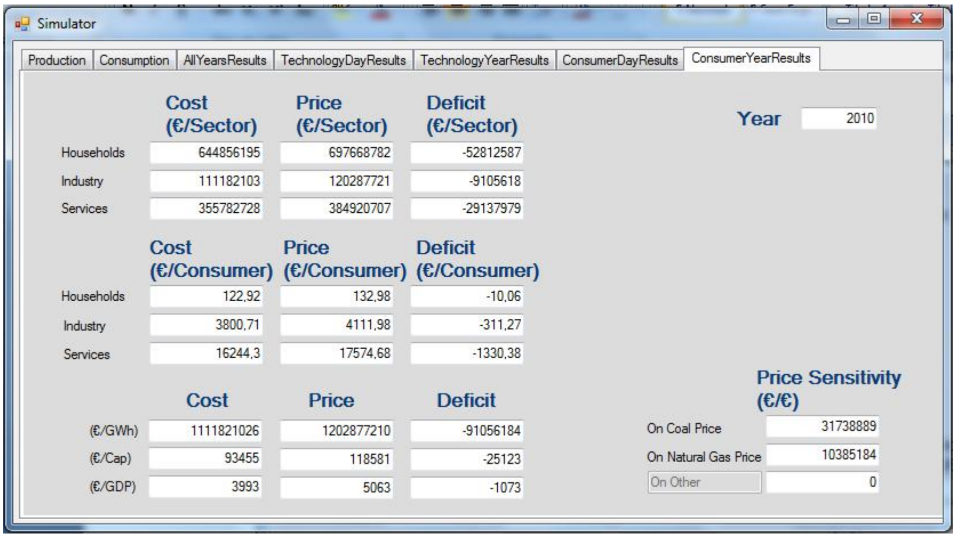

Figure 8. *Consumer data (by year) Tab.*

When the user wants to start the simulation for the next year there are two options: use the forecast button to allow the simulator to generate data for the next year and then correct or accepted the produced data or simple update the data in the input tabs. After that the user should hit the run simulator button to produce the results for the next year.

The all years overview tab is represented in Figure 9.

At the end of simulation, the AllYearsResults tab shows two graphics for the 15-year period simulated. The first graphic shows the energy consumption and the energy mix for the period in study. The second graphic shows a zoom of a technology selected.

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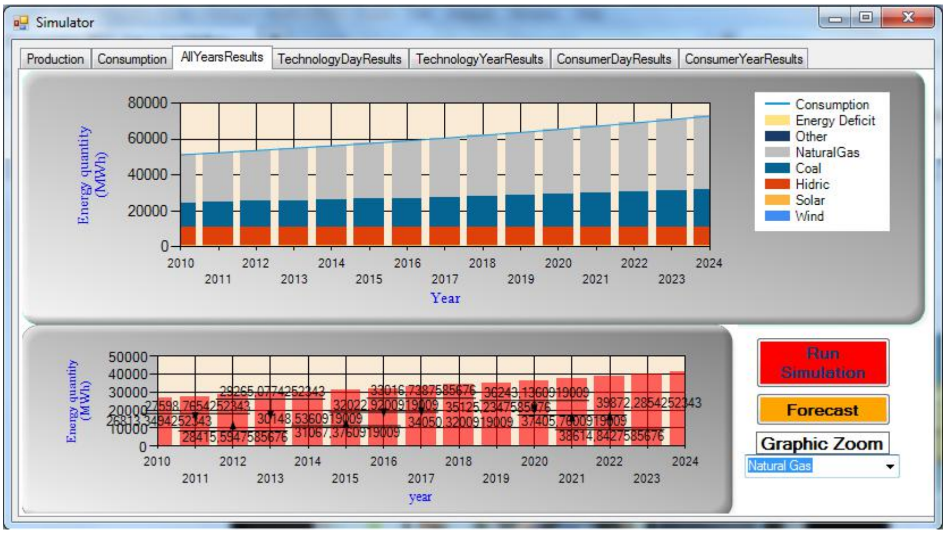

Figure 9. *All Years Output Tab at the end of the simulation.*

This tab gives a general overview of the period in analysis. For a micro analysis there are the following four tabs. The technology ones are more dedicated to the production sector and the consumer ones to the consumption sector.

4. Programming Reflections

In the present thesis it's used C++ instead of C for several reasons. First, the aim is to focus more on the data and behaviour and not on the functional aspect. Second, it's better for working with memory storage, since in C there's only one major memory allocation function (malloc) and in C++ there is a much larger library and the instructions new [ ] and delete [ ]. Third, C does not provide a native Boolean type: it can be simulated (for example using: typedef enum {FALSE, TRUE} bool;). Fourth, in C the main function doesn't provide return 0 automatically.

It's used class instead of struct to define the objects (agents, energy, prices, etc.). In programming, the only difference between a structure and a class is that structure members have public access by default and class members have private access by default. However, a class is an expanded concept of a data structure: instead of holding only data, it can hold both data and functions. The data represents the intrinsic characteristics of the object and the function represents the self-conduct and the interaction with other objects (how they influence and how they are influenced).

To sort the information on the most recent to the oldest one, the lists are implemented using the FILO (First In Last Out) criteria.

Even though the Simulator handles a significant amount of information, the amount of information storage in each individual list is relatively small. Thereby, it's not used any sort criteria (except the date). Otherwise, the running time on sorting will be higher than on searching.

For a better memory allocation, it's used pointers to define dynamic arrays instead of static ones. Otherwise, the memory wasted in the Simulator (using a lot of information) will turn the Simulator time inefficient.

5. Conclusions

It is to be expected that Industry 4.0 (also known as the Fourth Industrial Revolution) will provide several benefits for energy systems, consumers and businesses. The investment in technology allows employees to be allocated to more strategic activities, which really add value to the results and are consistent with the business objectives. In Industry 4.0, business resources are used more intelligently, in addition to gaining agility and reducing errors in the execution of processes. This is synonymous with increased operational efficiency and improvement in business performance indicators.

The electricity sector agents have several information to analyse before making any decision. Developing a user-friendly tool helps an electricity sector agent to organize the data to be analysed. Dividing the data by input and output tabs helps the DSS user on the task of collecting the characteristics of the electricity system and helps on the task of choosing what outputs can work as performance indicators.

Based on the performance indicators chosen, the user of the DSS can quantify the impact of their decisions on the electricity system.

Industry 4.0 creates opportunities to reduce expenses, generate savings and improve results.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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