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Abstract— The increasing environmental pollution resulting from the use of non-renewable fossil fuels as well as the development of economic dependencies among countries because of the lack of such types of fuels underline the intense need for the use of sustainable forms of energy. Biomass derived biofuels provide such an alternative. The main tasks of biomass feedstock production are planting and cultivation, harvest, storage, and transportation. A number of complex decisions characterize each of these tasks. These decisions are related to the monitoring of crop health, the improvement of crop productivity using innovative technologies, and the examination of limitations in existing processes and technologies associated with biomass feedstock production. Other critical issues are the development of sustainable methods for the delivery of the biomass while maintaining product quality. There is the need for the development of an automated integrated research tool based on resilience and sustainability which will allow the coordination of different research fields but also perform research on its own. The specific tool should aim in the optimization of different parameters which specify the research done and in the case of biomass feedstock production; such parameters are the transportation of biomass from the field to the biorefinery, the equipment used, and the biomass storage conditions. This paper presents an information system that provides automated functionalities for better decision making in the bioenergy production field.

Keywords—Bioenergy, Information System, Automation, Integration, Databases, Data Mining, Simulation

I. INTRODUCTION

There is the need for a systems informatics infrastructure which will be capable of providing appropriate management of the existing and the generated knowledge. The ultimate target of systems informatics is the improvement of the decision making process.

The long-term goal of the presented research is the provision of concurrency in the collection and integration of information from the research and development of different tasks in the bioenergy supply chain research and development. For this purpose, it is required that software engineering techniques which will perform problem requirements analysis and identification of the systems informatics architecture, are used. The central hypothesis of the presented research is that an information system with integrated functionalities can improve the process of data collection. Such an infrastructure can also provide more automation in the development of computational models and also enable the real-time collection of information. The rationale is that the provision of automation through the principles of object-oriented analysis, the identification of relationships between the attributes of these objects, the concurrent integration of data, the use of advanced software technologies, such as databases and visualization tools, and the combination of data for better decision support will improve life-cycle and gap analysis, the estimation of energy and mass balance, as well as the peer review of information.

The overall objective of the research is the development of an information management infrastructure which will aid in decision making during the research and development of biomass feedstock production systems, provide improved optimization processes and effectively handle data between the biomass feedstock production tasks and subtasks.

II. BIOFUELS AND THEIR SIGNIFICANCE

The energy needs of modern societies depend on fossil fuels. An example is the reliance of the United States on fossil fuels for the more than 85% of its energy needs [1]. Imported oil is about 44% of the foreign trade deficit [2]. The use of oil in transportation is approximately 25% of all energy use in the US and exceeds total oil imports to the US by about 50% [3]. This dependence increases as the quality of modern day life progresses. The result however is the exhaustion of oil resources and the creation of global environmental problems.

The resulting dramatic increase in oil prices has led to the increase in the use of biofuels. Biofuels are liquid, solid, or gaseous fuels produced by organic matter. Global biofuel production has increased from 4.8 billion gallons in 2000 to 16 billion in 2007. Approximately 90% of biofuel production is done in the United States, Europe and Brazil [4]. Furthermore, the Kyoto agreement has set the goal for many countries to utilize biofuels [5]. Bioenergy is considered as an alternative to fossil fuels as it reduces the negative effects on the climate [6].

Currently, biofuels fall into three main generations as outlined below:

•First Generation: This category includes petroleum gasoline and petroleum diesel substitutes. First generation biofuels are ethanol and butanol. Ethanol is produced by sugar fermentation extracted from sugar cane or sugar beets, or sugar extracted from starch contained in maize kernel or other crops which contain starch. Similar processing can produce butanol [7].

•Second Generation: In this category, biochemically produced petroleum-gasoline, thermo-chemically produced and thermo-chemically produced petroleum-diesel substitutes are included [7].

•Third Generation: Algae biofuels are included in this category. Microalgae are capable of producing 15-300 times more oil for biodiesel production than traditional crops. Microalgae have a very short harvesting cycle, and this allows multiple or continuous harvests with increased yields [8].

The use of perennial grasses for the production of bioenergy is a promising renewable energy option. Perennial grasses can be used for the production of electricity while the reduction of the use of fossil fuels will result to ecological benefits [9]. Examples of perennial grasses are miscanthus and switchgrass. Switchgrass can control soil erosion and with its extensive network of roots, it can reduce raindrop impact and erosion [1]. Miscanthus can be used for the generation of electricity and the direct heating of homes and businesses [10]. It is a low-maintenance, perennial grass which is characterized by long-life expectancy. Nitrogen and other nutrients are moved into the rhizomes during the growing season for next year's growth.

III. BIOMASS FEEDSTOCK PRODUCTION

Biomass feed stocks are used in the production of liquid transportation fuels. The biomass feedstock production system includes a number of inputs for the conversion of biomass into energy. It also includes the agronomic production of energy crops and the transportation and handling of biomass [11].

The different phases of biomass feedstock production are presented below:

•Pre-Harvesting: This stage is the initial stage of biomass feedstock production and includes operations such as crop selection, soil preparation, and planting. Since these operations are very significant for the realization of the next stages in biomass feedstock production, advanced remote sensing and precision agriculture technologies are employed.

•Harvesting: Harvesting is one of the major phases of biomass feedstock production. Harvesting can include mowing, raking, baling, staging, and loading. The type of equipment defines the time and cost of harvesting [24].

•Transportation: This task involves the transportation of biomass to the biorefinery or to a centralized facility for storage purposes. There are different ways of transportation of the biomass and these include pipelines, rail, or trucks.

•Storage: This task includes on-farm or centralized storage. Different parameters, such as microbial activity, dry matter loss, temperature, and moisture content, need to be considered when the storage occurs in different time periods.

IV. AGRICULTURAL SYSTEMS INFORMATICS

Systems Informatics is the combination of social and organizational informatics. Social informatics involves the design, implementation, and use of Information and Communication technologies over a wide range of social settings. Organizational informatics refer to the use of social informatics techniques within the limits of an organization [12].

An example of the use of systems informatics is the development of information systems. The main activities of information systems are data acquisition and data handling. Data acquisition is achieved through data suppliers, such as labs and automatic monitoring stations. Data handling is realized in computational centers while the use of information is done by decision makers [13].

This section provides examples of how information systems can be used in different applications in agriculture. The provided examples attempt to show how information systems correspond to the main principles of systems informatics.

IV.1 AUTOMATION-CULTURE-ENVIRONMENT ORIENTED SYSTEMS (ACESYS)

The concept of Automation-Culture-Environment oriented systems (ACESYS) facilitates abstraction of controlled environment plant production systems, describes the relationships among sub-systems or system elements, identifies information and protocols required for system analysis, and develops data processing algorithms. The ACESYS concept provides a modular description of the system by defining a number of classes and objects related to the system. A protocol is also required in order to integrate new information to the system. The use of appropriate data gathering and processing algorithms facilitates concurrent science and engineering [14]. An example of the use of ACESYS concept is an interactive web site which was developed in order to include all the essential aspects of the Advanced Life Support (ALS) systems analysis. The goal of this system is the establishment of concurrent science capabilities within the ALS community and the development of methodologies using the Web. The key elements of this system are an input mechanism for research project information, a set of databases, a display capability necessary for data presentation, an on-line discussion forum, and Java applets for data processing [15].

IV.2 TROPOS METHODOLOGY

The Tropos methodology which is an agent-based software development methodology. It is based on the use of knowledge level concepts, such as actors, goals and plans and the dependency between them, and also the critical role which is implemented to the preliminary phase of requirements analysis. The Tropos Methodology includes five software development phases which are the identification of early and late requirements, the design of the system's architecture, the design of the agent implementation architecture, and system implementation. The design of the system's architecture is the most significant phase since it allows the definition of the parts of the system which are represented as actors. Each actor is characterized by a set of capabilities and a set of social capabilities which allows the coordination with other actors [16].

IV.3 FARM MANAGEMENT INFORMATION SYSTEM

FutureFarm is a European Union project and it is part of the Seventh Research Framework Programme. The Farm Management Information System (FMIS) is part of the FutureFarm project and its aim is the introduction of new knowledge management techniques on farm management. This system allows more intelligent decisions about the use of different inputs for a number of crop rotation systems. In order to define a farm management information system, the design of a conceptual model which shows the different system components, is required. The development of such model is based on a rich picture which shows the everyday management problems of the farm from the perspective of the farm manager is the first step as well as the definition of the CATWOE (Customers, Actors, Transformation Process, World View, Owner, Environmental constraints) steps. The completion of these steps results to the creation of a conceptual model which underlines the need for use of specific equipments. Examples of such technologies are GPS systems, real-time sensors for weather monitoring, autonomous weed mapping systems, Also, a knowledge repository which includes agricultural standards, is required. The scope of this repository is to check whether the used farm management information system complies to the standards included in the repository. A metadata-based interface is used in order to access the repository [17].

IV.4 AGRICULTURAL WATER RESOURCES DECISION SUPPORT SYSTEM (AWARDS)

The Agricultural Water Resources Decision Support System (AWARDS) was developed in order to cover the need for the improvement in the estimation and forecasting of daily agricultural and riparian water use demands along the Middle Rio Grande. It is a web-based information system designed to assist water managers and users by providing easy access to rainfall and crop water use estimates. These estimates are based on real-time data acquired by NEXRAD (Next Generation Weather Surveillance Radar) radar systems and automated weather stations. The purpose of AWARDS is to improve the efficiency of water management and irrigation scheduling by providing guidance on when and where to deliver water, and how much to apply. AWARDS collects data from the NWS Hydrologic Rainfall Analysis Project (HRAP) which is a 4km x 4km resolution grid. The weather stations of AWARDS transmit weather data via radio signal, phone, or satellite to local computer systems. The daily and hourly data are then collected from the local computer systems via FTP into AWARDS [18].

V. BIOMASS FEEDSTOCK PRODUCTION ENGINEERING INFORMATION SYSTEM (BFPE-IS)

The Biomass Feedstock Production Engineering Information System (BFPE-IS) includes three layers: the concept diagrams which show the different tasks associated with bioenergy production scenarios and their respective sub-tasks, the Engineering Solutions for Biomass Feedstock Production Engineering Systems Informatics Architecture which shows the software technologies that consist of the skeleton of the presented information system, and the Biomass Feedstock Production Engineering – Application Programming Interface (BFPE-API) that enables the processing of information for data mining purposes. The different elements of the BFPE-IS are presented in detail in the next sections.

V.1 CONCEPT MODELING

Concept diagrams have been used for the representation of the different tasks associated to biomass feedstock production. The design of the diagrams is based on a top-to-down hierarchy in which the lower levels represent the sub-tasks of a specific task and the lowest levels correspond to the technologies used for the realization of the specific tasks and sub-tasks. Each box includes a number of attributes related to the specific task, sub-task, and technology. The identification of the different attributes is important as it helps in the development of connections among the tasks and sub-tasks.

The development of the concept diagrams was based on the collection of information from the literature and interviews with expects in bioenergy production. The concept diagrams are dynamic and this means that the information included in them can be changed any time depending on new information collected by the literature.

V.2 BIOMASS FEEDSTOCK PRODUCTION ENGINEERING SYSTEMS INFORMATICS ARCHITECTURE

The core element of the systems informatics architecture is a number of MySQL databases called Biomass Feedstock Production Databases (BFPDs). The structure of the databases is based on the concept diagrams designed for each task of the biomass feedstock production. Each of the databases can also refer to a specific sub-task. The concept diagrams provide the data-input protocol or in other words, the order in which the data are inserted in the database and also the hierarchical connections which characterize the structure of the database.

A set of graphical user interfaces have been developed in order to allow the manipulation (insertion, deletion, updating) of the data stored in the database and also the initiation of data discovery. The interfaces can additionally initiate the connection to a number of simulation and optimization software packages, such as MATLAB (The MathWorks, Natick, MA, United States of America) and GAMS (GAMS Development Corporation, Washington, DC, United States of America). These software packages are used for the development of models which accept data by the database. These models also provide data back to the database. The interfaces along with all the functionalities they offer consist of an Application Programming Interface (API) used for Biomass Feedstock Production data analysis. This API is referred as Biomass Feedstock Production Engineering (BFPE)-Application Programming Interface (API).

The ultimate purpose of systems informatics is the provision of automated search and analysis tools. The existing and the generated data will allow the peer review of information and the realization of different types of analyses, such as life-cycle and gap analysis. Extensibility is also a major target as it will allow the addition of new users who can enable the generation of more information and the expansion of the limits of the current research.

V.2.2 DESCRIPTION OF THE BFPE-APPLICATION PROGRAMMING INTERFACE (API)

The Biomass Feedstock Production Engineering (BFPE)-Application Programming Interface (API) is a way for users to communicate with the Biomass Feedstock Production database(s) (BFPD). The functionality of the API can be classified in three layers. The most basic layer is the database data access which allows the user to connect to the BFPD(s) using a number of different programming languages. The use of different programming languages allows users of different computing backgrounds to access the database. The next layer is the database data handling. This layer includes operations such as insertion of data in the database, deletion of data from it, and updating of its data. The database data discovery layer is the top layer of functionality of the API and includes advanced data mining and statistical analysis operations. Additionally, visualization and optimization techniques are part of this layer.

The BFPE-API is written in different programming languages and it is dynamic. The programming languages used for the development of the API are Java, Visual Basic, Python, PHP, Perl, Visual C#, C++, Ruby-on-Rails. A number of software tools are used as part of the API and these are MATLAB (The MathWorks Inc., Natick, MA, United States of America), Java APIs such as Lucene (Apache Software Foundation, Forest Hill, MD, United States of America), JFreeChart (Object Refinery Ltd., Harpenden, United Kingdom), and the Generic Algebraic Modeling System (GAMS) (GAMS Development Corporation, Washington, DC, United States of America). The BFPE-API and its interaction with the MySQL database(s) is shown in Figure 2.

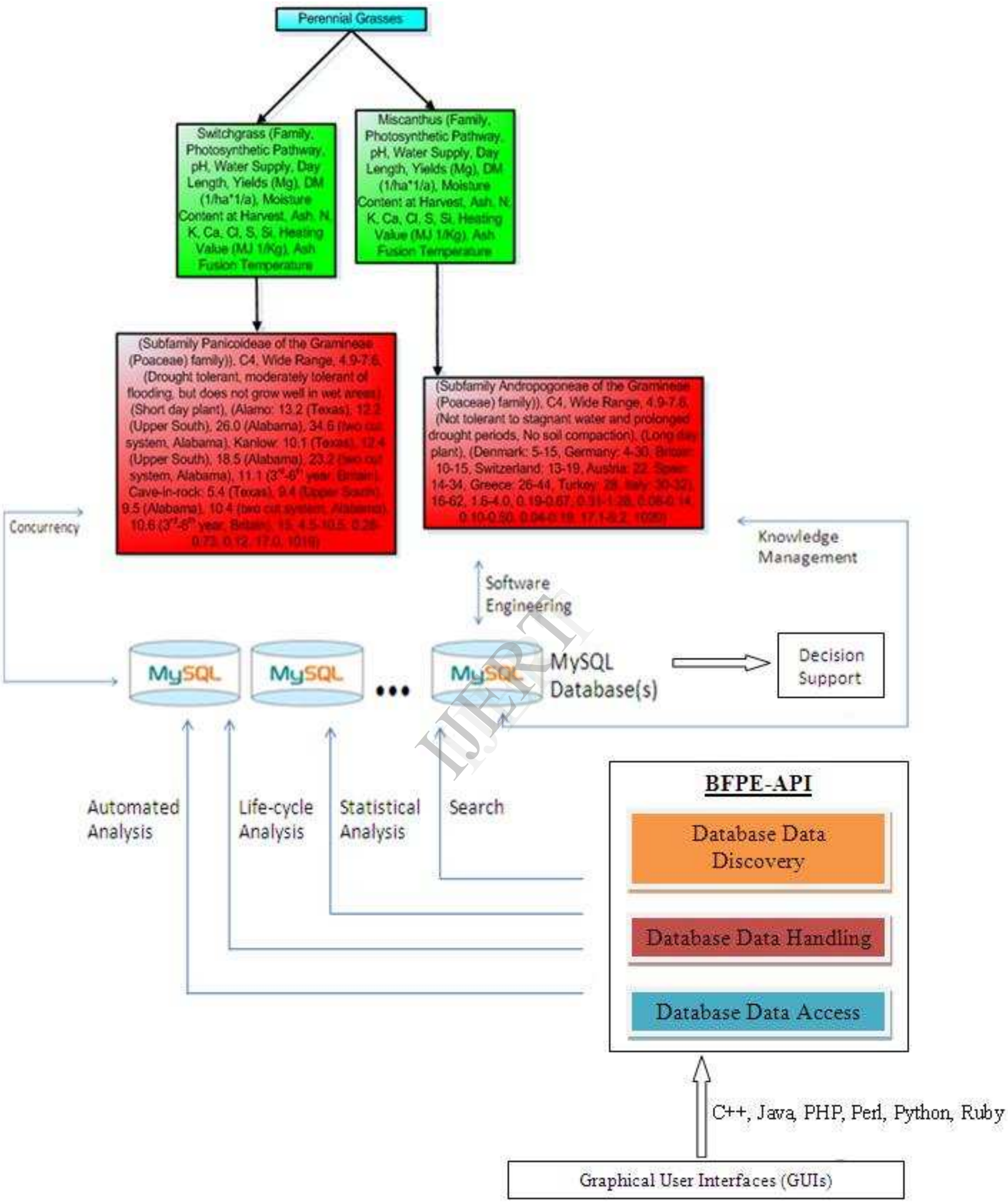

Figure 2 Systems Informatics Architect
[Adapted from [23]]

VI. BFPE-API FUNCTIONALITIES THAT LEAD TO DATA MINING

This section presents specific examples of the API functionalities that enable the efficient processing of biomass feedstock processing information. These functionalities are presented in detail below.

VI.1 Data Handling

Data handling is one of the capabilities offered by the application programming interface. The API uses different programming languages in order to utilize the data from the Biomass Feedstock Production (BFP) database. Data handling covers a number of operations such as data insertion, deletion, and updating. Furthermore, the users are able to create their own tables of data in the BFP database and also insert or delete new columns of data. The user is also capable of reading whole sets of column data or just individual data. Furthermore, he/she is capable of listing the columns of tables. The pseudo-code which is used for the insertion of data in the database is the following:

```
<Insert Data Method>
<Specify Table Column Name>
<Specify Data to be inserted>
<Execute Insert SQL statement>
```

The ‘Data Handling’ functionality offered by the BFPE-API allows the quick and efficient manipulation of biomass feedstock production-related data. The GUIs used for data handling allow the users to insert, check and update data to different tables that are included in the BFP databases. The GUIs are designed in such a way so that they

VI.2 MATLAB-MySQL Interaction

MATLAB (The MathWorks, Natick, MA, United States of America) can connect to the MySQL Biomass Feedstock Production database using the appropriate MySQL driver offered by MySQL AB. The first step is the placement of the directory of the specific driver on the classpath file of MATLAB and the placement of the extracted jar file from the downloaded driver to the 'jarext' folder of the MATLAB directory. The pseudo-code which is used for the connection to the MySQL database from MATLAB is the following:

```
Begin
<Define Host >
<Define User Name>
<Specify Password>
<Specify Database name >
<Specify Database Driver>
If (Connection to Database Successful)
   Display Contents of Specific Table
Else
  Database Connection Failed
End
```

The connection of MATLAB with the MySQL Biomass Feedstock Production Engineering databases allows the use of database data for numerical computations and the realization of simulations.

VI.3 GAMS-MySQL Connection

The Generic Algrebraic Modeling System (GAMS) (GAMS Development Corporation, Washington, DC, United States of America) enables the creation of mathematical models, especially optimization models. The connection between GAMS and MySQL is based on the development of an intermediate file between the two software packages. This file can be an Excel file (.csv file) or a text file (.txt file). The connection has two steps which are the following:

•*Importing from MySQL*:

In this case, the user has to create a ‘.csv’ file from the MySQL shell. The command which the user has to use is the following:

```
mysql> select * from <name_of_table> into outfile '<directory of the csv file>'
```

A GAMS file is then created which includes the csv file. It is also very important to include the created file in the GAMS directory. The GAMS code which has to be used in this case is the following:

```
set i /Washington, San Antonio/;
set j/Boston, Chicago, Topeka/;

parameter dist(i.j) /
$ondelim
$include <name of the csv file>
$offdelim
/;
display <name of MySQL table>
```

•*Exporting to MySQL*:

The contents of a GAMS file have to be extracted to an external file which can be .txt file. The code which has been used is the following:

```
file results /results.txt/;
put results;
put "Example";
put close;
```

In order to insert the contents of the .txt file to MySQL, the following command has to be executed:

```
mysql> load data infile '<directory of .txt file>' into table <name of table>
```

[21]

GAMS is used for the modeling of linear, non-linear and mixed integer optimization problems. GAMS models can be fed by MySQL data and these data are used for modeling different biomass feedstock production engineering scenarios. The results of the simulating different optimization scenarios using GAMS can be stored to respective BFPE databases.

VI.6 DATA MINING USING THE K-MEANS ALGORITHM AND HIERARCHICAL DATA CLUSTERING

The BFPE-Application Programming Interface uses data mining algorithms in order to extract useful patterns or relationships among the data included in the Biomass Feedstock Production databases. An example of such an algorithm is the K-Means algorithm. The scope of the algorithm is to find the minimum variance clustering given a dataset of n data points x1, x2, …, xn. Specifically, the algorithm attempts to find k points such that:

$$\frac{1}{n}\sum_{i=1}^{n}\left[\min_j d^2(x_i,m_j)\right]$$

is minimized, where d(xi, mj) denotes the Euclidean distance between xi and mj. The points mj are known as cluster centroids. The scope is to find k cluster centroids such that the average squared Euclidean distance between a data point and its nearest cluster centroid is minimized [22].

The pseudocode which describes the K-Means algorithm the following:

<Specify Number of Clusters>
<Specify distance of objects to centroids>
<Clustering based on minimum distance>

The K-Means algorithm has been used for the clustering of data that are stored in BFPE databases based on their different attributes. A set of clusters are formed based on specific attributes of the data included in the BFPE MySQL databases. Specifically, data are clustered based on the fact they present similarities to one or more attributes.

The next step is the hierarchical data clustering. There are two types of hierarchical clustering: the agglomerative and the divisive. The presented information system uses the agglomerative hierarchical clustering. The agglomerative hierarchical clustering is based on the merging of the closest pair in the set of the current clusters into a new cluster. Two clusters are merged when they present the largest similarity, thus the smallest distance. The distance matrix which has been created and which shows the distances among the initial clusters, needs to be updated. There are different methods for measuring the inter-cluster distance. For example, The distance between two clusters can be measured by calculating the distance between the closest pair of data objects that belo9ng to different clusters. Other methods that are used for the measurement of the inter-cluster distance are the calculation of the farthest pair of data objects, the calculation of the average distance of all pairs of data objects belonging to different clusters and the calculation of the distance of the centroids of the two clusters. A distance matrix using the distance values needs to be constructed. When two clusters are merged, they are removed from the matrix and the new cluster is placed instead. The distances of the new cluster from all the other clusters have to be evaluated and the distance matrix needs to be updated again. This procedure is repeated till one single cluster is formed.

Data clustering allows better classification of data which in turn allows development of more scenarios for bioenergy production simulation. The results of the simulating different bioenergy production scenarios using GAMS or MATLAB can be analyzed further using data clustering.

VII.CONCLUSIONS

The BFPE information system (BFPE-IS) was used by the researchers of the "Engineering Solutions for Biomass Feedstock Production" program of the Energy Biosciences Institute (http://www.energybiosciencesinstitute.org/). The main purpose of the BFPE-IS is the provision of better decision making for the Energy Biosciences Institute. The information system enabled the concurrent exchange of data among the researchers with respect to their different information technology backgrounds. Specifically, the use of different programming tools for the development of the information system allowed researchers to communicate with each other automatically using different software technologies. The examples of the BFPE-API functionalities which were presented in this paper, show how the analysis of data can be automated through the integration of database technologies with specific software tools. The specific examples achieve automated analysis, statistical analysis, and data search. Furthermore, they are good examples of knowledge management and also concurrent engineering, since they allow the bi-directional exchange/modification of data. Software engineering is also achieved in a more automated way. For example, the use of concept diagrams allows the updating of the data of the database(s) in an automated way.

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