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Two levels decision system for efficient planning and implementation of bioenergy production

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Abstract

When planning bioenergy production from biomass, planners should take into account each and every stakeholder along the biomass supply chains, e.g. biomass resources suppliers, transportation, conversion and electricity suppliers. Also, the planners have to consider social concerns, environmental and economical impacts related with establishing the biomass systems and the specific difficulties of each country. To overcome these problems in a sustainable manner, a robust decision support system is required. For that purpose, a two levels general Bioenergy Decision System (gBEDS) for bioenergy production planning and implementation was developed. The core part of the gBEDS is the information base, which includes the basic bioenergy information and the detailed decision information. Basic bioenergy information include, for instance, the geographical information system (GIS) database, the biomass materials' database, the biomass logistic database and the biomass conversion database. The detailed decision information considers the parameters' values database with their default values and the variables database, values obtained by simulation and optimization. It also includes a scenario database, which is used for demonstration to new users and also for case based reasoning by planners and executers. Based on the information base, the following modules are included to support decision making: the simulation module with graph interface based on the unit process (UP) definition and the genetic algorithms (GAs) methods for optimal decisions and the Matlab module for applying data mining methods (fuzzy C-means clustering and decision trees) to the biomass collection points, to define the location of storage and bioenergy conversion plants based on the simulation and optimization model developed of the whole life cycle of bioenergy generation. Furthermore, Matlab is used to set up a calculation model with crucial biomass planning parameters (e.g. costs, CO_2 emissions), over the predefined biomass supply chains. The GIS based interface allows visualization of all bioenergy conversion plants and storage data to support the users' decision based on quantifiable outputs. With the help of the graphical interface, the users can define easily the feasible biomass supply chains, take decisions and evaluate them according to their own interests, might they be environmental, economical, social or others. Therefore, the gBEDS supports biomass energy planners in both national and regional levels to assess the options (technically and economically) of biomass utilization and plan for bioenergy generation in a competent and sustainable way.

Keywords: Decision support systems; Geographical information system; Bioenergy; Data mining; Fuzzy C-means clustering; Biomass

1. Introduction

Bioenergy production from biomass resources is of great importance to keep the level of CO_2 emissions under control. The decisions of planning and establishing biomass utilization projects have to overcome satisfactorily widespread types of problems such as: economical and technical feasibilities of bioenergy production; low energy values of biomass and complicated supply chain designs [1–3]. In the last two decades, many research works have been directed towards estimating biomass potential as a source of energy at all levels of evaluation, i.e. global, national and regional [4–7]. At the same time, many attempts were conducted in the form of product and process development trying to overcome the different hindrances and provide

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possible promotion methods for biomass utilization [8–12] or as decision support systems that deal with a set of complicated problems to provide acceptable solutions [13–16]. Mitchell [13], reviewed a large number of decision support models and systems, but those were mostly built and designed for supporting the technical and economical feasibilities, while some others were established for environmental impacts estimations and only a few handle the social impact of biomass use. Some decision support systems are developed considering both the environmental and economical sides and benefits from the geographical information system (GIS) capabilities [17,18,14,16]. However, the previously proposed decision support systems and models in the bioenergy field are mostly constructed for one type of biomass from a specific point of view, i.e. economical, environmental or social, and focus on one decision level, either regional or national [19,20]. This exemplifies the need for a system that handles all bioenergy production stakeholders' objectives in both national and regional decision levels and involves different possible types of biomass with effective potential for energy production.

Decision support systems (DSS) are computer technology systems that can be used to support complex decision making and problem solving [21], providing the user with an accessible computer interface where the results are presented in a readily understandable form. DSS link the information processing capabilities of a management information system with modeling techniques and the judgment of managers to support decision making in unstructured situations. As the social concern is slowly moving towards seeking not only economical but also sustainable energy production methods as well as social benefits [22], a user oriented decision support system is needed to support the energy planners in meeting such changes in interests. In this respect, a general bioenergy decision system (gBEDS) with knowledge discovery capabilities, i.e. data mining has been proposed to assist in planning and implementing bioenergy production systems. In the following paragraphs, some of the aforementioned DSSs will be analyzed.

1.1. DSS for economical and environmental decisions

The development of an economical DSS is very popular in all applied science fields to deal with the entangled set of production and marketing problems to reach an optimal or near optimal solution, e.g. production planning, risk management [23] and recently in environmental decision making [24,25]. However, little work is found in the bioenergy planning field for economical and environmental decision making. This might be explained by the low economical attractiveness of biomass. The bioenergy assessment model (BEAM), a spreadsheet based decision support system has been developed [19] for technoeconomic assessment of biomass to electricity schemes, including investigation on the interfacing issues. The model considers biomass supply from conventional forestry and short rotation coppice and has the possibility of handling different conversion routes, combustion, pyrolysis, gasification and integrated gasification combined cycle (IGCC) to electricity as well as two biological routes to ethanol. A module for investigating the collection and generation of electricity from municipal solid waste (MSW) was also presented. Additionally, different scenarios of electricity and heat production from biomass were proposed and dynamically evaluated for economic efficiency by a mixed integer linear optimization model [26]. The model aimed at determination of the economic energy supply structure considering different kinds of users and investors to reduce biomass fuel prices. A decision support framework for choosing efficient, environmentally sound and economically feasible greenhouse gas (GHG) emission reduction scenarios in forestry is also constructed and tested for realistic scenarios including forest conservation, forest expansion, forest management, forest products usability and substitution of fossil fuels with woody biomass [20]. The system consists of three evaluation modules: the carbon assessment module for estimating emission reduction per hectare per year; the environmental assessment module for assessment of environmental impacts of carbon projects and the economic assessment module to obtain the net cost of 1 ton emission reduction.

1.2. DSS integrated with GIS

The idea of using the geographical information system (GIS) in decision support systems is not new and is found in the development of many decision support systems [27–30]. However, the integration between the GIS and the DSS technology is comparatively less extensive in the bioenergy planning field. An optimal planning decision support system of biomass as a source of energy for a consortium of municipalities in an Italian mountain region was developed [15]. That study suggests actions and policies for biomass exploitation in the region, the sizing of plants and the verification of the performance over the entire system. The authors applied mathematical optimization technologies integrated with the GIS and databases, whose information was gathered through experimental tests and interaction with experts. Voivontas [18] presented a method for estimating the potential of bioenergy production from agriculture residues at the regional level through a GIS decision support system. This DSS provides tools to identify the geographic distribution of the economical biomass potential in four exploitation levels, i.e. theoretical, available, technological and economical, relying on the modeling capabilities of the GIS environment. The authors used electricity production cost as the main criterion in the identification of the sites of economically exploited biomass potential. A two part method for estimating potential fuelwood resources from forests based on forest inventory data was also presented [14]. The first part considers the assessment of fuelwood resources potential, and the second part deals with the economical availability of resources. The biomass assessment data, location of conversion facilities and projected consumption were incorporated into an economic model based on the GIS to form industrial marginal cost of supply curves from an optimization of the allocation of fuelwood using linear programming. Another methodology, used a GIS application to generate marginal price surfaces when the number of potential supply points and the number of candidate plant locations are both very large, was developed to identify locations for switch grass to ethanol conversion plants [31]. The same methodology was tested to evaluate two ways of procurement pricing, fixed and discriminatory [32]. In the fixed pricing method of procurement, the facility pays one fixed price per delivered ton. In the discriminatory pricing method of procurement, the facility pays a source specific price per ton before delivery and then pays the cost of delivery transportation. Their results show a cost advantage of discriminatory over fixed pricing with the relative cost advantage variation as a function of location and facility size.

1.3. Data mining DSS

The use of data mining in decision support systems is popular in medical, information technology [30,33] and recently in environmental applications [34,35]. However, in the field of biomass planning and utilization, no previous work was conducted.

After reviewing previous works and careful consideration of their limitations, a two level general bioenergy decision system (gBEDS) is proposed to overcome such drawbacks and assist in planning for bioenergy generation from biomass and introduce data mining methods as a new decision support tool in the biomass energy production field. The proposed system provides general functions of data visualization, data analysis and simulation methods to support decisions regarding bioenergy generation. The gBEDS divides the bioenergy generation decisions into national and regional levels. Different methods of data visualization, analysis and simulation are provided for the two planning levels. In the following sections, the planning problem description and the possible solution methods for the two decision levels are discussed. A case study for planning Japanese forestry residues to electricity production is also presented.

2. Description of decision problems

The objectives of a national planner, who proposes a biomass exploitation strategy for the whole country, are different from those of regional planners and executers who are applying policies in a small scale with specific requirements and limitations, e.g. resources availability, topological restrictions and energy needs as shown in Fig. 1. Such differences in scope must be taken into account when developing systems for decisions and planning support for the exploitation of biomass as a bioenergy resource. For a macro-level of planning, such as that of national planners, a rough cost model is enough since their main concerns are defining: the available biomass materials in the whole country; the available energy conversion technologies for converting different biomass materials to different bioenergy media; economic effects (such as the cost of energy production or the potential legislative benefits) and the benefit in applying emission prevention legislation, e.g. emission taxation, renewable portfolio standard and fossil fuel taxation. Based on the decisions of the planners at the national level, the regional executers and designers will determine the detail unit processes (UPs) to meet these decisions: the detail optimal size of each biomass plant in terms of both energy production and feeding; the percentage of electrical energy with respect to the total energy produced; the quantity of biomass that must be collected and the detailed location for collection and production of biomass. Specifically, in the regional level, more detailed information is provided, so a rigorous model considering the

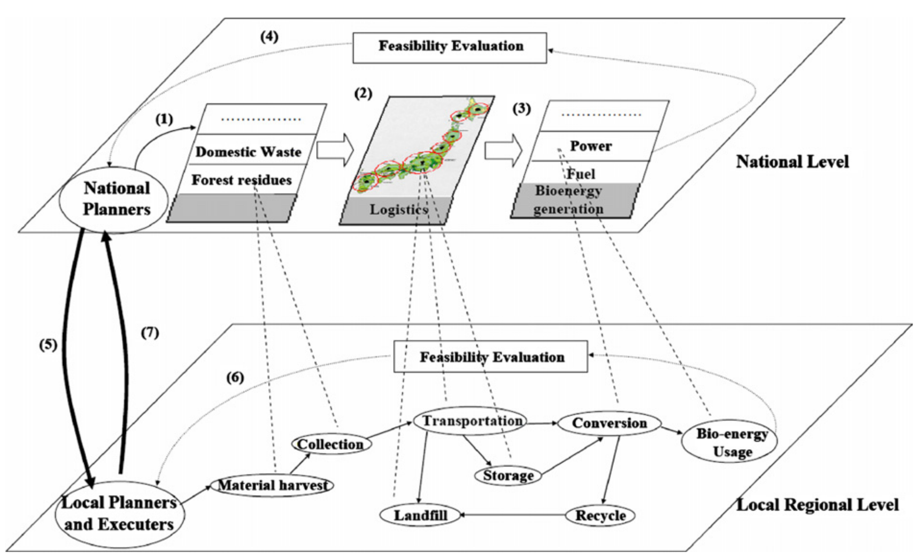

Fig. 1. The two levels with different objective in the gBEDS.

biomass and its logistic costs, the energy conversion costs produced by the whole system and the labor cost should be applied for its whole life cycle. To keep biomass exploitation sustainable, users need to determine which biomass and what quantities are feasible for collection, the collection points and, consequently, their geographical position. According to the decisions made by the regional planners and executers, the decisions of the national level may be applied, rejected or modified, as a result of typical regional inputs, as seen in the number sequence in Fig. 1.

3. System description

3.1. The gBEDS conceptual structure

As shown in Fig. 2, the proposed gBEDS consists of four parts; a common database; a simulation module; an in line domain knowledge evaluation module; and a user interface. The common database includes relevant data about biomass types database, biomass logistics database, biomass conversion database and GIS database. The planners define the feasible paths from the common database supported by the in line domain knowledge evaluation module, e.g. the selection of sewage sludge cannot match with the gasification without severe drying. After selection of the feasible path for biomass material, simulation and further data analysis performed by fuzzy C-means clustering algorithms and GAs [36,37] produce the results, which are visualized via ArcGIS for easier evaluation of the desired supply chain for decision making.

3.2. Development of the gBEDS

The gBEDS is built on a technological information infrastructure concept that captures the biomass entire life cycle [38] to support the design and operation simultaneously, considering economical impacts (total investments to establish the bioenergy business, costs per MWh of bioenergy etc.), environmental impacts (GHG emissions, energy saving and renewable portfolio standard (RPS) promotion) and social impacts (job creation potential and energy tax application). gBEDS deals with the biomass utilization problems as a source of bioenergy from a nationwide perspective to a regional one. The main ideas for gBEDS development will now be presented.

3.2.1. Technological information base

In this system, the whole life cycle from biomass resources to bioenergy should be considered due to the environmental problems, and many actors will be involved in the decisions, from the officer in the national level and the regional level to the detail experts in biomass harvest, transportation and bioenergy conversion and so on. Therefore, a general information base is developed and considered as the core of the system. The information system is built on MS Access 2000, which provides not only the functions to save the data but also the interface to edit and search the relevant data.

The technological information base includes:

(1) The basic information for the whole life cycle of biomass and bioenergy, e.g. the GIS database, the biomass material database, the logistic database and the conversion database.
(2) The model information for decision taking about biomass and bioenergy, e.g. model database saving the variables, parameters and equations, which are composed of some sub-model, i.e. UP database.
(3) The detail decision information, e.g. the parameters database, where default values are saved, the variable database, which is composed of the simulation value database (values obtained by simulation), the optimization value database (values obtained after optimization) and the real value database (values actually used).
(4) The scenario database, which is used for demonstration purposes for new users and as case based reasoning by planners and executers. Communication with the different database is managed by a proper ODBC (open database connectivity) interface.

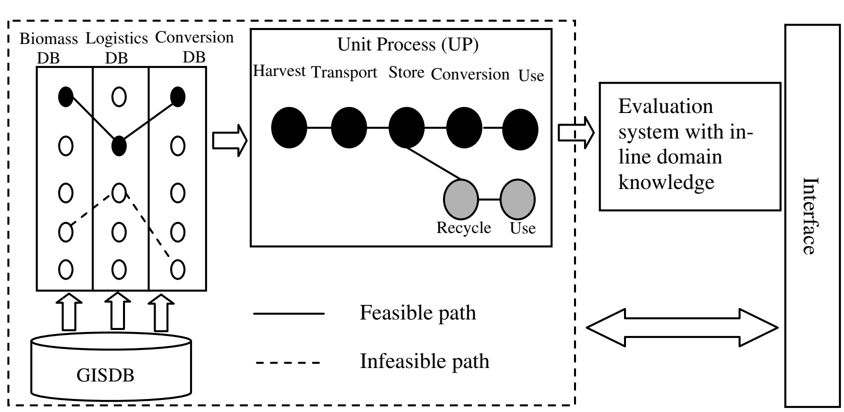

Fig. 2. The conceptual structure of the gBEDS.

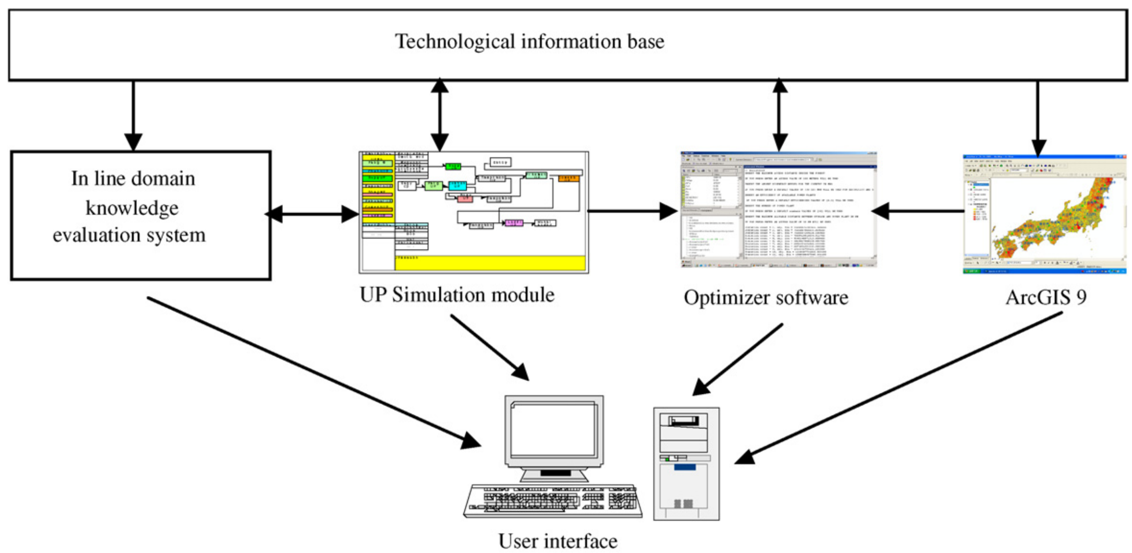

Fig. 3. gBEDS architecture.

3.2.2. System architecture

The decision support is provided based on the following modules as shown in Fig. 3:

(1) The technological information base, which is shared by the users.
(2) The GIS based interface using the ESRI commercial ArcGIS9 environment [39] for data visualization.
(3) The fuzzy C-means clustering methods and GA methods for optimal decisions; whose source code is provide by the Matlab environment [40].
(4) The unit process (UP) simulation interface module based on the UP definition [38].
(5) The in line domain knowledge for evaluating the user selections of the supply chain.
(6) The user interface between the modules mentioned above and the users.

The user's computer should have the following characteristics:

- At least 256 MB memory.
- 10 MB or more of free disk space (The data preservation area is excluded).
- A SVGA Monitor (800×600 256 colors) or better.
- Pointing device, such as mouse.
- Operating system that operates J2SE1.4 or higher as Java execution environment.

3.3. Solution methods for decision problems in the national level

The biomass GIS database for the country is provided, assigning the amount of biomass resource quantity attributes to each city in a year base (ton/year) in the form of points in case of spot production methods, e.g. food industry, saw mill residues or uniformly distributed over the city area. To help the user to have useful information from such data available, gBEDS provides the solution of the decision problems as explained in the following subsections.

3.3.1. Defining the feasible biomass quantity

The gBEDS classifies the biomass resources into available (all biomass resources produced), possible (the quantities of biomass that can be easily collected for all uses) and feasible (the biomass quantities that can be used for energy production). The first step is to subtract the biomass quantities used for different purposes, like fertilizers, bio-products or others, to have the possible quantities for energy production. At this level, the utilized quantity from the biomass type is estimated assuming a fixed utilization ratio of the total available quantity of the resource in the country. However, in the regional level, the specific quantity in each city is employed. In the case of distributed quantities, the total number of possible collection points and their locations in each city are determined by applying the algorithm shown in Fig. 4.

For all biomass types, the possible biomass quantities are feasible for collection except for the forestry residues where the feasible biomass quantities are determined based on the maximum access distance inside the forest from the road in the country and has to be defined by the user, the system omits all points located a distance more than the desired distance. The process algorithm is explained in Fig. 5.

3.3.2. Setting the technically feasible supply chain

The activities that take place in the biomass supply chain are highly interconnected, and it is easy to understand how upstream decision making affects later activities

```
Program: Collection points' data determination
  Program definition: goal: Randomly generating the collection points
                            locations around the city centroid,
                            defining the biomass quantity in each point and
                            define the feasible number of collection points.
inputs: city centroid, biomass generated per
        tree and number of trees per hectare.
outputs: collection points centroids and biomass quantity in each point.

Program body:
  constant (dry_forestry_residues_weight_tree)
        constant (number_trees_hectare)
              calculate (biomass_at_collection_points), (number_points_city)
for (each_city_centroid)
    generate (random_x_for_all_collection_points),
        generate (random_y_for_all_collection_points)
endfor
```

Fig. 4. Collection point determination algorithm in the gBEDS.

```
Program: Feasible collection points' data determination
  Program definition:
    goal: define the feasible number of collection points and
          total feasible biomass quantity.
  inputs: array of collection points
  outputs: feasible collection points centers, biomass
          quantity in each point and feasible biomass quantity
Program body:
  for (each_collection_points)
      if (distance_to_road¹access_distance)
                  omit (this_collection_point_from_data)
          construct (feasible_points_array)
      endif
endfor
feasible quantity(sum(feasible_points_array))
```

Fig. 5. Feasible collection points' data determination for forestry residues in the gBEDS.

in the chain. For example, a very cheap harvesting method may need very complicated transportation and conversion facilities that may increase the cost and CO_2 emissions per unit value of energy [41]. The gBEDS with its Unit Process Simulator (UPS) interface and the in line domain knowledge capabilities help the decision maker set the technically feasible supply chain.

In the UPS, the user should set the biomass input type and the desired bioenergy output, and then two options are possible: either to build the user's own supply chain with the help of the system; or to decide the suitable supply chain from the built in supply chain scenarios database. When designing the biomass supply chain, care must be taken to compromise between the different stakeholders' objectives, i.e. economical, environmental and social impacts of energy produced from biomass in order to reach an acceptable level of agreement. Those impacts mainly depend on their related supply chain. With the help of the system, the user can build the technically feasible supply chain that meets his concerns and fits the technical design point of view. That could be achieved by constructing different processing patterns for each UP, e.g. transportation patterns and storage patterns. A little introduction about what UP is follows.

3.3.2.1. What is UP? The UP concept is a powerful means of handling the complicated engineering problems [38] and is defined as: the processes necessary to manufacture (produce), transform, store, transport, collect and deliver products sold or bought in the market. The main UPs, e.g. transformation process, logistic process and transportation, are saved as information models. The typical UP contents are shown as Fig. 6.

3.4. Data mining and visualization

Based on the supply chain scenarios defined by the user, the gBEDS defines the locations, optimal sizes and capacities of the storage place (if it is included), the bioenergy conversion plants, the minimum traveling distance between collection points and the storage, minimum distance from the storage to bioenergy conversion plant for minimizing the transportation costs, CO_2 emissions and number of workers, which is realized simultaneously by clustering methods [42], i.e., fuzzy C-means clustering of the collection points.

3.4.1. Clustering

The fuzzy C-means clustering is a non-hierarchical clustering method and is designed to cluster the collections points into C clusters by minimizing the following function:

$$E_c = \sum_{p=1}^{P_k} \sum_{i=1}^{n} (x_{cpi} - \bar{x}_{ci})^2 \tag{1}$$

where c is the index of the cluster, $c = 1, \ldots, C$. x_{cpi} is the score on the ith dimension of the n dimension variables for the pth of P_c data points in the kth cluster, x_{ci} is the mean (i.e., the ith dimension of the centroid) on the ith dimension in the cth cluster, E_c is the error sum of squares for cluster c. The data clustering methods may be applied one or two times in the system depending on the supply

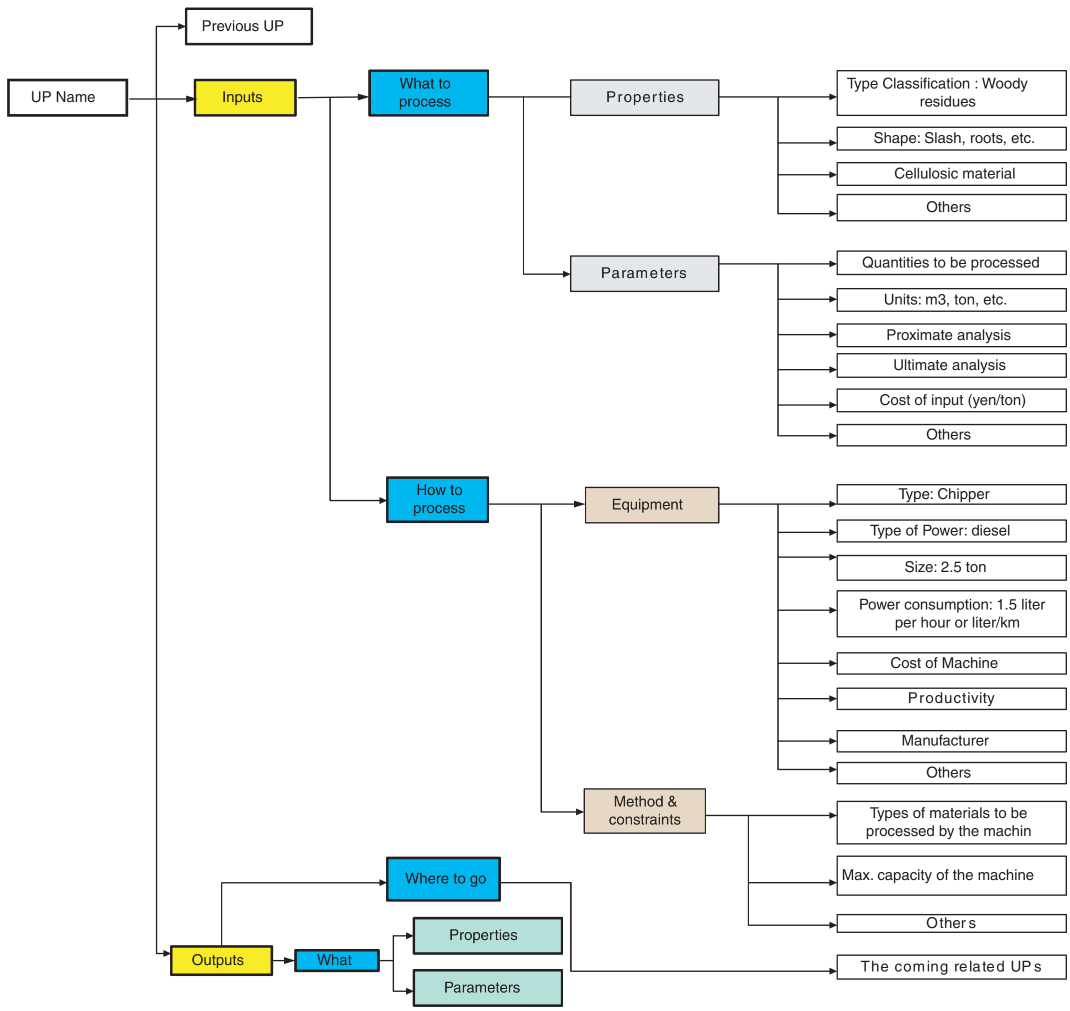

Fig. 6. Unit Process definition in the gBEDS.

chain defined by the user. That means if the supply chain includes storage, the clustering method will be applied first to define the potential location of the storage points by clustering the collection points considering the storage places as clusters centroids. To locate the bioenergy conversion plants, the resulting storage points (centroids of the first clustering iteration) are clustered to determine each bioenergy conversion plant location, assuming it will be located at the centroid of the c-cluster whose size is compared to the E_c, which means the transportation cost between the collection points to storage and from storage to conversion plants are also optimized by the fuzzy C-means clustering at the same time.

3.4.2. Clustering method in the system

In the local level, two ways are available in the gBEDS to define numbers and locations of storage and bioenergy conversion plants. The user can define the locations on the GIS screen based on his experience and supported by visual data provided by the system. This method is excluded in the national level, as it is an unrealistic solution for the large numbers of storages at that level and bioenergy conversion plants. In a second method, the numbers and locations are defined automatically by the criterion known as cluster validity index (VI) that is measured for the input data set [36]. The VI defines how well the clustering algorithm can partition the given data sets. In the gBEDS, the validity index to obtain the optimal number of clusters is represented as [36]:

$$\text{Validity} = \frac{\text{Intra}}{\text{Inter}}, \tag{2}$$

$$\text{Intra} = \frac{1}{N}\sum_{i=1}^{C}\sum_{x\in U_i}\|x - z_i\|^2, \tag{3}$$

$$\text{Inter} = \min_{i,j}(\|z_i - z_j\|)^2, \tag{4}$$

where $i = 1, 2, \ldots, c-1; j = i+1, i+2, \ldots, c, N$ is the number of collection points, C is the number of clusters (storage or bioenergy conversion plants) and z_i denotes the spatial location of storage or plant U_i. The objective is to minimize the intra-value, which is the average distance between the data points and the center of the cluster, and, at the same time, maximize the inter-value, which is the inter distance between the clusters centers. The VI for C is obtained by

Table 1
Validity index table provided to the user (storage locations)

Number of clusters	VI	Intra (m^2)	Inter (m^2)	Feasible biomass quantity (ton)
10	0.086482	1.67E+09	1.93E+10	86,568
50	0.51151	9.60E+08	1.88E+09	2,36,250
100	0.76462	5.77E+08	7.55E+08	2,45,740
150	1.3007	4.07E+08	3.13E+08	2,47,200
200	1.5765	3.11E+08	1.97E+08	2,47,770
250	2.4332	2.64E+08	1.08E+08	2,47,610
300	4.1897	2.17E+08	5.18E+07	2,47,690
350	3.6349	2.12E+08	5.83E+07	2,47,570
450	4.3634	1.64E+08	3.75E+07	2,47,770
500	10.178	1.57E+08	1.54E+07	2,47,610

minimizing the intra–inter ratio. The VI table, prepared for the specified data set as a pre-knowledge in the gBEDS, is provided to the user. The gBEDS also provides an option to allow calculation of the VI by the user, however, it takes a very long time because the computational complexity of the algorithm is $O(nct)$, where t is the number of iterations [36] (it took 48 h to establish the VI table of 500 clusters for 6195 collection points in a Pentium 3 1500 MHz CPU). A sample of the VI table prepared by the system for the Japanese forestry residues storage is shown in Table 1 for the national level. Using the VI table, the numbers of clusters, e.g. storages and bioenergy conversion plants that meet users requirements are defined. It is important to understand that the number of clusters and the maximum feasible amount of utilized biomass are not interrelated as shown in Table 1. If we considered 450 storages, the feasible quantity is more than that of 500 storages. Based on the optimal results by the fuzzy C-means clustering of the collection points, all bioenergy conversion plants attributes such as locations, capacities, number of workers etc. can be evaluated easily as will be explained in the next subsection.

3.4.3. Collection points clustering and impacts estimation

The desired VI is defined from the table or according to user requirements and the system is ready to estimate the biomass utilization impacts along the selected supply chains by applying the clustering method to the collection points data in the Matlab® environment, version 7.0.1 with service pack 1 [40]. The system asks the user to define some site specific inputs required for the impacts calculations such as type of bioenergy required; efficiencies of available bioenergy conversion plants, average access distance from transportations routes (in case of forest) and others. Default values are provided for users who do not have sufficient information about the required inputs. The data related with the required storages (locations, areas, costs etc.) are calculated and saved in a matrix (database file dbf) in order to establish the storage layer in the gBEDS interface. Furthermore, the system defines the different impacts (environmental, economical and social) of bioenergy production from the input type biomass (costs, CO_2 emissions per amount of electricity produced, number of men-labor per the supply chain, total investments required for establishing the business and others) for constructing a matrix of all data related to bioenergy production for each plant as a database file.

3.4.4. Output data visualization

The resulting data files for storage and bioenergy conversion plants are incorporated in the country map at the GIS interface and joined spatially with city layers to define the cities where storages and bioenergy production plants should be constructed. This way, the user can always visualize the storages and plants data interactively with the system. The resulting data are saved in an Excel file for further analysis by the different stakeholders in the decision making process.

3.5. The solution methods for the regional level

As explained in Section 2, a more complex and rigorous model in the regional level should be given. At this level, the decision process is given using an embedded hybrid data analysis technique, the fuzzy C-means clusters, within a genetic algorithm optimization framework [43]. The basic structure for the genetic algorithm optimization framework is shown in Fig. 7. A number of genomes constitute a population. During the genetic search, genomes are selected from the population with a probability proportional to their fitness value. Genetic operators such as crossover and mutation are applied to the selected genomes and the objective value of the offspring is calculated. Some or all of the members of the new generation replace the current population depending on the value of the objective function. The main input from the user is the definition of the method for calculation of the fitness, i.e. the cost functions. With the given value of the decision variables (e.g. the number of the cluster C) from the planner in the national level, the fuzzy C-means clustering method is used to define the optimal size and the location of the plants at first. Then, the simulation model based on the objective functions and the constraints is used to evaluate its feasibility, and if it is not feasible, a maximal value is given to the cost function, otherwise, the real cost is simulated according to the objective function as fitness value in the GA.

3.6. Relationship between planners in national and regional levels

After explaining the solution methods in the two decision levels, it is worthwhile to clarify the possible relationship between the planners in the national and regional levels. As shown in Fig. 1, the planners in the national level make a decision to select the biomass materials, biomass logistic methods and the bioenergy conversion methods based on a simple labor cost and environmental model. Moreover, in the national level, the whole land is divided into several local regions by the fuzzy C-means clustering methods based on the given biomass distribution GIS database

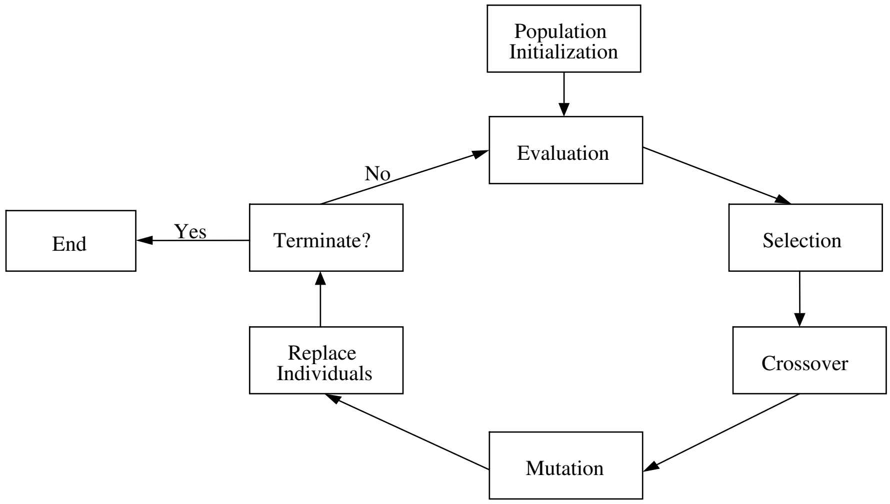

Fig. 7. General structure of genetic algorithms used in the gBEDS.

where the real geography information in the local regions is not considered. For instance, the difficulties imposed by hills are not taken into account in the possibility of transportation. Therefore, such decisions made in the national level should be reviewed in the regional level for its effective and practical feasibility. While making the decisions in the regional level, some input information should be given by the strategic planers in the national level to evaluate the real cost based on a detailed model. Therefore, we can conclude that there should be a synergetic integration among actors, perspectives, objectives and tools in both levels for efficient decision making.

3.7. System users and application

When designing any planning support system, one should consider who will use the system and the types of functionality the system will provide. In the following sections, these two important issues are considered under the framework of the system presented here.

3.7.1. User classification

The target users of the system include governmental policy designers of energy systems in the national level, individuals related to eco-management (environmental protection, environmental accounting and reporting) at the enterprise and governmental level, university and government researchers and companies interested in biomass management and technology in both the national and local levels.

3.7.2. Functionality

The proposed gBEDS is designed to provide the following functions:

- GIS data visualization methods to identify the geographic distribution of the economically exploitable biomass potential;
- data analysis methods (e.g., fuzzy C-means clustering methods and decision trees) for assessment of the theoretical, available and economically exploitable biomass potential;
- determination of the economical biomass collection points, storage points and bioenergy conversion plants geographical distribution; and
- simulation methods based on cost modeling to provide optimal decision making for bioenergy generation at the national and local levels.

4. Case study: electricity from forestry residues in Japan

Designing the forestry residues supply chains for power generation in Japan has different characteristics than in other countries like, for instance European countries. These differences originate from the nature of the land, forest residues density, forestry population and weather. For example, Japanese weather is mostly wet, and it can rain at any time, which creates a need for covered material storage. Also, the mountainous topography prevents high capacity equipments from being employed. Limited access distances and low density forests result in difficulties in estimating the feasible amount of forestry residues that may be used as a source of bioenergy. In this case study, the Japanese geographical information system data base (GISDB) for forestry residues is applied to demonstrate the gBEDS is efficient in supporting decision making for bioenergy production.

4.1. Supply chain in the case study

In this study, the harvesting is assumed in three episodes depending on the weather, two months for each [44]. After harvesting, the forestry residues are left to dry at the harvesting site for another two months before chipping at the harvesting site using a mobile chipper and moved to the roadside using small size forwarders [44–46]. Small size trucks are used along the roadside for transporting the chips to the storage place. Forestry residues chips are stored a maximum of 4 months before delivery to the power plant. That means storage facilities are utilized the whole year by one third of the chips amount, which reduce the storage costs to one third of whole year storage costs.

Because of the wet Japanese climate, indoor storage near the forests is assumed. The GHG emissions from storage in the system were modeled based on Wihersaari [47], assuming that CH_4 is released from wood chips in the first two months of storage and then N_2O starts to be released. Then, chips are transported in medium capacity trucks to be converted in the fluid bed combustion system, followed by steam turbine cycle power generation (C/ST). At last, after conversion, the ash is transported for landfill. In the bioenergy supply chain seen in Fig. 8, the costs of the connections and selling electricity are also included for cost estimation. Emissions from fossil fuels production, equipment manufacturing and infrastructure are not included in the calculations. These factors seem, however, to be of minor importance as stated in previous investigations [48].

4.2. Data used in the case study

In this case study, the data was collected from two main resources: meetings with experts and literature, not only from Japan, but also from other countries. All currency figures in this work are expressed in Japanese yen, JPY, on a 2005 year base unless otherwise noted. The required conversion to European Euro, €, and US dollar, $, has been done at the rate of 140.299 JPY and 118 JPY, respectively. Costs from the literature beyond year 2000 were used without considering the inflation rate, assuming that the cost reduction from the promotion of biomass utilization compensates the cost difference. The case study aims at estimating the different impacts of power generation using Japanese forestry residues. The forestry residues properties are shown in Table 2, and the equipment data and values are presented in Table 3.

In this case study, we assumed no cost for buying the forestry residues as it is mostly left in the forest until deterioration. For the electricity production planning, the cost model developed by Caputo [49] was used for the plant costs estimations, however, their cost model was constructed for 5 MW electricity power plants, which may increase the uncertainty in the costs estimation.

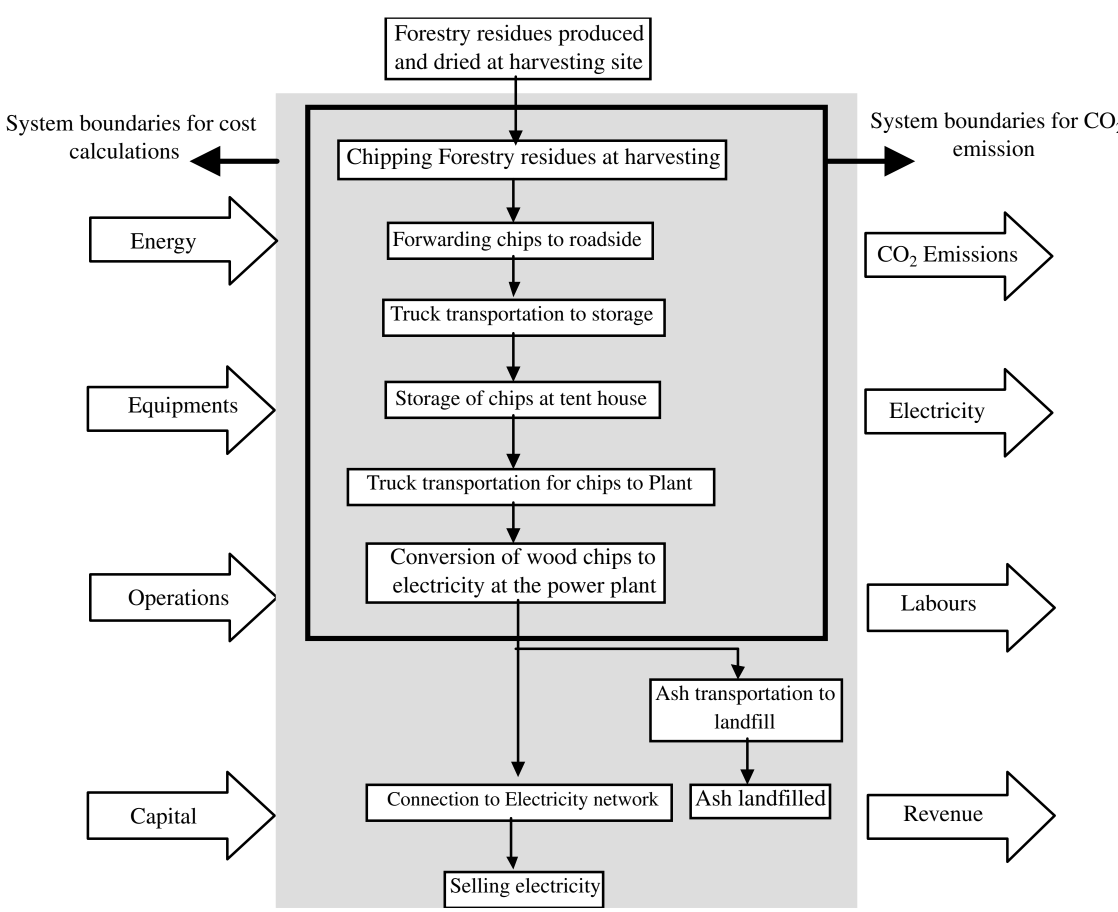

Fig. 8. Bioenergy supply chain in the case study.

Table 2
Forestry residues properties

Characteristics	Value
Moisture content (%)	35[a]
Heating values (MJ ton^{-1}, LHV)	14650[a]
Bulk density during transport (dry ton m^{-3})	0.2518[b]
Ash contents (%)	2[a]

[a] Ref. [49].
[b] Ref. [44].

Table 3
Equipment data

Feature	Value
Plant life (years)	30[b]
Net plant efficiency (LHV) (%)	30[b]
Plant operating hours (h/year)	8000[a]
Forwarders capacities (ton)	2.5–10[a]
Chippers weight (ton)	2.5[a]
Chippers productivity (ton/h)	0.45[a]
Truck capacity for transportation to storage (ton)	4
Truck capacity for transportation to plant (ton)	15

[a] Ref. [44].
[b] Ref. [50].

4.3. The gBEDS results for the supply chain

As explained in the targets of this research work, the gBEDS is constructed to support decisions making that can fulfill, as much as possible, the intentions of all the stakeholders in the bioenergy field. In this respect, the results are classified as: biomass potential (how much biomass is available in the country or the region); results for environmental decision support (CO_2 emissions, energy saving); results for economical decision support (cost of energy production, annual investments) and results for social decision support (number of workers, energy taxes). Those results are all shown to the user as explained in the following sub-sections.

4.3.1. Forestry residues potential

The amount of available forestry residues in Japan as calculated from the Japanese forestry GISDB was found to be 1.84 million ton of 15% moisture contents. However, according to our model calculations only a maximum of about 13% of that is feasible for all uses (in this case study, all residues were used for electricity production), which may produce about 50 MW for 200 m access distance inside the forest or almost 70 MW, if the access distance is increased to 300 m.

4.3.2. Results for environmental decision support

The CO_2 emissions from bioenergy production is considered as the main motivating reason in promoting biomass utilization projects in order to replace the main source of GHG, fossil fuels. The CO_2 emissions of electricity production from forestry residues was calculated for all the power plants locations proposed by the system and found to be between 125 and 135 kg CO_2/MWh. The CO_2 emissions from electricity production using oil as raw material in Japan is 742.3 kg CO_2/MWh [51] (this figure is supposed to be very high compared to that of Finland and Hungry, 312 and 342.8, respectively [52]). The big difference between biomass emissions and oil emissions may clarify their potential of emissions reduction when used as the source of electricity. More specific data are also provided by the system for each power plant to help decision makers in taking individual decisions for establishing or rejecting the proposed locations. The gBEDS includes more environmental decision support parameters individually described for each power plant, such as emissions from each UP considered.

4.3.3. Results for economical decision support

The gBEDS estimates total investments per year for the whole country for each proposed power plant location and the production costs of 1 MWh of bioenergy. The costs of electricity production ranged from 30,000 to 50,000 JPY/MWh depending on the location of the power plant and its distance to collection points. These cost figures are, as expected, very high compared to that of depleted materials. However, it is in good agreement with those of renewable energies [53,54]. The effect of applying environmental carbon taxation is also included in order to give the user information about the situation if the tax is applied. With environmental carbon tax equal to 9000 JPY/ton CO_2 released from fossil fuels use the costs per MWh could be reduced by about 5500 JPY. Also, many economical parameters are given for each power plant in the gBEDS, e.g. annual total required investments, number of equipment in each UPand costs of storage UP.

4.3.4. Results for social decision support

Carbon dioxide and energy taxes have a distinguished impact in the promotion of renewable energy and, at the same time, reduce the environmental impacts. On the other hand, these taxes are mainly paid by all society sectors, where we always find an immense resistance against applying them. Convincing the people through explaining the possible merits of renewable energy can be supported in the gBEDS by viewing the possible number of jobs that can be generated via bioenergy projects establishment. For instance, the forestry residues utilization for electricity production in Japan could generate about 1300 jobs with an average of 30 workers for the power plant. Furthermore, the emission reduction potential per MWh is also a social advantage of using forestry residues that is found to be about 600 kg CO_2/MWh. The energy saving potential of biomass is another issue that is handled by the gBEDS, which raises our responsibility towards the rights of new generations to save as much as we can from earth resources and environment. The utilization of Japanese forestry residues will save 1.2 million tonnes of oil equivalent (TOE).

4.4. Data visualization

As mentioned before, the data in the gBEDS are exposed to the user in three ways; first, the GIS visualizations, where all power plants data in the country are shown to the user. Figs. 9 and 10 show the name of the city, an economical location, where power plants should be positioned and the feasible biomass quantity of each city, respectively. The data also are given in matrix form for users who want to use further analysis.

Finally, the data are visualized as a bar drawing form for quick revision of the results as shown in Figs. 11 and 12 for the daily number of workers and annual investments required for a 2 MW capacity power plant.

4.5. Calculations uncertainties

The overall uncertainty of the estimates made in this case study is difficult to calculate because they are based on data from several sources with wide differences in reliability. Nevertheless, the chips storage is considered the most uncertain part of these calculations. First of all, the chosen emission factors have not been verified by any measurements from chips storage. That means the

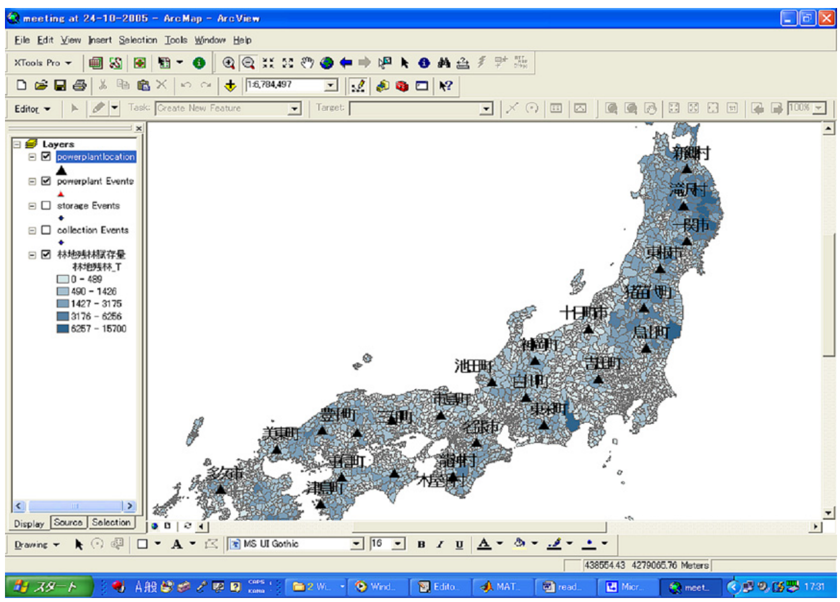

Fig. 9. Power plants data visualized by city name.

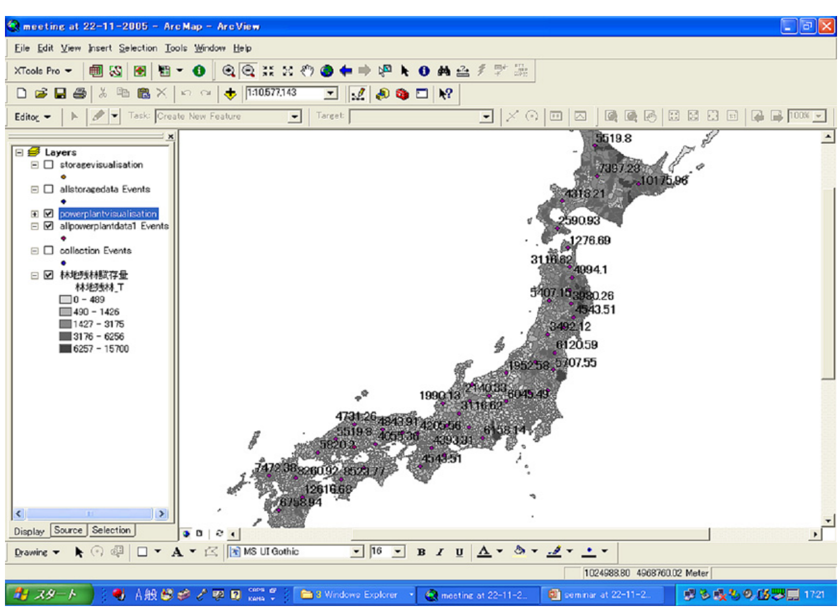

Fig. 10. Power plants data visualized by feasible biomass quantities.

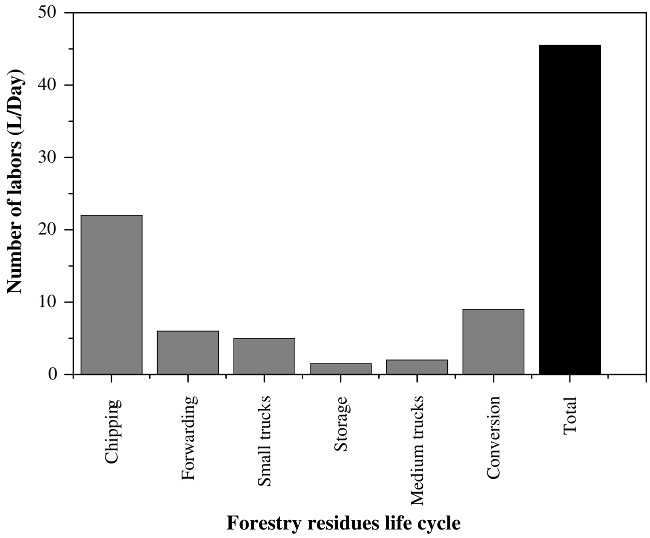

Fig. 11. Numbers of workers required at the electricity based forestry residues supply chain for a 2 MW plant.

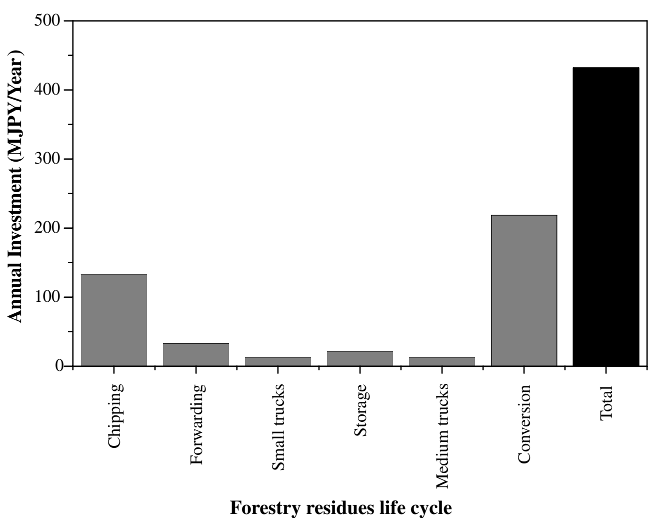

Fig. 12. Annual investments to realize the electricity based forestry residues supply chain for a 2 MW plant.

reliability of the model results for the studied supply chain depends on both the validity of the model structure and the accuracy of the model parameters. However, these uncertainties are a parametric issue, as when more reliable data exist, the system effectiveness estimations increase do not affect our approach in providing the user a decision support tool that includes all priority importance for the different players in the biomass field.

5. Conclusions and future challenges

This paper proposes a general bioenergy decision system (gBEDS) as an effective tool in planning for bioenergy production expansion as demonstrated by the case study. The user interface in the system provides decision makers with an integrated system, comprising data mining techniques (e.g. fuzzy C-means clustering and decision trees methods) to define the optimal size and location of the conversion plants as a first step and simulation models with a user interface to evaluate the selected supply chain for economical and technical feasibility. A calculation model is included to determine all data related to bioenergy production and evaluation. The bioenergy parameters data are then accessed in different visualization methods to enhance the decision makers' aptitude in data investigation, analysis and communication with different stakeholders. We also believe that the saved simulation models database. Though this system is developed under the ''Biomass Leading Project 2003–2005'' that is supposed to handle biomass utilization planning at five big Japanese cities, in this paper, we only provide a case study for the national level because the data available in the regional level are still not sufficiently complete.

One of the challenges ahead is to extend gBEDS to planning effectively biomass utilization integrated systems that includes more than one biomass type and to involving the existing exploitation systems. That is an essential task because individual utilization of biomass resources in many countries, especially in Japan as we see in the case study, seems to be not economic even with governmental subsides or applying the renewable energy institutions, such as, RPS, green products certificates and energy and emission taxes. Another challenge is how to develop such enhancements of the gBEDS to be a Web based Decision Support System for facile maintenance and update of the technological information base of the system while preserving the capability to manage biomass logistics and power plant locations by optimizing the traveling routs through network optimization techniques to assure high performance estimations of system output parameters.

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