Biomass Resource Mapping and Potential Evaluation in Hokkaido

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To promote the utilization of biomass energy, it is important to evaluate the potential resource and its distribution and accessibility appropriately. In this study, the available amount of various kinds of biomass resources was estimated based on several statistical data. These data are aggregated into the geodatabase with a uniformed and fine spatial resolution of 1km mesh by estimating its spatial distribution using geographic information system (GIS). Furthermore, the accessibility analysis was performed by the GIS-based network analysis based on the real road network in each region. As a result, the relationship between the accessible time and the resource potential was figured out in each region by this method. Moreover, the transportation costs of each resource were estimated by applying a cost condition. For instance, in Furano City, thinning woods have the highest potential in the entire region. However, crop residues have higher potential in the region accessible from the municipal office as a demand site within 20 minutes. Also, crop residues are considered more reasonable than the others throughout the region in terms of transportation costs.

Key Words

Biomass energy, Network analysis, GIS, Transportation cost

1. Introduction

Biomass energy (bioenergy) is one of the renewable energy sources and presumably plays a critical role in climate change mitigation 1). That can be utilized for power generation which can support base-load electricity demand, heat generation and motive fuel production (biorefinery). The Japanese government established "National Plan for the Promotion of Biomass Utilization" in 2010 to promote biomass resource utilization for energy and material uses and set the target of utilizing 26 million tons of carbon equivalent resources in 2020 2). Also, the feed-in tariff (FIT) system was started on July 2012. The system ensures purchasing electricity generated from renewable energy sources including biomass with fixed price and period.

Biomass resources consist of many kinds of materials such as unused thinning wood, crop residue and raw garbage. The quantity and availability of these resources are different between regions and these conditions are diverse. Energy density of these resources is lower than fossil fuels and several species are spatially-dispersed. Therefore, estimation of resource potential is a crucial step for subsequent process such as site selection of bioenergy facilities or decision making processes 3) 4) . Considering the situations, many studies have been conducted. In Japan, for instance, Yamamoto et al. (2007) developed biomass balance...
On the other hand, the spatialized data of these resources play important role, because the transportation cost tends to be higher as the distribution is more spatially widely dispersed and the density is lower. Especially, despite the advantage in the cost with larger systems which is known as economy of scale, the larger systems require more raw materials for energy conversion which result in higher transportation costs. From this perspective, it is considered that the biomass resources have high affinity to small-scale utilization and many studies have been conducted with consideration of transportation costs in various regions in the world. In Japan, several studies have also been carried out with specific biomass resources. For woody biomass, Yagi and Nakata (2011) established a tool which analyzes optimal plant size, plant location, the number of plants in an area and lower generation cost for each plant based on several input data including transportation cost. They prepared resource distribution data of 4 km² mesh in Miyagi Prefecture. The evaluated resources were logging residue, unused thinned wood, sawdust and cutting edge. Kinoshita et al. (2009) calculated the spatial costs of forestry operations and woody biomass harvesting using Geographic Information System (GIS) with considering the series of working process from felling to chipping including transportation. This study targeted Yusuhara Town in Kochi Prefecture. The resource distribution data were derived from “forest register” data and its spatial resolution are 0.01 through 1ha. Similar approach was carried by Yoshioka et al. (2011) with 50m-grid data in one of the towns in the middle of analyzed optimal plant allocation with same method as Yagi and Nakata (2011) based on 1 km² resource data of Kuzumaki Town in Iwate Prefecture. Yabe (2013) created a distribution map of cow manure with agricultural community scale data in entire region of Hokkaido Prefecture and carried out optimal site allocation analysis based on this database with network analysis procedure using GIS.

Although these studies similarly evaluate the contribution of transportation costs based on spatial resource distribution data, the targeted resource species in those are limited. On the other hand, abovementioned comprehensive databases are based on limited spatial resolution such as municipality or larger region. Under these spatial scales, it is difficult to take into account accessibility from demand site to dispersed resources for bioenergy utilization planning, especially in small scale utilization. No previous studies have conducted comprehensive potential estimation taking into account the accessibility among various resources.

The objective of this study is, therefore, to evaluate availability of biomass resources for energy utilization among various species within each municipality by considering accessibility based on the actual road network data. The following procedure was conducted.

1. The spatialized database (geodatabase) which consists of various resources was established in a uniform spatial scale in the entire region of Hokkaido Prefecture of Japan.
2. The network analysis was carried out on the geodatabase within each municipality. The relationship of accessible time and available energy quantity was figured out.
3. The transportation costs were calculated based on the accessible time data, and the preferable resources and its amount in terms of the transportation cost in each region was figured out.

2. Estimation of spatial distribution

2.1 Biomass resource mapping

Firstly, we established geodatabase of resources from several related statistical data. Calculated resource potential and distribution depend on each statistical spatial scale. We used GRASS GIS 6.4.3 and QGIS 2.4.0 for geospatial processing (vector processing like intersect, merge and so on, and other raster processing). The database is based on SQLite 3 and batch processing was conducted by scripts with Python 2.7.5. These are free and open source software, and therefore, the methodology developed with these processes are simpler and more effective than that associated with proprietary software.

Targeted resources in this study are as follows: cattle manure, raw garbage from households, raw garbage from commercial sector, organic waste, sewage, thinning wood/logging residue, wood plant debris, construction waste, pruned branches from public parks, pruned branches of orchard and crop residue.

These potential were mainly calculated by the
following equation:

\[ W = a X \]  

(1)

where \( W \) is the weight of resources, \( a \) is the unit weight based on \( X \), and \( X \) is the corresponding amount. The methodology of the calculation is fundamentally based on previous study \(^{6, 7}\). The corresponding amount \( X \) of each resource, its spatial unit and other data source are shown in Table 1. The processed amount of sewage was obtained directly from each plant data.

Forest resources generated by forest management or logging process are not utilized as thinning wood and logging residues. The thinning wood is a whole tree according to each wood species. BEF is the volume ratio directly from each plant data.

\[ W_{\text{whole}} = V_s \times \text{BEF} \times D \]  

(2)

\[ W_{\text{residue}} = V_s \times (\text{BEF} - 1) \times D \]  

(3)

where \( W_{\text{whole}} \) is the weight of whole aboveground parts of tree, \( W_{\text{residue}} \) is the weight of aboveground parts without stem, and \( V_s \) is the stem volume. Equation (2) was applied to unutilized thinning wood. Equation (3) was applied to logging residue.

The resource amount in Hokkaido which is classified by their management authority and tree type was calculated based on the 5-year average of the cut volume \(^{26}\). The amount was distributed to the forest sub-compartments which are not restricted to cut down \(^{20, 26}\).

### Table 1: Biomass resources and data source estimated in this study. The amount of each resource was calculated by the product of the unit amount and the corresponding amount \( X \) (see Eq. (1)). The spatial unit scale of the estimated resource amount depends on the spatial unit of the source data

| Biomass resource                          | Corresponding amount \( X \) | Spatial unit                      | Reference |
|------------------------------------------|------------------------------|----------------------------------|-----------|
| Cattle manure                            | The number of cattle         | Agricultural community           | 19        |
| Raw garbage from households              | Population                   | Standard regional mesh           | 20-22     |
| Raw garbage from commercial sector       | The number of employee       | Standard regional mesh           | 23, 24    |
| Organic waste                            | Production value             | Standard regional mesh           | 25, 26    |
| Thinning wood/ Logging residue           | Area of forest sub-compartment without logging restriction | Forest sub-compartment | 27-30 |
| Wood plant debris                        | Shipment value               | Standard regional mesh           | 25        |
| Construction waste                       | Gross floor area             | Municipality                     | 31, 32    |
| Pruned branches from public parks        | Area of public park          | Standard regional mesh           | 33        |
| Pruned branches of orchard               | Cultivation area             | Agricultural community           | 19        |
| Crop residue                             | Crop area                    | Agricultural community           | 34-38     |
and mesh \( j \), respectively. \( a_{ij} \) is the area of land use type \( x \) in small area \( ij \). The relation is shown in Fig. 1.

Resources processed on the data of vegetation survey and the related vegetation type are as follows: cattle manure (related vegetation type: grass farm) and pruned branches of orchard (related vegetation type: deciduous orchard). In general, although cattle manure is mainly generated from both of cattle stall and grass farm, there are no available location data of individual cattle stalls. Therefore, it was assumed that cattle stalls locate nearby grass farms and redistribution process was performed following this vegetation type.

The estimated distributions of these resources are summarized in Fig. 2 (crop residue), Fig. 3 (raw waste: raw garbage from households/commercial sectors and organic wastes), Fig. 4 (woody biomass: thinning wood/logging residue, wood plant debris, construction waste and pruned branches) and Fig. 5 (cattle manure).

Fig. 1 Visualization of overlay process

Fig. 2 Estimated distribution of crop residue in standard regional mesh

Fig. 3 Estimated distribution of raw wastes (raw garbage from households and commercial sector and organic wastes) in standard regional mesh

Fig. 4 Estimated distribution of woody biomass (thinning wood/logging residue, wood plant debris, construction waste, pruned branches from public parks and orchards) in standard regional mesh

Fig. 5 Estimated distribution of cattle manure in standard regional mesh
3. Accessibility analysis

3.1 Accessible time

As mentioned in Chapter 1, the transportation cost is an essential factor for optimization of regional biomass utilization, and thus, many models have been developed within transportation cost estimation. The methodology to estimate the cost in previous studies are mainly classified into two types. One type is based on straight distance between source and destination sites. One of the previous studies has simply estimated with straight distance \(^{17}\) and the others have estimated with multiplication of the direct distance by fixed expansion ratio of actual road length to direct distance \(^{13-16}\). The other type is based on real road network. This methodology can be allowed by applying network path search geoprocessing procedure of GIS \(^{15,18}\). Of course, the expansion ratios applied to direct distance are different between regions in practice and they depend on the tortuosity of the road network \(^3\). Therefore, it is considered that the accessibility can be evaluated based on the actual road network more preferably.

We conducted network analysis on the real road network data (road center line data from GSI Japan \(^43\)) and the resources map data expressed in Chapter 2. The optimal path determination process was performed using GRASS GIS’s vector geoprocessing module (“v.net”), based on Dijkstra’s algorithm \(^{42}\). In this study, the destination point of the transportation was located at the municipal office, and the processing was carried out in each municipality region. The road type restriction which is limited to normal roads (not such as trail ways or stairways) and free roads (excluding express ways). The maximum speed condition was applied according to road width as shown in Table 2, based on Japanese Road Act and the other road rules.

Furthermore, the actual speed condition was taken into account. There are several restrictions for trip speed such as traffic conditions, traffic rights, intersections. To consider the contribution of these restrictions, we referred to the actual traffic data in Hokkaido (2010 Road Traffic Census Data \(^43\)). We examined the relationship of actual speed (measured speed on the road in the survey) and limited speed of the road. The frequency distribution of the ratio of actual speed and limited speed was figured out (Fig. 6). It is considered that these surveyed actual speeds also include above restrictions. Therefore, based on this result, the fixed coefficient (0.88) was adopted to the maximum speed as the actual speed. Then, the optimal trip time from all points in each municipality (source point) to the destination point was defined as “accessible time” and was calculated in each region (Fig. 7).

3.2 Transportation cost

Based on the accessible time, the transportation costs of each resource in each mesh were calculated. The transportation costs \(C_r\) was calculated by follow equations:

\[
u_r = \bar{d}_r \times v_r, \quad (7)\]

\[C_{ry} = T_y \times 2 \times c_r, \quad (8)\]
\[ C_{\text{ty}} = C_{\text{ty}} \times \frac{W_{jy}}{U_y \times (1 - m_y)} \]  

where \( u_y \) is the loadable raw weight of resource \( y \), \( d_y \) is the bulk density on transportation of resource \( y \), \( v_y \) is the loadable volume of the vehicle of resource \( y \), \( C_{\text{ty}} \) is the round trip cost to transport the resource \( y \) from demand site to mesh \( j \), \( T_j \) is the accessible time from demand site to mesh \( j \), \( c_y \) is the unit cost of the vehicle to transport resource \( y \), \( W_{jy} \) is the dry weight of resource \( y \) in mesh \( j \), \( m_y \) is the moisture content of resource \( y \), and \( C_{\text{ty}} \) is the transportation cost of the resource \( y \) in mesh \( j \). The unit cost \( c_y \) is calculated by the following equations:

\[ \text{Unit cost } c_y = \text{Vehicle cost} + \text{Fuel cost} + \text{Operator cost} \]  

(10)

The parameter values are listed in Table 3.

Additionally, to assess the resource potential equivalently, the resource quantity was converted to energy quantity with each lower heating value (LHV) based on a previous work (7). Here, the equation is shown as follows:

\[ E_{jy} = W_{jy} \times e_y \]  

(11)

where \( E_{jy} \) is the energy potential of resource \( y \) in mesh \( j \) and \( e_y \) is the energy potential per unit weight of resource \( y \).

Finally, these results were sorted by the cost and the relationship between the transportation cost and the potential was examined for each municipality.

4. Results and discussion

With the abovementioned procedure, the spatialized database of the resources was established, and the accessibility to the resources based on the actual road network was figured out in both terms of time and cost.

For example, the results of Furano City are shown in Figs. 8 - 10. Furano City is located in the center of Hokkaido Prefecture and its region area and population is about 600 km² and 25,000, respectively. The municipal government has developed various regional plans related to environment and renewable energy (Basic Environmental Plan, Action Plan for the Environmental Protection, Action Plan for Global Warming, the Vision for Regional New Energy (6)), and has been promoting the citizens' garbage separation. As a result, the city has achieved relatively high rate of garbage recycling. The recycling rate of non-industrial waste of Furano City has been 61% in average for 10 years from 2003 to 2012 whereas that of national average was 20% (3). A refuse-derived fuel (RDF) plant is located in the city and the manufactured fuel is utilized for energy at a paper mill and so on. Thus, the utilization of waste biomass has already been improved in the city. However, the other resources have not been utilized yet.

Figs. 8 - 10 show the relationship between the resource potential in TJ and accessible time, or unit transportation cost based on resource weight (wet-t) or based on resource potential (GJ), respectively. Although unit transportation cost, load capacity (showed in Table 3) and lower heating value of the resources vary according to resources, the relationships between resources are similar to one another (Figs. 8-10). The results show that thinning wood and logging residue (forest biomass) and

| Biomass resource                              | Vehicle (size) | Vehicle cost [JPY/h] | Fuel cost [JPY/h] | Operator cost [JPY/h] | Unit cost \( c_y \) [JPY/h] | Bulk density \( d_y \) [wet-t/m³] | Load capacity \( u_y \) [wet-t/car] | Moisture content \( m_y \) [%] |
|-----------------------------------------------|----------------|----------------------|-------------------|-----------------------|----------------------------|---------------------------------|---------------------------------|-----------------------------|
| Cattle manure                                 | Septic truck (8 t) | 8,610                | 1,638             | 1,700                 | 11,948                     | -                               | 8                               | 80                          |
| Sewage                                        |                |                      |                   |                       |                            |                                 |                                 | 90                          |
| Raw garbage from households                   | Garbage truck (4 m³) | 2,900                | 649               | 1,700                 | 5,249                      | 0.74                           | 3                               | 80                          |
| Raw garbage from commercial sector            |                |                      |                   |                       |                            |                                 |                                 | 90                          |
| Organic waste                                 |                |                      |                   |                       |                            |                                 |                                 |                             |
| Thinning wood/Logging residue                 |                |                      |                   |                       |                            |                                 |                                 | 0.2                         |
| Pruned branches from public parks             | Truck (4 t. 10 m³) | 1,520                | 932               | 1,700                 | 4,152                      | 0.1                            | 1                               | 50                          |
| Pruned branches of orchard                    |                |                      |                   |                       |                            |                                 |                                 |                             |
| Wood plant debris                             |                |                      |                   |                       |                            |                                 |                                 | 0.14                        |
| Construction waste                            |                |                      |                   |                       |                            |                                 |                                 | 0.15                        |
| Crop residue                                  |                |                      |                   |                       |                            |                                 |                                 | 0.29                        |

The cost data were configured based on Hokkaido Regional Development Bureau (2014) (66). Other parameters were configured based on References 7 and 46-54.
often necessary to be transported with raw condition from supply site to processing site (e.g. drying, shredding etc.) and several species have high moisture content and/or low bulk density (Table 3). Therefore, the unit transportation cost on raw resource weight directly affects to delivery price, and this representation is reasonable for resource supply side. On the other hand, for the energy supply side, unit transportation cost based on energy potential of resource is more reasonable. For example, in Furano City (Fig. 10), these costs are less than 10% of LHV equivalent price of paraffin oil (2,643 JPY/GJ), considering that the LHV of paraffin oil and its average price of last 3 years (2012/04-2015/03) in Hokkaido Prefecture were 36.7MJ/L and 97 JPY/L 55), respectively. These representations are both valuable to discuss about system profitability of biomass utilization.

The transportation costs estimated in this study do not include truck loading/unloading costs and the waiting time. Some species might need much more time and/or costs on the loading/unloading procedures. Therefore, the transportation costs estimated in this study are relatively ideal and optimistic. Also, the procurement costs of resources are not only transportation costs but also the other processing costs such as collection and forwarding. Therefore, by integrating the other procurement costs data and the data obtained in this study, the available potential of biomass resources in the region can be clarified as much more robust information.

The statistical data used in this study were partly treated as confidential data (blank data) in terms of protection of personal information. We could not calculate
the resource extent on that site. Therefore, the result with confidential data is considered to be underestimated. Several species (e.g. excrement of swine and chicken) were not able to be redistributed due to lack of spatial data associated with the resources, and therefore, these resources were not evaluated. Collection of the suitable data is required to improve the reliability.

We hypothesized the maximum speed condition of each road based on the road width, and therefore, these data can be improved for more robust estimation by applying the actual condition. The road network data applied in this study do not cover the whole forest roads and forest working roads, either. We would very much like to integrate the data to figure out more suitable accessibility maps.

The destination site was fixed to the municipal office in this study. However, if the demand site is changed, the result of the analysis will also change. The optimal site determination problem based on comprehensive database of bioenergy and network analysis are both challenging work in the future.

5. Conclusion

In this study, we established comprehensive geodatabase with 11 biomass resources in a uniform and higher resolution (1 km mesh) than that of the previous comprehensive databases in Hokkaido Prefecture. Subsequently, we conducted accessibility analysis based on the actual road network data and estimated the accessible time and the transportation cost from destination point in each region. By these procedures, the distribution of resources was figured out and the relationships between transportation cost and resource potential of each resource was depicted. In Furano City, it was considered that the crop residue was more concentrated near the central area than forest biomass in terms of energy potential accessible within 20 minutes. Furthermore, unit transportation costs of crop residue are less expensive than that of forest biomass. Therefore, the crop residue can be considered as a reasonable resource in terms of transportation in Furano City.

The geodatabase can be significantly improved by integration with additional data such as the forest road data, the traffic condition of each road, the data which covers confidential area and the other procurement cost data. Most of statistics used in this study cover the entire Japan, so this methodology can be applied to the other regions in Japan. Also, the current database can be updated by the latest statistic data in the future.

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