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Article

국내 주요도시 주변의 바이오매스 에너지 잠재량 분석

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Analysis of Biomass Energy Potential around Major Cities in South Korea

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초 록

바이오매스 자원은 고체, 액체, 기체 등의 다양한 형태의 에너지 자원으로 전환되어 이용될 수 있기 때문에 필수적인 재생에너지 자원으로 여겨지고 있다. 더불어 바이오매스는 화석 연료의 고갈과 지구 온난화를 해결할 수 있는 방법으로도 각광을 받고 있다. 바이오매스 에너지 전환 플랜트의 규모를 결정하고 경제성을 분석하기 위해서는 지역 내의 바이오매스 에너지 잠재량과 에너지 밀도에 대한 정보가 유용하게 이용될 수 있다. 농업 폐기물, 임업 폐기물, 축산 폐기물, 도시생활 폐기물 등의 국내 에너지 잠재량과 에너지 밀도를 정부 및 연구 기관들이 발표한 최신 자료를 수집하여 분석되었다. 바이오매스 자원을 확보하기 위한 지역이 증가할수록 에너지 잠재량은 증가하나 에너지 밀도는 감소하는 것으로 나타났다.

Abstract

Biomass is recognized as one of important renewable energy sources because it can be converted and used as solid, gaseous and liquid forms. Also, biomass is one of promising ways to solve the depletion of fossil fuels and global warming problems. The information about local biomass energy potentials and space energy densities can be powerfully utilized to determine the scale of biomass energy conversion plant and to analyze economic effects. The latest data on domestic biomass resources, such as agricultural, forestry, livestock and urban wastes, were collected from various government organizations and institutes and were analyzed to calculate biomass energy potential and space energy density. As local areas in South Korea to collect biomass resources increased, energy potentials increased, but space energy densities of total biomass decreased.

Keywords: *Biomass, Energy density, Energy potential, Bio energy*

1. Introduction

Energy sources might have been classified in three categories: renewable sources, fossil fuels and nuclear sources. The energy markets of world depend highly on fossil fuels which consist of coal, petroleum crude and natural gas by sources of power, fuels, and chemicals[1]. However, fossil fuels have severe limit about reserves and millions of years are required to form fossil fuels in the earth. Nuclear sources are relatively abundant, but there are many environmental issues to use nuclear sources.

The biomass, which is derived from living or recently living organisms is similar to fossil fuels because of hydrocarbon contents. However, biomass is recognized as one of promising renewable energy sources and is gaining increased public and scientific attention, driven by factors such as oil price spikes and the need for increased energy security. Biomass is potential alternative to fossil fuel, which can be chemically and biochemically treated to convert it to energy. Biomass is often regionally available and conversion into secondary energy carriers is feasible without high capital investments. Biomass is the most developed renewable energy source providing 35% of the primary energy needs of developing and industrialized countries, respectively[2,3]. Biomass can be used for direct heating in industrial applications, for steam production in power generation sector or for biofuels production. Direct heating is the most widespread application, but electricity manufacture and biofuels are currently gaining respectable interest among energy policy makers[4].

Biomass resources can be classified as forestry wastes, produced from wood products industries; agricultural wastes, generated by crops, agro-industries and animal farms; energy crops, i.e. crops and trees

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Table 1. Basic Data Used in this Study

Sector	Data	Institution	Year
Agricultural byproducts	Annual report of Agricultural byproducts / Agricultural research report	Statistics Korea (KOSTAT)	2010
Forestry products	Annual report of forestry products	Korea Forest Service	2010
Livestock waste	Annual report of Livestock	Statistics Korea (KOSTAT)	2010
Municipal solid waste (MSW)	Annual report of Waste Generation and Treatment	Ministry of Environment	2010

Table 2. Energy Conversion Factor of Biomass

Sector	Key resources	Caloric value conversion factor (kcal/kg)	Generation rate conversion factor
Agriculture byproducts	rice straw	3416	65.3 ton/km^2
	wheat straw	4100	29.8 ton/km^2
	rice husk	3616	11.8 ton/km^2
	soybean stem	4069	26.9 ton/km^2
	sweat potato stem	4534	64.6 ton/km^2
	apple byproduct	4320	45.9 ton/km^2
Forestry products	hard wood	5000	0.440 ton/m^3
	soft wood	4706	0.750 ton/m^3
	mixed forest	4353	0.595 ton/m^3
Livestock waste	cow manure	5158 $kcal/m^3$	281 m^3/dry measure ton
	pig manure		649 m^3/ dry measure ton
	chicken manure		359 m^3/ dry measure ton
MSW	paper	3177	-
	wood kind	2673	-
	rubber leather	6510	-
	plastics	6510	-
	Etc.	3844	-

dedicated to energy production; and urban waste. Given the numerous applications of biomass and the variety of sources, it is not surprising that wide arrays of biomass conversion technologies are under development and commercialized[5-8]. However, the cost of collecting enough biomass to be used in commercial biomass energy conversion plants is remained as big hurdle for biomass energy conversion. So, the techno-economical evaluation of biomass energy resources for energy conversion should be completed before the decision of commercialization. But there is not enough information about local biomass energy potentials.

In order to estimate the availability of domestic biomass energy potential and choice appropriate process, energy potentials and energy densities of biomass resources such as agricultural wastes, forestry wastes, livestock wastes and urban wastes in Korea were collected and analyzed by using the latest database from Korean government organizations and institutes. In korea, there are thermal plants in Taean, Seocheon, Boryeong, Honam, Dangjin, Samcheonpo, Yeongdong, Yeongheung, and all thermal plants are located within a radius of 90 km from the major city except Yeongdong plant. In this study, energy densities were calculated and analyzed with the radius of 5 major cities in Korea ranging from 30～90 km to make useful information about economical collecting cost of biomass resources.

2. Analysis

2.1. Energy potential

Various non-edible biomass resources were classified in agriculture waste, forestry waste, livestock waste and urban waste in this study. Databases used in the analysis were summarized in Table 1. forestry wastes contained softwood, hardwoods and mixed and agricultural wastes sorted rice straw, rice husk, wheat straw, soybean stalks, sweet potato stems, apple byproduct. Livestock wastes was distinguished by cow manure, pig manure, chicken manure and Urban wastes was selected as food waste, paper, wood kind, rubber leather, plastics[9-12].

Biomass resources potential is analyzed using TOE (ton of oil equivalent) qualities which are calculated by using well proven energy conversion factor of biomass[13] to easily compare with by regional groups in Korea (Gangwon-do, Gyeonggi-do, Jeollabuk-do, Jeollanam-do, Gyeongsangbuk-do, Gyeongsangnam-do, Chungcheongbuk-do, Chungcheongnam-do, Jeju Island). Energy conversion factor of biomass was summarized in Table 2.

Table 3. Ratio of Land/Sea with Radius of Major Cities

Radius of Major City	Seoul		Daegu		Daejeon		Gwangju		Busan	
	Land (%)	Sea (%)	Land (%)	Sea (%)	Land (%)	Sea (%)	Land (%)	Sea (%)	Land (%)	Sea (%)
30 km	100	0	100	0	100	0	100	0	56.83	43.17
60 km	82.33	17.67	100	0	100	0	87.46	12.54	37.8	62.2
90 km	70.9	29.1	98.07	1.93	95.33	4.67	72.3	27.7	41.69	58.31

Table 4. Available Potential of Total Biomass in Korea

Area	Agricultural wastes (TOE/y)	Livestock wastes (TOE/y)	Urban wastes (TOE/y)	Forestry wastes (TOE/y)	Total (TOE/y)
Gangwon-do	27,170	79,364	114,408	2,615,753	2,836,695
Gyeonggi-do	60,502	302,872	495,865	710,409	1,569,649
Jeollabuk-do	75,139	188,904	70,301	713,400	1,047,744
Jeollanam-do	99,852	197,929	127,521	881,102	1,306,404
Gyeongsangbuk-do	109,542	213,268	136,104	1,976,503	2,435,417
Gyeongsangnam-do	54,635	175,691	146,463	929,416	1,306,205
Chungcheongbuk-do	36,206	99,622	73,659	597,685	807,172
Chungcheongnam-do	79,934	300,034	106,579	592,747	1,079,294
Jeju-do	2,538	2,068	11,198	76,760	92,563

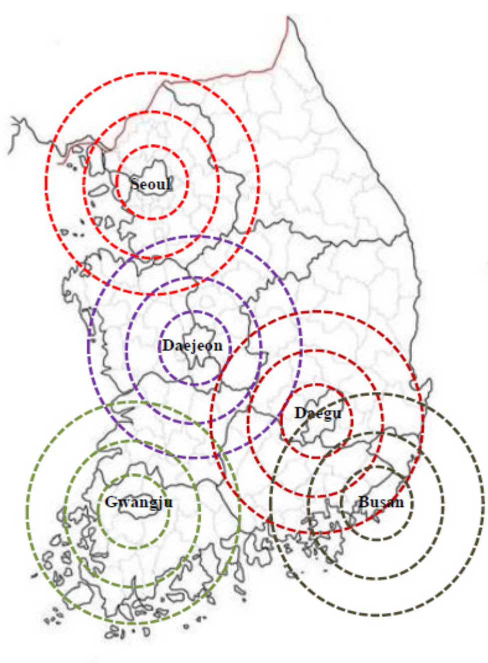

Figure 1. Radius of Metropolitan Cities.

2.2. Space energy density

To compare biomass availabilities with each local area, the term of Space energy density was used in this study. Space energy density (TOE/km^2) is defined as biomass energy potential over areas with radius of major cities in Korea. Based on radius of 5 cities in Korea ranging from 30~90 km, Space energy densities were calculated and compared in this study. The image of radius (30, 60, 90 km) of cities was shown in Figure 1. As can be seen in Figure 1, it is indicated that the sea of area is included within radius of area. But in this study, it is considered that biomass resources are only applied to land to calculate Space energy density. The ratio of land/sea with radius was shown in Table 3. Metropolitan cities in Korea, which are including Seoul, Daejoen, Daegu, Gwangju and Busan, are the fiducial points of this study.

3. Results and Discussion

3.1. Available energy potential in Korea

To analyze domestic biomass available potentials, various biomass resource databases were classified as agriculture byproducts, forestry products, livestock waste and urban waste arranged by TOE. Table 4 showed the biomass total available potential in Korea. The biomass total available potential in Gangwon-do and Gyeongsangbuk-do are respectively, 2,836,695, 2,435,417 TOE/y.

Also, densely populated and urbanized Gyeonggi-do is occurred about 1,569,649 TOE of urban waste. The energy potential of domestic forestry products are investigated based on softwood, hardwood, mixed forest. It had a large deviation according to the presence of mountainous terrain of the corresponding area. The energy potentials of forestry product in Gangwon-do and Gyeonsangbuk-do were 2,615,753, 1,976,503 TOE/y, respectively. The livestock waste resources were generated in most local areas, except metropolitan cities.

The generation and quantities of livestock waste were affected with/without a large-scale breeding. The energy potential of livestock waste in Gyeonggi-do and Chungcheongnam-do were 302,872 TOE/y and 300,034 TOE/y because there are many livestock breeding. In contrast, Gangwon-do and Cungcheongbuk-do have lower energy potential

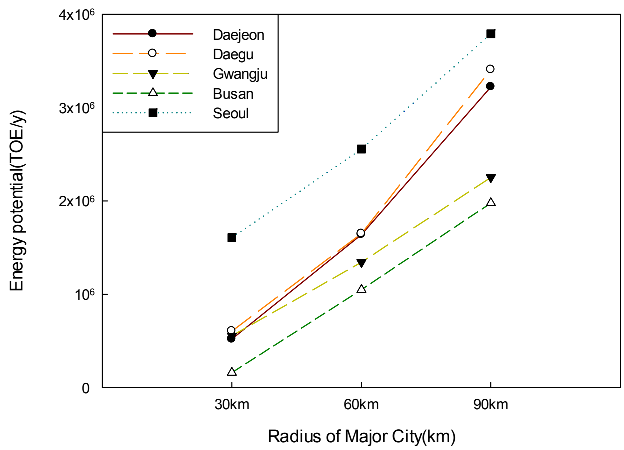

Figure 2. Accumulated total biomass energy potential (Base year : 2010).

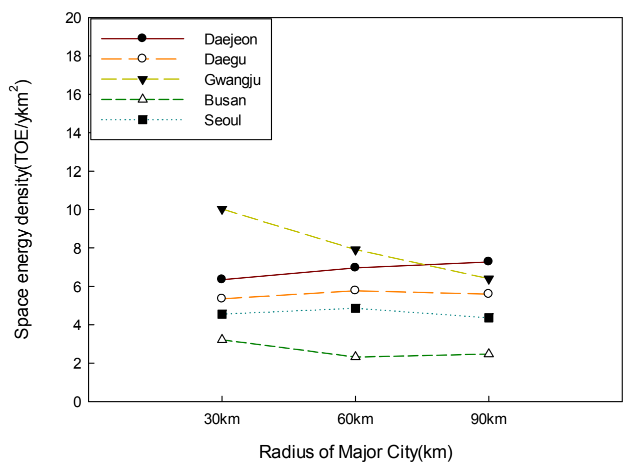

Figure 3. Space energy densities of agricultural byproducts (Base year : 2010).

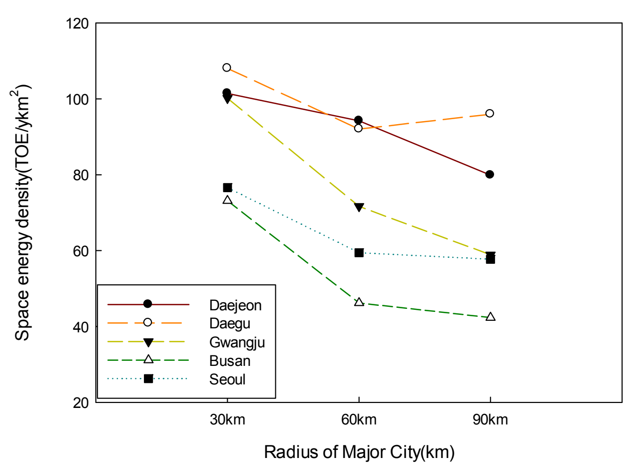

Figure 4. Space energy densities of forestry products (Base year : 2010).

than any other area. In terms of agricultural biomass wastes, local areas which had broad plain areas such as Jeollabuk-do, Jeollanam-do, Chungcheongnam-do, Gyeongsangbuk-do had higher agricultural biomass energy potential than other areas. Especially mountainous Gangwon-do had lower agricultural biomass energy potential than any other regions. Urban waste was influenced by urbanization of local areas, population, industrialization and so on. The energy potential of urban waste in Gyeonggi-do, Jeollanam-do, Gyeongsangbuk-do, and Gyeongsangnam-do were 495,865 TOE/y, 127,521 TOE/y 136,104 TOE/y and 146,463 TOE/y, respectively.

Accumulated total biomass potential according to the distance is shown Figure 2. As shown in Figure 2, Gwangju and Busan has relatively lower accumulated total biomass potential at the region around the city than Seoul, Daejeon and Daegu. On the other hand, in Seoul, Daejeon and Daegu, accumulated biomass resources were mesured higher as the distance increase from the city. Especially, Seoul which immensely emits urban waste due to the industrialization shows highest availability of biomass by 3,790,000 TOE/y.

3.2. Space energy density in Korea

Although biomass energy potential is high, it is essential to estimate the cost of collecting biomass for commercial plants because of wide distribution of biomass. Space energy densities of 4 different types of biomass were compared with the bases of 5 megacities in Korea. Figures. 3～7 are the resource density of agricultural byproducts, forestry products, livestock waste, urban waste product according to the radius of metropolis.

Space energy densities of agriculture byproducts were shown in Figure 3. As shown in Figure 3, Space energy densities are decreased sharply with increasing the radius of Gwangju in spite of higher Space energy densities of agricultural byproducts. Since Gwangju region which located in Honam state has well-developed agricultural industry, generation of byproducts for energy from shows higher in the immediate area, while relatively shows lower amount further th the city. Space energy densities increased with increasing distance in Daejeon and Daegu. The area of radius within 90 km of Daejeon and Daegu city are included in Chungcheongnam-do which has well-developed agriculture shows high density of agricultural by product. Space energy densities of agricultural byproducts in Busan and Seoul areas were significantly lower than other cities. Seoul and Busan which has a number of large industrial companies and high population density shows relatively low agricultural byproduct density. It meant that Busan and Seoul area might be not suitable to establish energy conversion facility for agriculture byproducts.

Space energy densities of domestic forestry products depending on the city were shown in Figure 4. Unlike energy potential evaluation, Space energy densities of forestry in Daegu and Daejeon area were higher than other areas. Because of the perimetric basin topography of Daejeon and Daegu, forest resources are relatively abundant further away from the city. Therefore, Daegu and Daejeon area might be suitable to develop biomass energy conversion facility using the forestry products. Space energy densities of forestry products in Seoul were lower than other local areas, so it might be unfavorable to set up conversion facility using the forestry products.

Space energy densities of livestock waste were shown in Figure 5. In case of areas with radius of 30 km and 60 km, Space energy densities of livestock waste in Gwangju were higher than other areas.

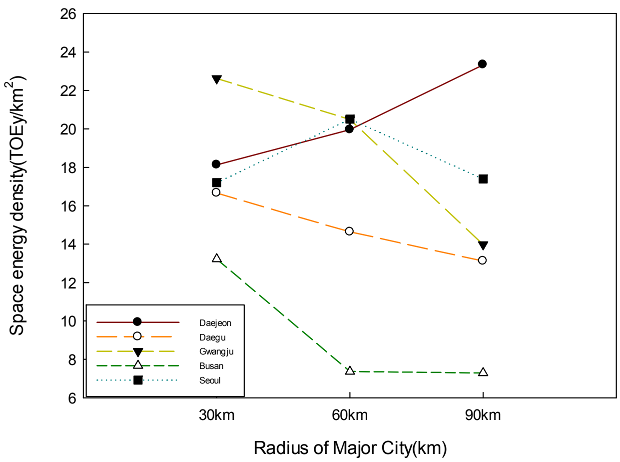

Figure 5. Space energy densities of livestock waste (Base year : 2010).

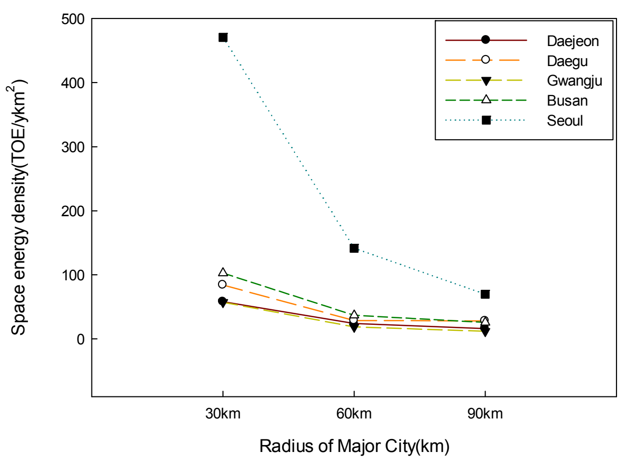

Figure 6. Space energy densities of MSW (Base year : 2010).

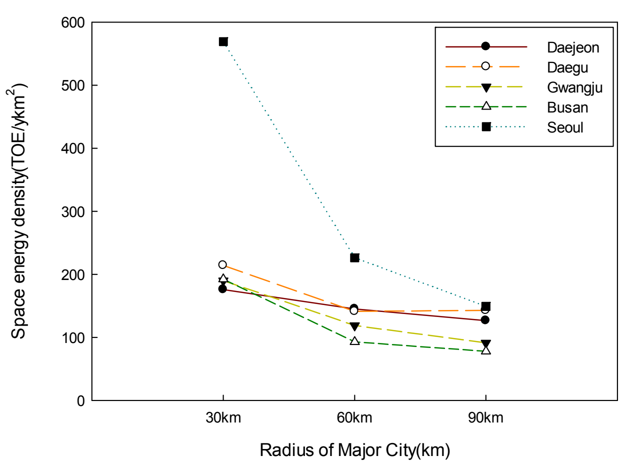

Figure 7. Space energy densities of total biomass (Base year : 2010).

However, Space energy densities of livestock waste decreased at the area of 90 km radius. To develop an economical energy conversion plant for livestock waste in Gwangju, small size plant which would consume all livestock waste generated in 60 km radius of Gwangju might be more effective. Space energy densities of livestock in Daejeon relatively increased with increasing areas. It meant that Daejeon might be appropriate to embark on domestic livestock waste because of the secure profitability. The Space energy densities of livestock waste within radius of Daegu and Busan tended to decrease with increasing the distance. It was appreciate expanding livestock waste industry within 30～60 km area.

Space energy densities of urban waste calculated according to the classification of city were shown in Figure 6. Energy potential and Space energy density of urban waste in Seoul are higher than other cities in Korea since Seoul is densely populated and industrialized megacity in Korea. Although Space energy densities in other regions were lower than those in Seoul, the tendency of Space energy densities of urban waste was similar to those in Seoul because other cities were also populated and industrialized.

In Figure 7, Space energy densities of total biomass resources were shown. Since Space energy densities of urban waste were higher than those of other types of biomass resources, Space energy densities of total biomass resources were similar those of urban waste. Therefore urban waste might be major biomass resources in urban areas. With increasing areas for gathering biomass resources, energy potential might increase and Space energy density might decrease in Korea. Although the cost per energy might decrease with increasing production volume, size of biomass energy conversion plants should be restricted for the commercialization of biomass energy conversion because of decreasing Space energy densities in Korea.

4. Conclusion

Biomass resource of forestry products had the highest energy potential than other resources and so the energy conversion process for forestry wastes might be useful in Korea. However, urban waste might be most important biomass resources in 5 megacities in Korea. Although biomass energy potential increased with increasing local areas, Space energy densities of total biomass resources mostly decreased. It meant that the size of biomass energy conversion plant might have a limitation because of increasing the cost of gathering biomass resources in Korea. The results from the evaluation of biomass energy potential and Space energy density in Korea might be useful to estimate the availability of conversion processes of biomass energy and to choice a appropriate energy conversion process.

References

1. B. Mustafa and A. Günhan, Biomass Energy in the world Use of Biomass and Potential Trends, *Int. J. Taylor & Francis*, **27**, 931-940 (2005).
2. R. Van den Broek, Sustainability of biomass electricity systems-an assessment of costs, macro-economic and environmental impacts in Nicaragua, Ireland and the Netherlands., Utrecht University (2000).
3. W. C. Turkenburg, Renewable energy technologies, in World Energy Assessment., Washington DC: UNDP (2000).
4. C. Wereko-Broddy and E. B. Hagen, Biomass conversion and technology., England: Wiley (1996).
5. J. L. Easterly and M. Burnham, Overview of biomass and waste

fuel resources for power production, *Int. J. Biomass and Bioenergy*, **11**, 72-92 (1996).
6. G. Grassi and A. V. Bridgwater, The opportunities for electricity production from biomass by advanced thermal conversion technologies, *Int. J. Biomass and Bioenergy*, **4**, 339-345 (1993).
7. R. I. Graham, W. Liu, M. Downing, C. E. Noon, M. Daly, and A. Moore, The effect of location and facility demand on the marginal cost of delivered wood chips from energy crops: a case study of the state of Tennessee, *Int. J. Biomass and Bioenergy*, **13**, 117-123 (1997).
8. R. Venendaal, U. Jorgensen, and C. Foster, European energy crops : a synthesis, *Int. J. Biomass and Bioenergy*, **13**, 147-185 (1997).
9. Korea Forest Service, Annual report of forestry products (2010).
10. KOSTAT, Annual report of Agricultural byproducts (2010).
11. KOSTAT, Agricultural research report (2010).
12. KOSTAT, Annual report of Liverstock (2010).
13. KIER, New & Renewable Energy Data Center, http://www.energy.or.kr.