Sustainability Science (2020) 15:1461–1471
https://doi.org/10.1007/s11625-019-00734-4

SPECIAL FEATURE: CASE REPORT

Developing Sustainable Bio-Energy Systems in Asia

Rethinking sustainable bioenergy development in Japan: decentralised system supported by local forestry biomass

Chun Sheng Goh[1,2] · Takanobu Aikawa[3] · Amanda Ahl[4] · Kanae Ito[5] · Chihiro Kayo[6] · Yasunori Kikuchi[7,8,9] · Yasuo Takahashi[10] · Takaaki Furubayashi[11] · Toshihiko Nakata[11] · Yuichiro Kanematsu[8] · Osamu Saito[1] · Yoshiki Yamagata[2]

Received: 13 January 2019 / Accepted: 9 September 2019 / Published online: 19 September 2019

Abstract

Bioenergy has been promoted in Japan with ambitious targets. However, the incentive schemes excluded renewable heat and overlooked synergies with local forest management, leading to the development of large-scale biomass plants that heavily rely on overseas biomass supplies. This case report discussed an alternative scenario of decentralised bioenergy systems supported with local biomass through five important questions. The currently available knowledge indicates that such a scenario is feasible with integrative forest management that considers both ecosystem services and multiple uses of wood. In addition to various environmental benefits, replacing imported fossil fuels with local biomass can also enhance energy security. Realising this scenario requires careful consideration of local context, empowerment of local governments and encouragement of both public and private initiatives.

Keywords Biomass · Bioenergy · Japan · Forest · Sustainability · Decentralised system

Introduction

Bioenergy is deemed a negative emission solution for climate change when it is combined with sustainable land and forest management (including afforestation and reforestation). On the one hand, bioenergy can potentially substitute

Handled by Fabrice Renaud, University of Glasgow School of Interdisciplinary Sciences, Germany.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11625-019-00734-4) contains supplementary material, which is available to authorized users.

✉ Chun Sheng Goh
gohchunsheng@unu.edu; gohchunsheng@hotmail.com

1 United Nations University, Institute for Advanced Sustainability Studies (UNU-IAS), 5-53-70 Jingumae, Shibuya-ku, Tokyo 150-8925, Japan

2 Japan's National Institute for Environmental Studies (NIES), 16-2 Onogawa, Tsukuba, Ibaraki Prefecture 305-0053, Japan

3 Renewable Energy Institute, 1-13-1 Nishi-Shimbashi, Minato, Tokyo 105-0004, Japan

4 Department of Innovation, Tokyo Institute of Technology, 3-3-6 Shibaura, Minato, Tokyo 105-0023, Japan

5 Graduate School for Law and Politics, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 1130033, Japan

6 Tokyo University of Agriculture and Technology, 3-5-8 Saiwai-cho, Fuchu, Tokyo 183-8509, Japan

7 Integrated Research System for Sustainability Science (IR3S), The University of Tokyo, Institutes for Advanced Study, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8654, Japan

8 Presidential Endowed Chair for ''Platinum Society'', The University of Tokyo, Ito International Research Center, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

9 Department of Chemical System Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

10 Institute for Global Environmental Strategies (IGES), 2108-11 Kamiyamaguchi, Hayama, Kanagawa 240-0115, Japan

11 Department of Management Science and Technology Graduate School of Engineering, Tohoku University, 6-6-11-815 Aoba-yama, Sendai 980-8579, Japan

fossil materials in solid, liquid and gaseous forms without major alteration of existing energy systems. On the other hand, sustainable land management can mitigate carbon stock loss, improve carbon sequestration and increase bioproduction.

In Japan, bioenergy has been promoted as a key renewable energy source, especially after the Fukushima nuclear plant disaster in 2011. The government aims to generate approximately 4% of the total power supply or 40–50 TWh from biomass by 2030 (MAFF 2017a). The Feed-in Tariffs (FIT) scheme has been implemented to accelerate electricity generation from renewable sources, including bioenergy. As a result, in just 1.5 years, the approved biomass power generation capacities have sharply risen from 6 to 16 GWe by the end of 2017 (METI 2017). This has raised serious concerns about the availability and sustainability of biomass feedstock.

Despite approximately 70% of the country being covered by forest, it is physically and economically challenging to mobilise local woody biomass for energy purposes due to the shrinking forestry sector and thus the high procurement cost. In other words, this option can only become feasible when it is considered within a bigger scope of forestry revitalisation with active forest management, economies of scale and infrastructure development. Meanwhile, the other non-wood bio-waste streams, mainly agricultural residues, can only fractionally fulfil the target (MAFF 2017a).

Furthermore, the FIT scheme was designed exclusively for electricity generation with heat production excluded. For bioenergy, such a setting discourages more energy-efficient combined heat and power (CHP) systems. The difference in efficiency between a system that only generates power and a CHP system can be as large as 30% vs 80%. A CHP system can also be advantageously adopted in less populated areas with better access to domestic biomass resources due to its scalability. However, this potential has been largely overlooked by both the government and industry in recent years (Aikawa 2016).

As a result, large-scale centralised power plants (to be) fed with imported biomass (especially from Southeast Asia and North America) have been the main focus of the industry. Nevertheless, overseas supplies also remain highly uncertain, and can be risky in terms of sustainability in the absence of proper monitoring and governance as additional demand may trigger improper land use in the producing countries (Goh et al. 2016). In fact, a major food ingredient, palm oil, is among the planned feedstock for 5 GW_e of the approved capacities (METI 2017).

This case report re-examined bioenergy development in Japan by exploring two lines of inquiry: (i) mobilising domestic biomass resources alongside forestry revitalisation and (ii) developing decentralised CHP systems with bioenergy. It is based on an expert workshop involving scientists, government officials, industry representatives, and NGOs. A snowball approach was used in identifying and inviting experts (through peer recommendations), and in total 35 attended. Based on preliminary discussions and interviews with the experts prior to the workshop, five key questions were formulated to identify available knowledge and remaining gaps to reach across the two lines of inquiry. During the workshop, 20 participants presented their views and work, with each presentation followed by discussion sessions. Multiple group discussions, interviews, and personal communications were also conducted after the workshop to verify the information. This work may be deemed among the first steps in addressing the very complex and overarching issues of bioenergy development in Japan.

Decentralised bioenergy system supported by domestic woody biomass

The key questions discussed in this section are

1. Environmental implications: how much wood can be sustainably harvested from domestic forest?
2. Economic viability: how much can domestic woody biomass be sustainably mobilised for energy considering multiple uses and cost implications?
3. Supply–demand dynamics: how much energy demand can be met with domestic biomass?
4. Biomass and people: what are the socio-economic and policy challenges?
5. Overall sustainability: what are the overall impacts, synergies, and trade-offs of using local woody biomass?

Environmental implications: how much wood can be sustainably harvested from domestic forest?

A healthy, productive and sustainable forestry sector with economies of scale is regarded as the foundation of a bioenergy system based upon domestic woody biomass. As Japan's forestry sector has been relatively less active for decades with low outputs, it is important to first clarify potential domestic forest productivity and environment implications.

In terms of area, Japan is endowed with ~ 25 Mha of forests as reported in 2016 (MAFF 2016a). Approximately 40% is manmade planted forest: heritage of the active forestry sector during the late Edo period (nineteenth century) during which there were incentives to harvest and replant trees for timber (Saito 2009). The peak production was reported in the 1960s at 60 million m^3 (FAOSTAT 2018). However, these manmade forests were largely abandoned in the 1970s due to the adoption of an import-oriented policy for wood. Since then, the annual industrial production greatly shrank to less than 20 million m^3 until the early 2010s. As an indication, only about 30% of the planted forests obtained a certified "Forest Management Plan" from local municipalities by 2016 (MAFF 2017b). The decline in productivity was largely species oriented. Substantial declines were observed in broadleaf, pine and spruce wood production (MAFF 2016b) (Figure S2). Meanwhile, harvesting rates of the largest planted species, cedar, remain relatively stable. Although the production volume of timber has slowly recovered and reached 20 million m^3 in 2015, this amount is still far from the government's target of 40 million m^3 by 2025 (FAOSTAT 2018; MAFF 2018a). In addition, despite a decrease in demand in recent years, the self-sufficiency rate still dropped below 35% (Figure S1).

Overall, the data show that the stock has increased rapidly from < 2 billion m^3 in 1966 to 4.9–6.7 billion m^3 in 2012/2013 (Kato 2018; MAFF 2018c, e). However, more than half of the stock is stored in planted forests and not the more bio-diverse natural forests. Figure 1 illustrates the stock (by region) and stock density (stock per prefectural area). The stocks are reported in ranges due to the differences in calculation models and limited data availability (especially for old forests). Generally, prefectures in the south have higher stock density, but those in the north and central regions have experienced higher stock growth. Meanwhile, forests in highly urbanised areas in the Kanto and Kinki regions show both lower stock density and growth.

Nevertheless, in the near future, the rapid growth rate in the past decades may significantly slow down due to the ageing of trees (> 50 years old) as the majority of them were planted post-war (Figure S3). To maintain healthy stock replenishment and carbon removal, it is necessary to keep an active harvesting and replanting cycle to establish a well-balanced age distribution (Kanematsu et al. 2017; Yoshioka et al. 2005). Achieving this requires long-term (decades) and back-casting approaches for forest management. Furthermore, proper management and improvement, such as regular harvesting and thinning of cedar plantations, as well as possible replacement with multiple species are deemed vital to restore forest health and ecosystem services. The rapid regeneration and superabundance of cedar monoculture have already caused and may further exacerbate the loss of biodiversity and ecosystem resilience that underlies increasing wind throws, soil erosion and landslides. It also has become a source of widespread public disservices, i.e. pollen allergies (Ota 2002; Matsumoto et al. 2016). In other words, enhancing productivity can actually be accompanied by various environmental and health co-benefits.

The harvesting potential seems substantial given the large area of unmanaged forests, but the environmental impacts need to be thoroughly examined. In quantitative terms, Kayo et al. (2018) provided some indications of environmental impacts in various scenarios with varied forest productivity. They showed that while a rapid increase in wood harvest may provide various environmental benefits considering the fact that wood products can store carbon and substitute other carbon-intensive materials, improper methods and rates of wood extraction (i.e. clear cutting without replanting) could add significant pressure on land use. However, only linear relationships were employed to estimate impacts caused by 1-unit increments of wood harvest. The broader place-based spatio-temporal effects were not accounted for to evaluate region-wide synergies and trade-offs when harvesting rate is increased. Currently, such information is still limited in the case of woody biomass production in Japan. More comprehensive modelling tools like those demonstrated by Yamada (2018) are needed to evaluate the balancing of forest functions from a regional perspective.

To avoid unintended consequences, it is crucial to promote the early adoption of sustainable forest management practices prior to escalating productivity. More evidence on sustainable forest management would better justify the use of domestic woods over imports. Currently, the uptake of sustainable certification in Japan is rather low at 7% (Aikawa 2018). As many forests have not been well-managed for decades, it is vital to ensure proper monitoring of the actual situations on the ground, e.g. using the latest tools in remote sensing and geographical information systems (Ooba et al. 2016).

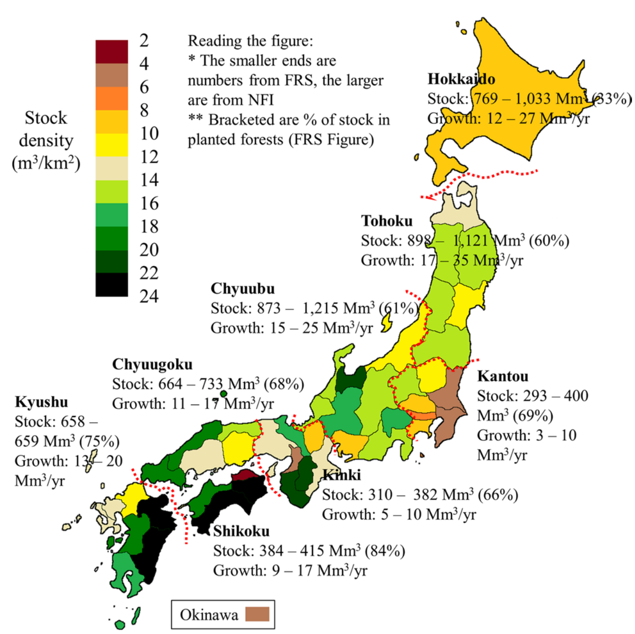

Fig. 1 Forest stock and growth rate (by region) and stock density (stock per prefectural area) for the year 2012. [Modified based on Forest Resource Survey by MAFF (2018c) and National Forest Inventory by MAFF (2018e)]

Economic viability: how much can domestic woody biomass be sustainably mobilised for energy considering multiple uses and cost implications?

Alongside high-value wood production, voluminous low-value biomass is also generated during harvesting and processing. In addition, multiple wood products also turn into waste towards the end of their lifespan, such as used furniture and wood from demolitions. These low-value biomass resources could potentially be used as feedstock for heating and power generation. This question explores if the mobilisation cost can be significantly reduced for energy purposes in the presence of an active domestic forestry sector.

In Japan, such low-value biomass resources are categorised as 'waste' and 'unused' streams (MAFF 2017a). The first category mainly refers to sawmill residue and waste wood from demolition and construction. MAFF (2018b) estimated that the current national annual generation of 'waste' streams is about 18 million m^3, but > 90% of that has already been in use for materials (especially for paper and cardboard) and conventional fuels. The second category, namely 'unused' streams, consists of harvesting residues (e.g. branches and leaves) and thinning woods left unused on site which is still largely untapped (MAFF 2018b). Previous studies estimated that for each m^3 of high-value roundwood harvested, about 0.2–0.5 m^3 of harvesting residues will be generated (Yoshioka et al. 2005; Matsumoto et al. 2016). In other words, about 4–10 million m^3 is currently generated annually, and the amount may be doubled with doubling of total roundwood production. The amount of 'unused' biomass becomes larger when thinning woods are also included, making a total of about 15–25 million m^3 (NEDO 2011; Saragai 2018; Kuboyama 2018; Kayo et al. 2018). Currently, only about 2 million m^3 of 'unused' biomass is being used, still far from the government target of > 8 million m^3 by 2025 (Saragai 2018).

The quantity of low-value biomass may grow larger if domestic forestry is reactivated with higher production and use of wood, especially in substituting non-wood materials in, e.g. buildings and packaging. In a scenario with a rapid increase of roundwood production to 50 million m^3, Kayo et al. (2018) predicted that additionally about 2.4 million m^3 of processing residues and 4.7 million m^3 of waste wood will be generated. Furthermore, it is expected that in such a scenario, mobilisation of these additional residues and waste wood would be relatively feasible in synergies with active wood industries. Furubayashi et al. (2017) also optimistically predicted that an additional 6 million m^3 of energy wood may be practically mobilised alongside roundwood production at 30 million m^3. This is close to an estimation by Kuboyama (2018).

However, more sophisticated analysis, especially on spatial distribution, is required to further understand the mobility of this biomass. An analysis by NEDO (2011) at prefectural and municipality level (Fig. 2) shows that the distribution of 'unused' biomass across the country can be quite uneven. Based on the then situation of forestry, it was estimated that for most prefectures only 3–4% of these biomass resources could be economically mobilised, totaling to only about 0.8 million m^3 for the entire country. Some regional studies have also further analysed biomass potential considering multiple logistical factors and regional differences, such as cases in river basin (Ooba et al. 2012), mountainous areas (Yoshioka et al. 2011), small island (Kanematsu et al. 2017) as well as different scales such as a large region (Furubayashi and Nakata 2018) or a small town (Nakahata et al. 2013). However, all of these studies did not quantitatively investigate economic feasibility in a scenario with productive wood industries, in which the cost may be significantly reduced with economies of scale and infrastructure development. A recent development in Kochi prefecture demonstrates that the average procurement cost of low-value biomass has been reduced with improved infrastructure and logistics, owing to the growing wood industry in the prefecture (Onoda 2018; NEDO 2011).

A general opinion that arose during the workshop is that the procurement cost can still be reduced with proper deployment of strategies in line with local conditions. Asada et al. (2017) found that the procurement cost (including reforestation costs) in Japan on average could be as high as four times of that in Sweden. One reason could be due to the fact that a significant portion of Japan's forests is located in hilly areas.

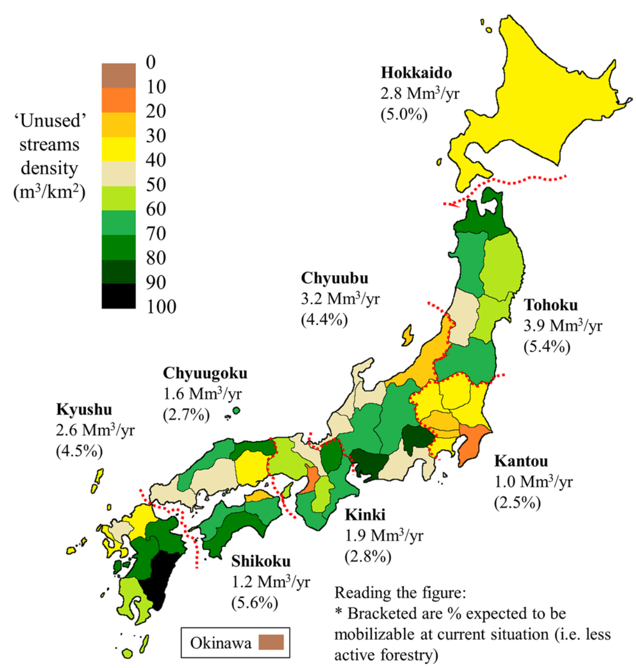

Fig. 2 Unused streams of woody biomass (by region) and density (biomass per prefectural area). Modified based on NEDO (2011)

In reality, the procurement cost varies significantly by place due to distinctive geographical and socio-economic characteristics. Moreover, innovations in various aspects can help in cost reduction. Technically, Yoshida et al. (2017) found that the overall cost can be substantially reduced through the use of secondary and smaller roads for wood transportation in combination with mobile chippers and intermediate landings. In the near future, the application of technologies such as remote sensing and Internet of Things (IoT) may further improve the efficiency of supply chains as demonstrated in some local projects (see, e.g. Yoshida 2018).

While the general expectations among the experts have been positive, the concerns, however, are with the supply–demand dynamics for bioenergy. Compared to a large-scale centralised power plant, a decentralised bioenergy system that optimally matches domestic biomass supply with domestic demand for both heat and power is regarded as a better option in terms of cost, as the transportation distance is minimised. In such a setting, innovative business models tailored based on local geographical and socio-economic conditions can further strengthen the economic feasibility of bioenergy. An example case in Fukui prefecture demonstrated that supply–demand matching and downstream integration (e.g. renting of boilers to households) are among the key elements in establishing a profitable biomass business (Taki 2018). Currently the FIT scheme in Japan, which rules out renewable heat, has not yet adequately addressed this type of decentralised bioenergy system. Rethinking the entire incentive structure is necessary to stimulate the growth of more efficient and effective bioenergy models that suit different parts of the country.

Supply–demand dynamics: how much energy demand can be met with domestic biomass?

While mobilisation of biomass can become more economically feasible through some improvements on the production side, it also highly depends on demand locations. A better understanding of the types and spatial distribution of energy demand is required. Especially, small- to medium-scale residential and commercial demands are considered the main targets in a decentralised setting. For FY2015, the final energy consumption of these two categories had reached 1.9 EJ and 2.5 EJ, respectively (Statistics Japan 2018a).

While the electricity distribution network is relatively well-established in Japan, district heating and gas grids are much less developed. As a result, kerosene and liquified petroleum gas (LPG) have remained the major fuels for household heating and cooking in many rural places. For household heating alone, the annual consumption of oil products in FY2015 was reported to be about 1.2 EJ (Statistics Japan 2018a). Unfortunately, there is no clear understanding of the actual distribution of demand, as current public monitoring systems of energy consumption at the municipal level are highly incomplete. At best, only coarse estimations are available for prefectures (Saitoh and Masui 2014; Takita et al. 2016).

To obtain a brief impression, a municipal-level analysis of residential demand that may be potentially fulfilled by woody biomass is presented in Fig. 3 (estimation by the authors). Three key assumptions are (i) biomass within one municipality is only used locally, (ii) residential demand is proportional to population in the particular municipality and (iii) efficiency of energy conversion is 80%. With these assumptions, it was found that in total about 200 PJ or 11% of household energy demand may be potentially met with biomass. If highly urbanised areas like the Tokyo metropolitan area are excluded, the percentage would also rise sharply. This can be reflected in terms of self-sufficiency, here referred to as the percentage of household demand that can be met by local biomass, in certain prefectures. Municipalities in the Akita, Shimane, Iwate, and Miyazaki prefectures show among the highest self-sufficiency levels with prefectural averages > 40%. Some individual municipalities, especially those in Hokkaido, may even achieve 100%, with excess supply. For the entire country, the excess is estimated at approximately 20 PJ and may be potentially used in local commercial and industry sectors.

While this analysis has quantitatively strengthened the idea that decentralised biomass systems can be supported

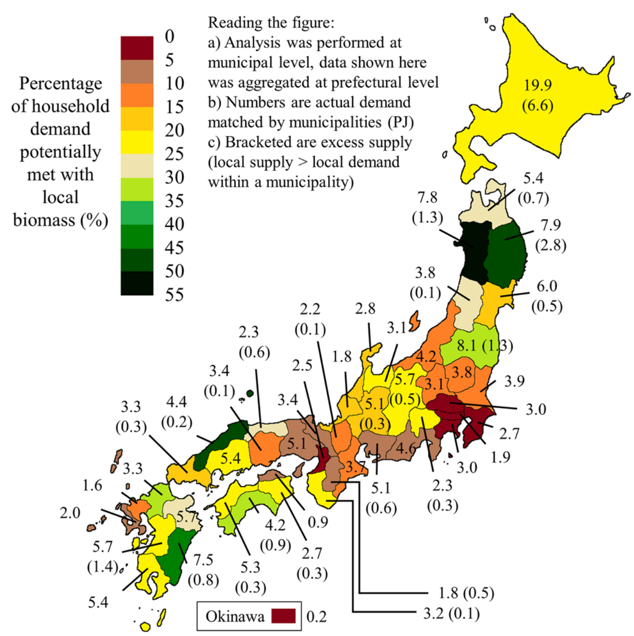

Fig. 3 Residential energy demand that can be potentially fulfilled by local woody biomass supply in > 1700 municipalities in Japan [estimated based on MIC (2018) for numbers of household, NEDO (2011) for biomass potential and Statistics Japan (2018a) for energy demand per household]

by local supplies, the actual supply–demand dynamics, however, also relies on the design of the energy system. For district-level CHP plants, evidence shows that scale and type of technologies are key economic factors in optimising supply–demand balance by taking trade-offs between size and distance to supply into account (Yagi and Nakata 2011; Kanematsu et al. 2017). Meanwhile, small-size boilers and stoves fuelled with woody biomass can also be used in public facilities and single-family homes as well as for horticulture facilities wherever the socio-economic conditions are suitable, as shown in several cases across Japan (e.g. Odachi 2018; Kozai et al. 2015).

In addition, domestic biomass may be strategically combined with imported biomass as well as other renewable energy sources in such a decentralised system. A potential option to look at is the integration with municipal solid waste (MSW) incineration systems. Currently, the incineration systems are not very efficient in producing power and heat in municipalities as not all incineration plants have power generators. Roughly, $< 10\%$ of the energy in MSW (excluding recycled materials) was converted at the waste incinerators in Japan, delivering about 36 PJ from 18 million dry tonnes in 2015 [author calculation based on Statistics Japan (2018a, b; MOE (2017)]. As a comparison, > 20 PJ of electricity and heat was generated from 2.7 million tonnes of dry bio-genic MSW incinerated in the Netherlands in 2015 [author estimation based on Statistics Netherlands (2018) and Mai-Moulin et al. (2016)]. Seeing this large room for improvement, integrating woody biomass with existing local waste incinerators may provide new opportunities in Japan.

Evidence from various cases across Japan has demonstrated that sustainable decentralised bioenergy could play a significant role in the energy system if designed optimally in an economic sense, considering various types and locations of demand. Currently, the national target of bioenergy (i.e. at 40–50 TWh per year or 144–180 PJ by 2030), as well as incentive schemes, are created for electricity and exclude heating (MAFF 2017a). Roughly, achieving this 'electricity only' target requires 70–85 million m^3 of biomass assuming a low heating value of 20 GJ/dt and a power plant efficiency of 30%. This equals to 3.5–4 times of the current annual roundwood production in Japan. To achieve a similar level of primary energy supply substitution, approximately 26–33 million m^3 of biomass would be required if CHP systems with an efficiency of 80% are adopted (Aikawa 2016). The latter case can be more practically realised with a decentralised system supported by local biomass as estimated in Fig. 3. Nevertheless, there are still major socio-economic challenges to realising such an energy system, which will be discussed in the next section.

Biomass and people: what are the socio-economic and policy challenges?

In addition to infrastructure and technology, the realisation of decentralised bioenergy is also strongly linked to local socio-economic dynamics. In many municipalities, one immediate challenge is small-scale, scattered and ineffectively documented forest ownerships—there are cases that owners remain unknown due to missing documents (Gain and Watanabe 2014). In such a situation, the majority of the forests has been abandoned, i.e. not actively and sustainably managed (MAFF 2016a). An example of an attempt to improve on this is the promulgation of the 'Forest Management Law,' which allows the shift of responsibility for forest management from passive forest owners to municipalities (Onoda 2018). This practically grants the municipalities more power to effectively manage larger and connected areas of forests.

Furthermore, the ageing and declining rural population in Japan also adversely affects forest management and development. As the population in rural Japan is projected to decrease sharply in the next several decades, there will likely be an insufficient labour force to support the forestry sector in the near future (IPSS 2018). To tackle this problem, several national government initiatives have been created to boost the forestry workforce, such as the 'Green Employment Program' which has a special focus on young populations from urban areas. It provides forestry skill-building and promotes alternative 'green' lifestyles in rural areas, aiming to attract young people to migrate from overcrowded cities to less populated areas (MAFF 2016a). Nevertheless, the programme itself may in practice suffer from a shortage of local supporting forestry staff.

While results of the aforementioned programme are yet to be seen, current forest management is highly dependent on 'Forest Owner Cooperatives' which have a passive operating mechanism. Basically, they rely heavily on subsidies for forest management as opposed to market mechanisms. This is reflected by the declining forestry sector with limited forest-based businesses and employment opportunities. Such a model faces difficulty in keeping pace with technological innovation and skill-building related to forestry, as well as market opportunities that arise from wood materials and bioenergy. In fact, the synergies between different sectors have not been fully tapped through the current subsidy structure. For example, the FIT scheme does not address potential links of renewable energies to local revitalisation or sustainable forest management. The new 'Forest Environment Tax', which will be in effect from 2019, may be an entry point to change this situation. Starting from JPY 20 billion/year in 2019 and gradually increased to 60 billion/year in 2025, funds will be channelled to prefectures and municipalities in proportion to private forest plantation area, forestry workforce and population (MAFF 2018d). These funds are mainly for forest ownership surveys, investment in forestry infrastructure, workforce and capacity building as well as the promotion of domestic wood use (MAFF 2018d).

In addition to economic development and job creation (Remedio and Domac 2003), socio-cultural aspects and relationship-building throughout the bioenergy supply chain, both formal and informal (Ahl et al. 2018; Ristanti and Yan 2015), is key in facilitating decentralised solutions in the long term as shown in multiple cases of actual management (Nemoto et al. 2017). The diverse stakeholders and social complexities involved, especially related to traditions and generational heritage, are vital elements in understanding local human–forest relationships (Aguilar 2014; Ito 1998). For instance, a case study of the Kochi prefecture by Kraxner et al. (2009) depicts a typical situation in Japan, in which a majority of forest owners were elders over 50 years of age. These owners showed concerns about the ecosystem and cultural services, such as recreational, cultural and spiritual value provided by the forest. Policy-making would benefit from the incorporation of such concerns and priorities of stakeholders in different local settings.

At present, the majority of local governments lack financial and human resources to develop sustainable biomass initiatives. External inputs and public incentives are still needed to kick-start the development of sustainable decentralised bioenergy in Japan. At national level, three ministries relevant to bioenergy development are (i) Ministry of Economy, Trade and Industry, (ii) Ministry of the Environment, and (iii) Ministry of Agriculture, Forestry and Fisheries. However, the current policy-making processes are highly sector-oriented by individual ministries. The incoherence in policies have become a significant challenge for bioenergy development at local level as the local governments and communities could get confused due to lack of integrated consultations beyond sectors.

The municipality of Shimokawa, or so-called ‘Forest Future City’, is an exceptional case focused on revitalising local forestry with bioenergy. However, it is a unique model based on considerable external funding and technical support. Nevertheless, it provides valuable lessons for bioenergy development in rural Japan, especially about empowering local communities in forest and energy management (Ristanti and Yan 2015; Fujino and Asakawa 2017). Sharing of knowledge and experiences among the municipalities may support an improved understanding of how bioenergy can fit into various local conditions of natural, human and financial capital, with all of these elements forming a complex web of impacts, synergies, and trade-offs (Cavicchi 2017; IGES 2018).

Overall sustainability: what are the overall impacts, synergies and trade-offs of using local woody biomass?

The last question in this paper discusses the evaluation of the overall sustainability of the decentralised bioenergy system supported by local forestry in Japan. Overall, bioenergy is promoted in the country for three key reasons: (i) emission reduction, (ii) local socio-economic revitalisation and (iii) energy security. The latter two can only be relevant when local biomass supply is used (Figure S1, S4). To evaluate against these objectives, the overall carbon balance and socio-economic dynamics, from multiple land functions to multiple uses of wood, must be assessed in a comprehensive manner (Werner et al. 2010; Smyth et al. 2014). In this regard, the two key variables would be (i) import substitution and (ii) material and fuel substitution.

In terms of emission reduction, as emphasised in "Environmental implications: how much wood can be sustainably harvested from domestic forest?", carbon removal by domestic forests can be further improved by active harvesting and replanting. Sustainable use of local wood (for both material and energy use), especially when replacing tropical wood imports from Southeast Asia [which amounted to 10 million m^3 per year as reported by FAOSTAT (2018)], could potentially reduce pressure on carbon and biodiversity-rich tropical forests. Furthermore, an increase in wood use for materials in long-lived products (e.g. furniture and building) in replacement of steel and concrete could reduce environmental impacts via (i) avoiding substantial emission from production of steels and concretes and (ii) storing carbon in harvested wood products (Kalt et al. 2016; Morris 2017). It is also important to consider multiple stages and recycling of wood before it ends up as fuel. A quantitative estimation by Kayo et al. (2018) showed that 1.2 tonne CO_2-eq/m^3 can be avoided through stages of material and fuel substitution with domestic wood. If this substitution would go up to 50 million m^3/year by 2050, about 3% of additional emission saving can be achieved for the case of Japan. As a comparison, the annual GHG emissions in 1990–2015 are in the range of 1.2–1.4 billion tonne CO_2-eq as reported by NIES (2017).

Meanwhile, increasing the use of local wood can greatly enhance local socio-economic development through ripple effects. It can potentially turn subsidy-dependent local forestry companies into self-sustained productive businesses. A number of case studies across Japan demonstrated that using local biomass for energy could bring substantial economic benefits to the local society (see, e.g. IGES 2018; Ogawa and Raupach-Sumiya 2018). To visualise the economic structure, Oshita and Kikuchi (2014) employed structural path analysis (SPA) to analyse the monetary flows of log production in Japan (Figure S5). As illustrated in the figure, the ripple effects from the use of local wood can be very complex, forming a large web of products that end up as consumables, different types of capital or export. For 2005, the total monetary output from domestic log production was found to be up to 229 billion JPY, with more than half of the amount linked to residential construction and repairing. Meanwhile, a relatively small percentage of monetary value was created for electricity production (in the form of wood chips) and private power generation including heating (mainly from construction waste). Based on this method, Heiho et al. (2015) furthered the analysis to assess the impacts on employment using a biogas project in Hokkaido as a case study. The authors found that jobs and income were, directly and indirectly, generated both in and outside the project area. These studies demonstrated that additional use of woody biomass to replace imported fossil fuels and materials can further enhance economic 'circularity', i.e. keeping monetary value within the country.

In the context of energy security, as a replacement to fossil fuels, the availability, affordability, technological development and sustainability of bioenergy must be taken into consideration (Sovacool and Mukherjee 2011). At the time of writing, most biomass power generation projects in Japan rely heavily on imported biomass, especially from North America and Southeast Asia. These biomass sources bring similar problems as imported fossil materials: limited availability and fluctuating prices (JWBA 2018; personal communications with industrial informants and authors' own knowledge). While using imported biomass may be necessary to jumpstart bioenergy development in Japan in the absence of large-scale domestic biomass supplies at the early stage, long-term local-based solutions must be accounted for in view of security issues. Furthermore, the scope should not be limited to coal replacement in power plants, as biomass can also substitute kerosene as a heating fuel in suburban and rural areas.

These components, i.e. sustainable forest management, intraregional cash flow, and energy self-dependency, may be integrally placed under the concept of 'regional circular economy'. It emphasises the synergies between local actors from different sectors, especially in exchanges of goods and services, so that local communities can maintain socio-economic development as well as the environment (Odachi 2018). While a few studies were mentioned in this section, quantitatively evaluating the sustainability of the entire bioenergy system remains a massive and daunting task to be tackled. Especially considering the diversity of local societies, such a comprehensive evaluation must also be coupled with engagement of local communities, e.g. through narrative interviews and choice experiments (Levidow and Papaioannou 2016; Nakai et al. 2018).

Final remarks

This paper pinpointed existing knowledge and gaps to understand the current and potential development of decentralised bioenergy systems supported by local forestry biomass for the case of Japan through five questions. The first question expressed the importance of evaluating the environmental implications of increasing wood production in Japan. Then the second and third questions described the gaps in examining potential supply/demand and innovative ways to match them. The human factor was then brought into discussion in the fourth question, elaborating the multiple aspects of bioenergy and forestry beyond environmental and economic considerations. Finally, the fifth question highlighted the importance of practically integrating knowledge across disciplinary boundaries and provoking thoughts about a more holistic approach to understanding sustainability.

From a sustainable development perspective, utilising domestic biomass to partly substitute fossil fuels could be a strategic opportunity for not only the energy sector but also local forestry and waste management. While mobilisation of domestic biomass has many practical challenges, deploying a balanced biomass portfolio in combination with a more spatially dispersed bioenergy system with local feedstock may improve both energy security and energy systems' resilience. Furthermore, the environmental benefits of local forest revitalisation have not been envisaged and added into the overall equation given the large percentage of unmanaged monoculture forests across Japan. If the use of domestic biomass, especially forestry biomass, for energy purposes can trigger sustainable forest management, it could contribute significantly to the emission reduction targets of Japan by 2030. This can also generate synergetic effects with local socio-economic and ecological revitalisation.

The uncertainties of overseas biomass supply to feed centralised large-scale power plants imply urgency to enhance the flexibility and efficiency of the bioenergy system. This is especially crucial considering the risk of unwanted environmental and social consequences accompanying imports. It is discernible with shreds of evidence across the country that bioenergy could contribute significantly to the rural energy system (144–180 PJ by 2030) with the strategic design of the supply–demand system. However, the precarious state of domestic forestry is preventing the industry to rely on local feedstock. The procurement cost of low-value biomass would need to be reduced to a reasonable level alongside the revitalisation of local forestry.

The challenges do not only lie within the production side, but also the creation of demand for local wood for multiple purposes to create economies of scale. A key element to make this feasible is incentives for renewable heat, which are currently lacking in Japan. More importantly, efforts devoted to addressing local-specific barriers are still insufficient as current energy and development policies employ more top-down approaches. Bottom-up approaches may spur innovation in business models to better fit local contexts, not only in an economic sense but also based on social and cultural values. In this regard, the application of cutting-edge technologies such as remote sensing and IoT holds the potential to improve governance and coordination across spaces. Furthermore, the forestry and bioenergy business can be combined with multiple services of forests (e.g. ecotourism), creating sustainable development packages in conjunction with environmental management to reap full benefits. Such combinations may be described using the notions of a sustainable 'bio-economy', 'eco-economy' or 'regional circular economy'. They have been observed in various on-ground revitalisation projects and proposals across the country, but have not yet been given enough attention in major policy instruments. To effectively motivate the participation of local stakeholders in developing own effectual forestry and bioenergy strategies, collaboration among actors across sectors and scales must be expanded.

Addressing these complex issues requires due consideration to the impacts, synergies, and trade-offs of the bigger system that covers land, material, and energy use instead of individual components. To realistically reduce emissions, the performance of all components should be properly considered. The current knowledge generally reflects that it is beneficial and crucial to maximise synergies among them, but there is no clear quantitative evidence yet for such a complex system. For example, the import of biomass for energy is not necessarily negative if the source is sustainable. This import may become a key to jumpstart bioenergy projects and later a useful supplement to local bioenergy systems. This requires deeper deliberation on energy security and landscape management in aspects of both productivity and conservation. More importantly, the 'people' aspect and the interaction between people and the environment should be given more attention.

Acknowledgements The first author was supported by JSPS KAKENHI Grant number JP 17F17776 to carry out this work. Presenters and participants of the workshop (on 28 June 2018 at UNU, Tokyo) that was purposely organised to discuss the questions posted in this paper are acknowledged for their valuable information and comments (see https://ias.unu.edu/en/news/news/bioenergy-workshop-2.html#info). We would like to especially thank Prof. Hideo Sakai and Dr. Mika Yoshida for their inputs in the beginning.

References

Aguilar FX (2014) Wood energy in developed economies. Resource management, economics and policy. Routledge, Oxford

Ahl A, Eklund J, Lundqvist P, Yarime M (2018) Balancing formal and informal success factors perceived by supply chain stakeholders: a study of woody biomass energy systems in Japan. J Clean Prod 175:50–59

Aikawa T (2016) Recommendations for woody biomass power generation under FiT for the realization of a sustainable use of bioenergy. Renewable Energy Institute, Tokyo. http://www.renewable-ei.org/en/activities/reports_20161226.php. Accessed 17 Apr 2018

Aikawa T (2018) Session 4: "Measuring sustainability: The overall impacts, synergies and trade-offs". Workshop: rethinking bioenergy development: exploring an alternative scenario with decentralized bioenergy system supported by domestic woody biomass supply. United Nations University. 28th June 2018. https://ias.unu.edu/en/news/news/bioenergy-workshop-2.html#files. Accessed 29 July 2018

Asada R, Kaibe K, Otomo J, Yamada K (2017) Production cost structure and cost reduction scenario of woody biomass in Japan. J Jpn For Soc 99:187–194

Cavicchi B (2017) The influence of local governance: effects on the sustainability of bioenergy innovation. Sustainability 9(3):1–22

FAOSTAT (2018) Forestry production and trade. http://www.fao.org/faostat/en/#data/FO. Accessed 29 July 2018

Fujino J, Asakawa K (2017) Taking action on the SDGs in Japanese cities—the "FutureCity" Initiative and its achievement on the SDGs. IGES Discussion Paper November 2017. IGES City Taskforce. https://pub.iges.or.jp/pub_file/iges-dp-sdgs-city-en-1pdf/download. Accessed 17 July 2018

Furubayashi T, Nakata T (2018) Cost and CO_2 reduction of biomass co-firing using waste wood biomass in Tohoku region, Japan. J Clean Prod 174:1044–1053

Furubayashi T, Sumitomo Y, Nakata T (2017) Wood flow chart for Japan: material and energy utilization. J Jpn Inst Energy 96:206–216. https://doi.org/10.3775/jie.96.206 **(in Japanese)**

Gain D, Watanabe T (2014) Forest management in Japan: application issues of sustainable forestry and the potential of improvement through accredited forest certification. Soc Soc Manag Syst Internet J SMS 13:3731

Goh CS, Wicke B, Verstegen J, Faaij A, Junginger M (2016) Linking carbon stock change from land-use change to consumption of agricultural products: a review with Indonesian palm oil as a case study. J Environ Manag 184:340–352

Heiho A, Hondo H, Moriizumi Y (2015) Social life cycle assessment of biomass projects focusing on employment changes in regions. J Jpn Inst Energy 94(2):159–169

IGES (2018) Shimokawa town the sustainable development goals (SDGs) report. https://www.iges.or.jp/en/sdgs/report.html. Accessed 30 July 2018

IPSS (2018) Population and household projection. National Institute of Population and Social Security Research. http://www.ipss.go.jp/site-ad/index_english/population-e.html. Accessed 30 July 2018

Ito T (1998) Review of forest culture research in Japan: toward a new paradigm of forest culture. In: Sassa K (ed) Environmental forest science. Forestry sciences, vol 54. Springer, Dordrecht

JWBA (2018) Monthly custom clearance statistics. Japan Woody Biomass Association. https://www.jwba.or.jp/%E3%83%87%E3%83%BC%E3%82%BF%E3%83%99%E3%83%BC%E3%82%B9/%E4%B8%80%E8%88%AC%E5%85%AC%E9%96%8B%E7%94%A8%E3%83%87%E3%83%BC%E3%82%BF-%E7%9B%AE%E6%AC%A1/%E6%9C%88%E5%88%A5%E9%

80%9A%E9%96%A2%E9%87%8F%E3%81%A8%E4%BE%A1%E6%A0%BC%E3%81%AE%E6%8E%A8%E7%A7%BB%EF%BC%91/. Accessed 28 Nov 2018 **(in Japanese)**

Kalt G, Höher M, Lauk C, Schipfer F, Kranzl L (2016) Carbon accounting of material substitution with biomass: case studies for Austria investigated with IPCC default and alternative approaches. Environ Sci Policy 64:155–163

Kanematsu Y, Oosawa K, Okubo T, Kikuchi Y (2017) Designing the scale of a woody biomass CHP considering local forestry reformation: a case study of Tanegashima, Japan. Appl Energy 198:160–172

Kato T (2018) Historical trend of wood demand and supply, forest stock. Workshop: rethinking bioenergy development: exploring an alternative scenario with decentralized bioenergy system supported by domestic woody biomass supply. United Nations University. 28th June 2018. https://ias.unu.edu/en/news/news/bioenergy-workshop-2.html#files. Accessed 29 July 2018

Kayo C, Dente S, Aoki-Suzuki C, Tanaka D, Murakami S, Hashimoto S (2018) Environmental impact assessment of wood use in Japan through 2050 using material flow analysis and life cycle assessment. J Ind Ecol. https://doi.org/10.1111/jiec.12766

Kozai T, Niu G, Takagaki M (2015) Plant factory: an indoor vertical farming system for efficient quality food production. Elsevier, Tokyo

Kraxner F, Yang J, Yamagata Y (2009) Attitudes towards forest, biomass and certification—a case study approach to integrate public opinion in Japan. Bioresour Technol 100(17):4058–4061

Kuboyama H (2018) About the possibility of sustainable woody biomass utilization. Workshop: rethinking bioenergy development: exploring an alternative scenario with decentralized bioenergy system supported by domestic woody biomass supply. United Nations University. 28th June 2018. https://ias.unu.edu/en/news/news/bioenergy-workshop-2.html#files. Accessed 29 July 2018

Levidow L, Papaioannou T (2016) Policy-driven, narrative-based evidence gathering: UK priorities for decarbonisation through biomass. Sci Publ Policy 43:46–61. https://doi.org/10.1093/scipol/scv016

MAFF (2016a) Annual Report on Forest and Forestry in Japan, Fiscal Year 2016. Forestry Agency, Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan. http://www.maff.go.jp/e/data/publish/attach/pdf/index-64.pdf. Accessed 17 Apr 2018

MAFF (2016b) Timber supply and demand report and statistical survey, Fiscal Year 2016. http://www.maff.go.jp/j/tokei/kouhyou/mokuzai/index.html. Accessed 3 July 2018

MAFF (2017a) Circumstances surrounding the utilization of Biomass. Biomass Policy Division Food Industry Affairs Bureau, April 2017. www.maff.go.jp/e/policies/env/attach/pdf/index-2.pdf. Accessed 24 Nov 2017

MAFF (2017b) Preliminary analysis table of policy evaluation on measures implemented in FY2017. In Japanese. http://www.maff.go.jp/j/assess/hanei/zisseki/h29/pdf/jizen29_18.pdf. Accessed 14 Nov 2018

MAFF (2018a) Annual Report on Forest and Forestry in Japan, Fiscal Year 2017. Forestry Agency, Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan. http://www.maff.go.jp/e/data/publish/attach/pdf/index-95.pdf. Accessed 30 Nov 2018

MAFF (2018b) Generation and utilization of woody biomass. www.rinya.maff.go.jp/j/riyou/biomass/con_1.html. Accessed 23 Apr 2018

MAFF (2018c) Forests and Forestry White Paper 2017 (announced on June 1, 2018). http://www.rinya.maff.go.jp/j/kikaku/hakusyo/29hakusyo/index.html. Accessed 12 July 2018

MAFF (2018d) 'The establishment of the Forest Environment Tax and its subsidy scheme (provisional title)', Rinya, 131, pp 3–7. http://www.rinya.maff.go.jp/j/kouhou/kouhousitu/jouhoushi/attach/pdf/3002-7.pdf. Accessed 12 Sep 2018

MAFF (2018e) Forest ecosystem diversity basic survey data analysis program. In Japanese. http://www.rinya.maff.go.jp/j/keikaku/tayouseichousa/chousadeta.html. Accessed 14 Nov 2018

Mai-Moulin T, Goh CS, Junginger M (2016) Sustainable biomass and bioenergy in the Netherlands: Report 2015. https://english.rvo.nl/sites/default/files/2016/05/Sustainable-biomass-bioenergy-netherlands.pdf. Accessed 30 July 2018

Matsumoto M, Oka H, Mitsuda Y, Hashimoto S, Kayo C, Tsunetsugu Y, Tonosaki M (2016) Potential contributions of forestry and wood use to climate change mitigation in Japan. J For Res 21(5):211–222

METI (2017) Biomass power generation with ordinary wood. In Japanese. http://www.meti.go.jp/committee/chotatsu_kakaku/pdf/032_01_00.pdf. Accessed 17 Apr 2018

MIC (2018) Reference material 4 Population and number of households by municipality. Ministry of Internal Affairs and Communications (MIC). http://www.soumu.go.jp/menu_news/s-news/17216_1.html. Accessed 11 July 2018

MOE (2017) Japan's waste management 2015. http://www.env.go.jp/recycle/waste_tech/ippan/h27/index.html. Accessed 10 Sep 2018

Morris J (2017) Recycle, bury, or burn wood waste biomass? LCA answer depends on carbon accounting, emissions controls, displaced fuels, and impact costs. J Ind Ecol 21(4):844–856

Nakahata C, Uemura R, Saito M, Kanetsuki K, Aruga K (2013) Estimating harvest costs and projecting quantities of logging residues for small-scale forestry in Nasushiobara, Tochigi Prefecture, Japan. J For Res 25(4):965–974

Nakai M, Okubo T, Kikuchi Y (2018) A socio-technical analysis of consumer preferences about energy systems applying a simulation-based approach: a case study of the Tokyo area. Energy Res Soc Sci 46:52–63

NEDO (2011) Biomass stock—estimation of potential quantity for effective use. http://app1.infoc.nedo.go.jp/biomass/index.html. Accessed 1 July 2018

Nemoto K, Inuzuka H, Nakamura S, Mori Y (2017) Supply chain analysis for determining the requirements for continuous woody biomass energy utilization systems: comparison of the actual management conditions in Japan. Int J Environ Rural Dev 8(1):203–209

NIES (2017) National Greenhouse Gas Inventory. Report of JAPAN 2017. Ministry of the Environment, Japan and Greenhouse Gas Inventory Office of Japan (GIO), CGER, NIES. http://www-gio.nies.go.jp/aboutghg/nir/2017/NIR-JPN-2017-v3.1_web.pdf. Accessed 23 July 2018

Odachi A (2018) NPO Shinrin projects in Miyagi prefecture. Workshop: rethinking bioenergy development: exploring an alternative scenario with decentralized bioenergy system supported by domestic woody biomass supply. United Nations University. 28th June 2018. https://ias.unu.edu/en/news/news/bioenergy-workshop-2.html#files. Accessed 29 July 2018

Ogawa Y, Raupach-Sumiya J (2018) Economic impacts of renewable energy to the local economy—case study with value chain analysis. Jpn Soc Environ Sci Jpn 31(1):34–42

Onoda M (2018) Forestry and forestry policies in Kochi Prefecture—toward regional sustainable and responsible supply (wood and energy). Workshop: rethinking bioenergy development: exploring an alternative scenario with decentralized bioenergy system supported by domestic woody biomass supply. United Nations University. 28th June 2018. https://ias.unu.edu/en/news/news/bioenergy-workshop-2.html#files. Accessed 29 July 2018

Ooba M, Fujita T, Mizuochi M, Fujii M, Machimura T, Matsui T (2012) Sustainable use of regional wood biomass in Kushida river basin, Japan. Waste Biomass Valor 3:425–433

Ooba M, Fujii M, Hayashi K (2016) Geospatial distribution of ecosystem services and biomass energy potential in eastern Japan. J Clean Prod 130:35–44

Oshita Y, Kikuchi Y (2014) Flow analysis on products of agriculture, forestry, fisheries industry using structural path analysis. In: Proceedings of 22nd international input-output conference 2014. https://www.iioa.org/conferences/22nd/papers.html. Accessed 28 Nov 2018

Ota I (2002) The shrinking profitability of small-scale forestry in Japan and some recent policy initiatives to reverse the trend. Small Scale For Econ Manag Policy 1(1):25–37

Remedio EM, Domac JU (2003) Socio-economic analysis of bioenergy systems: a focus on employment. Wood Energy Programme, Food and Agriculture Organization (FAO) of the United Nations (UN). https://pdfs.semanticscholar.org/b08b/9ca610e46f4be0ea60f1f9b1fe15786c7932.pdf. Accessed 17 Apr 2018

Ristanti EY, Yan W (2015) Lessons learned from government and private-sponsored 'woody biomass' project—case study of Shimokawa and Hita. Proc Environ Sci 28:21–26

Saito O (2009) Forest history and the great divergence: China, Japan, and the West compared. J Glob Hist 4(3):379–404. https://doi.org/10.1017/S1740022809990131

Saitoh S, Masui T (2014) Consideration of problems concerning the estimation of energy consumption in local municipalities. Public Policy Design Program. Dept. of Industrial Engineering and Management, Tokyo Institute of Technology. In Japanese. http://www.me.titech.ac.jp/~masui-kanamori/ronbun/abstract/AY2014/M2014_Shun_Satoh.pdf. Accessed 11 July 2018

Saragai S (2018) Current and targeted use of woody biomass. Workshop: rethinking bioenergy development: exploring an alternative scenario with decentralized bioenergy system supported by domestic woody biomass supply. United Nations University. 28th June 2018. https://ias.unu.edu/en/news/news/bioenergy-workshop-2.html#files. Accessed 29 July 2018

Smyth C, Stinson G, Neilson E, Lempriere T, Hafer M, Rampley G, Kurz W (2014) Quantifying the biophysical climate change mitigation potential of Canada's forest sector. Biogeosciences 11:3515–3529

Sovacool BK, Mukherjee I (2011) Conceptualizing and measuring energy security: a synthesized approach. Energy 36(8):5343–5355. https://doi.org/10.1016/j.energy.2011.06.043

Statistics Japan (2018a) Statistics year book 2018. 11-1 Supply and Demand of Energy (F.Y.2015). http://www.stat.go.jp/english/data/nenkan/67nenkan/1431-11.html. Accessed 11 July 2018

Statistics Japan (2018b) Statistics year book 2018. 17-5 Disposal of General Waste Matters (Garbage and Human Excrement). http://www.stat.go.jp/english/data/nenkan/67nenkan/1431-17.html. Accessed 29 July 2018

Statistics Netherlands (2018) CBS Stateline: Energy balance sheet; supply and consumption, sector. https://opendata.cbs.nl/statline/#/CBS/en/dataset/83989ENG/table?ts=1532922783764. Accessed 30 July 2018

Taki R (2018) For sustainable forestry and wood biomass energy business—cases in Fukui and Fukushima prefecture. Workshop: rethinking bioenergy development: exploring an alternative scenario with decentralized bioenergy system supported by domestic woody biomass supply. United Nations University. 28th June 2018. Presentation not publicly available

Takita Y, Furubayashi T, Nakata T (2016) Analysis of local energy demand-supply distribution and visualization of the energy spatial information toward smart community. Trans JSME. https://doi.org/10.1299/transjsme.16-00100 **(in Japanese)**

Werner F, Taverna R, Hofer P, Thürig E, Kaufmann E (2010) National and global greenhouse gas dynamics of different forest management and wood use scenarios: a model-based assessment. Environ Sci Policy 13(1):72–85

Yagi K, Nakata T (2011) Economic analysis on small-scale forest biomass gasification considering geographical resources distribution and technical characteristics. Biomass Bioenergy 35:2883–2892

Yamada Y (2018) Can a regional-level forest management policy achieve sustainable forest management? For Policy Econ 90:82–89

Yoshida T (2018) Evaluation of Potential Biomass: DOUSHI case study. Workshop: rethinking bioenergy development: exploring an alternative scenario with decentralized bioenergy system supported by domestic woody biomass supply. United Nations University. 28th June 2018. https://ias.unu.edu/en/news/news/bioenergy-workshop-2.html#files. Accessed 29 July 2018

Yoshida M, Son J, Sakai H (2017) Biomass transportation costs by activating upgraded forest roads and intermediate landings. Bulletin of the Transilvania University of Braşov, Special Issue Series II: Forestry, Wood Industry, Agricultural Food Engineering, 10 (59):1. http://rs.unitbv.ro/Bulletin/Series%20II/2017/BULETIN%20I%20SI/10.%20Yoshida%20et%20al.pdf. Accessed 12 July 2018

Yoshioka T, Hirata S, Matsumura Y, Sakanishi K (2005) Woody biomass resources and conversion in Japan: the current situation and projections to 2010 and 2050. Biomass Bioenergy 29:336–346

Yoshioka T, Sakurai R, Aruga K, Sakai H, Kobayashi H, Inoue K (2011) A GIS-based analysis on the relationship between the annual available amount and the procurement cost of forest biomass in a mountainous region in Japan. Biomass Bioenergy 35:4530–4537