Sustainability Science (2020) 15:1531–1553
https://doi.org/10.1007/s11625-019-00728-2

SPECIAL FEATURE: ORIGINAL ARTICLE

Developing Sustainable Bio-Energy Systems in Asia

Smart technology applications in the woody biomass supply chain: interview insights and potential in Japan

Amanda Ahl[1] · Mika Goto[1] · Masaru Yarime[2,3,4]

Received: 25 January 2019 / Accepted: 14 August 2019 / Published online: 4 September 2019

Abstract
In light of climate change, there is pressure worldwide to curb emissions via energy efficiency, conservation, and renewable energy. Woody biomass has a role in sustainable energy transitions, contributing to emissions reduction, economic development, and energy security as a dispatchable resource. This potential is recognized globally, but the woody biomass supply chain has faced technical and social challenges. Smart technologies are increasingly discussed in discourse on supply chain management, such as their potential to improve transparency and efficiency. Despite a variety of research related to woody biomass as well as smart technologies, little attention has been given to integrating the two perspectives. This study explores this intersection by highlighting smart technologies and mechanisms by which they may contribute to overcoming challenges in the woody biomass supply chain, exemplified by the case of Japan. Based on qualitative expert interviews, exploratory results suggest potential of smart technologies that would contribute to addressing both social and technical challenges of woody biomass in Japan. These challenges include transportation infrastructure, biomass quality management, business model integration (cascading), stakeholder relationship management, and local community revitalization and socioeconomic development. This contribution is based on various mechanisms such as improved transparency, information-sharing, accountability, automation, and value maximization. The results of this paper delineate a potential future development path that integrates smart technologies, woody biomass supply chains, and sustainability goals. This is an important further consideration for energy policy in academia, industry, as well as government.

Keywords Smart technology · Woody biomass · Supply chain · Decentralized energy · Bioenergy · Japan

Introduction

Global warming is likely to reach 1.5° above pre-industrial levels by 2052 if escalation persists at the current rate, introducing climate risks for natural and human systems (IPCC 2018). The energy sector has received immense attention in sustainability strategies, with fundamental steps including energy efficiency and renewable energy expansion (Yarime 2017; Paredes-Sanchez et al. 2013; Khansari et al. 2013; Calvillo et al. 2016). Bioenergy is a puzzle piece in phasing out fossil fuels, as its resources are flexible and enable polygeneration of power, heating and cooling (Calvillo et al. 2016). It can also be useful for power grid-balancing, frequency control, seasonal balancing, back-up capacities, and enhanced stability in systems with an increasing share of intermittent resources such as solar and wind power (Arasto et al. 2017). Dispatchable bioenergy can contribute to energy security and economic efficiency via energy diversification

---

Handled by Yoshiki Yamagata, National Institute for Environmental Studies Center for global environmental research, Japan.

✉ Amanda Ahl
ahl.aa.a@m.titech.ac.jp

[1] Department of Innovation Science, School of Environment and Society, Tokyo Institute of Technology, 3-3-6 Shibaura, Minato, Tokyo 105-0023, Japan

[2] Division of Public Policy, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

[3] Department of Science, Technology, Engineering and Public Policy, University College London, Gower Street, London, UK

[4] Graduate School of Public Policy, The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan

even under an increase of intermittent resources (IEA 2018; Arasto et al. 2017; Jiang et al. 2017; Chuahan and Tewari 2014).

Intermittent renewable resources are expected to significantly increase in future urban electricity systems (Jiang et al. 2017). In this perspective, flexible bioenergy can aid in supporting intermittent renewable energy in cities (Jiang et al. 2017). One of few studies on this topic is the scenario-modeling of urban waste for bioenergy in Amsterdam by Jiang et al. (2017). The authors found that biomass can contribute to energy security and climate change mitigation in cities as backup capacity supporting intermittent renewables. Scenarios with higher shares of wind and solar power may reduce the biomass backup storage needed to maintain energy supply stability (Jiang et al. 2017), explainable by the complementarity between solar and wind resources (Jiang et al. 2017; Miglietta et al. 2017).

In the current paper, it is suggested that woody biomass can contribute both to urban and rural areas in regional bioenergy systems facilitated by urban–rural linkages. Such linkages refer to flows between urban and rural areas, such as of people, capital, goods, information, waste, and services (IIED 2019). For example, entrepreneurs which produce agricultural or artisanal products in rural areas and export them to urban regions contribute to urban–rural linkages (Mayer et al. 2016). In regional systems, these linkages can strengthen and diversify rural economies as well as facilitate urban area access to critical resources (Mayer et al. 2016). Woody biomass can be one such critical energy resource, but its supply chain is complex with a diversity of stakeholders and business models (Whalley et al. 2017; Welfe et al. 2014). The upstream supply chain both impacts and is impacted by forest and agriculture management, sustainability compliance, and resulting capacities to ensure wood fuel supplies (Gold and Seuring 2011). This incurs complexity in effectively managing supply chain activities and material flows, as well as analyzing environmental and socioeconomic impacts (Soares et al. 2018). This complexity suggests a need for new innovative approaches.

Smart technologies are increasingly adopted as mediators in sustainability strategies (Caputo et al. 2017). There is a clear relationship indicated in the literature between sustainable development and information and communication technology (ICT) (Bifulco et al. 2016, 2018; Lombardi et al. 2012; Barile et al. 2018), for example with new models for supply chain (Kache and Seuring 2017) and energy management (Bifulco et al. 2018; Paredes-Sanchez et al. 2013). Such models may facilitate sustainability and efficiency in wood supply chains, for example via tracking and optimization. Technological innovation is also markedly enabling the transformation from centralized to decentralized energy systems (EPA 2018). The increasing complexity of energy and information flows can be supported by digital technologies via mechanisms of connectivity, data collection and analysis, intelligence, communications, and system control (DOE 2015). It is proposed that the advancement of smart technologies may facilitate development of regional woody biomass supply chains. There is abundant literature on smart technologies and on woody biomass supply chains, but a lack of research combining the two perspectives. The current paper explores this research gap.

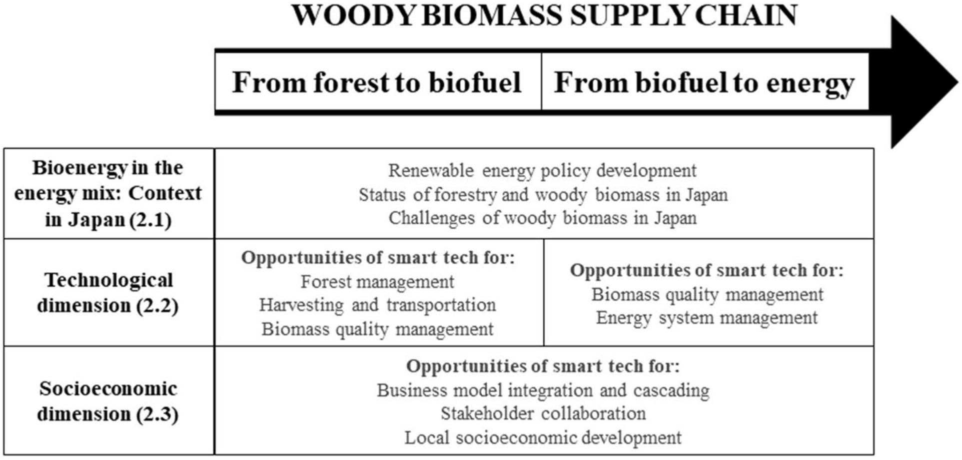
With this background, this is a conceptual paper aiming to explore the gap between smart technology and bioenergy literature, and formulate some initial theoretical assumptions on mechanisms by which smart technologies can contribute to regional woody biomass supply chains. The research question of this study is: How can smart technologies be used to overcome challenges in the woody biomass supply chain? The paper aims to support researchers and professionals by identifying possible answers to this question, and by offering indications on new approaches for woody biomass supply chain development. This is explored based on in-depth review of academic and grey literature, as well as qualitative analysis of structured interviews with 20 experts in the fields of forestry, woody biomass, and smart technologies. Opportunities of smart technologies are exemplified in an exploratory manner by referring to woody biomass and challenges in Japan. The remainder of this paper is organized as follows. The next section carries out a literature review to investigate smart technologies, woody biomass, and discourse combining the two perspectives, followed by a section that describes the methodology. The section "Results of exploratory analyses" presents and discusses key findings of smart technology pathways in overcoming challenges in woody biomass supply chains in Japan, followed by the section that provides an integrated overview and discussion of policy implications. The last section concludes with strategic implications and suggestions for further research.

Literature review and concepts

As follows, energy policies and developments in Japan are discussed. Thereafter, literature indicating opportunities of smart technologies in the woody biomass supply chain is explored from technological and socioeconomic dimensions. Figure 1 shows the structure and main factors of the literature review.

Bioenergy in the energy mix: context in Japan

In Japan, among the main incentives for renewable energy is the electricity feed-in-tariff (FIT) initiated in 2012 (IEA 2017). This scheme has a 20-year rate of 32 JPY/kWh (0.29 USD/kWh, 2019-01-21) for power plants over 2 MW utilizing woody biomass from forest-thinning, and 40 JPY/kWh



WOODY BIOMASS SUPPLY CHAIN

	From forest to biofuel	From biofuel to energy
Bioenergy in the energy mix: Context in Japan (2.1)	Renewable energy policy development Status of forestry and woody biomass in Japan Challenges of woody biomass in Japan	
Technological dimension (2.2)	Opportunities of smart tech for: Forest management Harvesting and transportation Biomass quality management	Opportunities of smart tech for: Biomass quality management Energy system management
Socioeconomic dimension (2.3)	Opportunities of smart tech for: Business model integration and cascading Stakeholder collaboration Local socioeconomic development	

Fig. 1 Overview of key factors of literature review: the technological and socioeconomic dimensions of woody biomass supply chains

(0.36 USD/kWh, 2019-01-21) under 2 MW (JETRO 2016). In its biomass agenda, the government also promotes local revitalization in light of aging rural societies (METI 2014). In the 2006 Biomass Nippon Strategy, 300 Biomass Towns were planned for 2010 to further mobilize domestic biomass (Pambudi et al. 2017), defined as areas "…where a comprehensive biomass utilization system is established and operated through the cooperation of various stakeholders…" (MAFF 2018). For its 2030 energy mix the government targets a biomass share of 3.7–4.6% (Kimura and Ninomiya 2017). This target and the FITs apply to electricity, ergo combined heat and power (CHP) has not expanded to a great extent (Aikawa 2018).

The potential for woody biomass in Japan has been countered with inconsistency between policy targets and infrastructure (Pambudi et al. 2017). The share of domestic wood declined from 70 to 20% 1964–2000, as domestic forest productivity levels were unable to sustain supplies and prices that could compete with imported wood (Fujiwara 2003). Yoshida et al. (2014) pointed out that among the main setbacks of the Biomass Towns of 2010 were deficient rural infrastructure and forest road networks. Despite the present FITs and land consisting of approximately 2/3 forest in Japan (MAFF 2016), biomass operators have primarily utilized imported fuels (Obayashi 2017) of which the proportion is expected to increase (Kimura and Ninomiya 2017). There is at present a large quantity of mature, unmanaged forest in Japan (Yanagida 2015), indicating a need for improved forestry practices for expanded use of domestic woody biomass.

With biomass energy policies increasing worldwide, biomass resource mobilization strategies need to follow (Welfe et al. 2014). Technical drivers (e.g. forest productivity), infrastructure (e.g. harvesting and transport), and market/policy drivers are important for improved biomass supply chains at large (Welfe et al. 2014). Nishiguchi and Tabata (2016) highlighted financial costs of wood collection and transportation as well as labor shortages in Japanese forestry as key current challenges of woody biomass. Ahl et al. (2018) investigated challenges perceived by woody biomass supply chain stakeholders in a case study in Kyushu, Japan. The identified challenges include transportation infrastructure, biomass quality control, business model integration (cascading), building stakeholder respect, relationships and trust, and local community revitalization (Ahl et al. 2018). This indicates both technological and socioeconomic challenges, linkable to sociotechnical system transformation (Camarinha-Matos 2016; McCauley and Stephens 2012; Lund et al. 2017; Barile et al. 2018). In understanding how smart technologies may be utilized in the woody biomass supply chain, it would be important to discuss literature and industrial examples related to both dimensions.

Technological dimension

Initially it would be important to define a smart technology. While there are various interpretations, a smart technology can be defined by its ability to use "sensors, databases, and wireless access to collaboratively sense, adapt, and provide for users within the environment" (Elwood 2008). Systems can manage complexity and react to changing environments via smart technologies such as cognitive machines, deep learning (Barile et al. 2018), semantic webs, cloud computing, and Internet of Things (IoT) in real-world interfaces (Bifulco et al. 2018). Such technologies can also facilitate connectivity among stakeholders (Bifulco et al. 2018; Caputo et al. 2017) for more participatory systems (Bifulco et al. 2018; Khansari et al. 2013), effective governance (Barile et al. 2018), and innovation-boosting settings (Bifulco et al. 2016). These capabilities can contribute to renewable energy supply chain and stakeholder management, from sourcing to power generation to distribution (Yarime and Karlsson 2018; Camarinha-Matos 2016).

In supply chain literature at large, several authors have discussed opportunities of smart technologies. For example, Kache and Seuring (2017) discussed the use of big data analytics, advanced statistics, stored communication records including images, GPS signals, and sensor readings, to contribute to predictive management, cost-savings, and risk analyses. In addition, radio-frequency identification (RFID) tags (Guo et al. 2015; Tzoulis and Andreopoulou 2013) and cloud technologies (Guo et al. 2015) can enable product-tracking, transparency, and data-driven decision-making in supply chains. Such technologies and mechanisms may present several opportunities for woody biomass supply chains, from forest to biofuel production, and from biofuel to energy generation. Relevant literature is explored as follows.

From forest to biofuel

Enhanced decision-supporting tools are needed for the sustainable implementation of bioenergy (Soares et al. 2018). Such tools benefit from capacities in data collection and analysis. A key pre-requisite of forest biomass estimation is high-quality data (Sinha et al. 2015). While data quality is not yet sufficient for fully reliable and informed decision-making, it is rapidly improving with the help of satellite systems, drones and IoT (Yarime 2017). In terms of forest management in the upstream woody biomass supply chain, such developments present several opportunities.

Forest biomass estimation can be carried out through (1) field measurements, (2) geographic information systems (GIS), and (3) remote-sensing (Sinha et al. 2015). Field measurement may provide accurate data, but is time- and capital-intensive for large areas (Lu et al. 2016; Sinha et al. 2015). GIS involves the integration of database operations with maps. GIS improvements can be utilized to more effectively identify natural resources (Calvillo et al. 2016). Lu et al. (2016) noted that remote-sensing can enable more accurate large-scale aboveground forest biomass estimation. Remote-sensing generally refers to methods for retrieving information about the Earth based on satellite or airborne vehicles, which in turn can be used in GIS systems. For example, airborne Light Detection and Ranging (Lidar), or laser-scanning, from satellite systems can be a suitable technique for forest biomass estimations (Koch 2010). In reviews on remote-sensing for biomass estimation, Lu et al. (2016) and Sinha et al. (2015) both noted the importance of the integrated use of multi-source (optical and radar) data for reduced data saturation and uncertainty. For example, the combination of synthetic aperture radar (SAR) and optical data has potential to improve estimation performance (Sinha et al. 2015).

Improved data on forest biomass can enable decision-making and planning processes across the supply chain. Remote-sensing for data collection can be carried out in satellites, airplanes, and also increasingly drones. Drone technology still has limitations in this regard, such as capacities to cover large forest areas. However, drones are advancing rapidly, such as for surveillance and mapping. Coupled with image analytics, drones can contribute to the development of geospatial surveys for investment planning, vegetation monitoring, and so on (PwC 2017). It can be suggested that they may be useful within a toolbox of technologies for forest management. The potential of drones to provide ultra-high spatial resolution data in local or regional scales on forest stand characteristics was demonstrated by Zhang et al. (2016). Drones may also be integrated with Lidar (Zhang et al. 2016), seen by companies such as Velodyne Lidar based in California (Velodyne Lidar 2019) and YellowScan in France (YellowScan 2019). Forest biomass measurements collected by remote-sensing, such as via satellites or drones, may also be analyzed by AI (Gingras and Charette 2017). Considering declining populations and workforce in rural Japan, drones may be especially useful for resource-efficient and targeted monitoring of forests.

In terms of harvesting and transportation of woody biomass: robotics, image analytics, AI, and machine learning offer potential for automation to increase efficiency and human safety (Gingras and Charette 2017; Kies and von Lengefeld 2018). One example is the "Smart Crane Control" project coordinated by the Cluster of Forest Technology of Sweden, through which an automated harvesting crane is being developed (Skogstekniska Klustret 2014). In the project "Auto2", partly automated and partly remotely controlled forestry machines are being co-developed by industry and research institutes in Sweden and Japan (Skogforsk 2018). High-quality forest data using satellite images and laser-scanning will be utilized to facilitate the automation (Skogforsk 2018). Starting from the onset in upstream forest management and throughout the supply chain, woody biomass quality control is also an important point for discussion.

Woody biomass quality includes parameters such as size, shape, density, ash, sugar and moisture content (Kenney et al. 2013). Such parameters change significantly along the supply chain, and would benefit from improved management practices, rapid assessment, and pre-processing technologies (Kenney et al. 2013; Eisenbies et al. 2016). Moisture content is likely the most challenging parameter in feedstock supplies and operations (Kenney et al. 2013). Smart technologies may facilitate more efficient quality monitoring and control. An industrial example is Inray Fuel Control, a European Union (EU)-funded company that conducts solid-fuel quality X-rays for moisture, foreign substance, and energy content analysis (Inray 2018). This data is measured and shared in real-time: useful for fuel-pricing, process optimization, emissions reduction, and reduced costs related to maintenance, sampling and analysis (Inray 2018).

In addition to harvesting, transportation, and quality management, sustainable forest management (SFM) is an important consideration in the woody biomass supply chain. Woody biomass can involve several sustainability challenges, such as bio-diversity loss, water, air quality, and soil quality (Soares et al. 2018). Sustainability depends at large on the proportion taken from the forest and proportion left to maintain habitat health (Welfe et al. 2014). Data availability is useful when analyzing overall environmental impacts (Nakagawa et al. 2018) and verifying processes. Forest verifications often depend on tracking methods that are centralized and data that is easily tampered with: paper-based Chain of Custody Systems (Dudder and Ross 2017). Smart technologies can contribute in myriad ways to SFM and traceability of wood origins (Kies and von Lengefeld 2018). In this context, blockchain technology may facilitate effective tracing of timber resources and associated sustainability criteria at any point in the supply chain (Clement 2018; Dudder and Ross 2017). Blockchain technology is a distributed ledger which can operate without a third party, offering potential to contribute to transparency, traceability, and stakeholder trust in the biofuel supply chain (Clement 2018). While blockchain is extensively researched in the finance sector, its potential for sustainability in supply chains and distributed data therein is a key research gap (Dudder and Ross 2017). One of few examples of research on potential applications of blockchain in the wood supply chain is by Dudder and Ross (2017). The authors found that certification schemes can effectively verify legalities and SFM in a universal digital blockchain platform (Dudder and Ross 2017).

From biofuel to energy generation

In the energy supply chain, the use of smart technologies has at large centered on downstream energy management and smart grids. This is a system that adopts ICT for real-time, bi-directional communication of electricity consumption and generation (Calvillo et al. 2016). Smart grids have been highlighted by several authors as critical for the integration of distributed and intermittent renewable energy as well as for enhancing system efficiency (Caputo et al. 2017; Lund et al. 2017; Mohammadi et al. 2017; Carvalho, 2012). In a survey of future trends, Camarinha-Matos (2016) found that IoT, sensor networks, cloud-computing, big data analytics and AI in smart grids are likely to increasingly facilitate collaborative energy systems and new business models. These business models are related to the development of new energy services leveraging the integration of digital and energy technologies (Camarinha-Matos 2016).

Several authors (Mancarella 2012; Calvillo et al. 2016; Kylili and Fokaides 2015) emphasized the integration of new energy services in smart cities by leveraging ICT. Based on the intelligence and communication made possible by ICT (Calvillo et al. 2016), the lines between energy generation, storage, infrastructure, facilities, and mobility are fading into integrated networks of distributed energy (Mancarella 2012; Calvillo et al. 2016). Lund et al. (2017) discussed the multi-sector, integrated “smart energy system” as a paradigm shift leveraging sub-sector synergies for combined energy services. Such synergies may be across electricity, heating, cooling, and mobility (Mancarella 2012; Calvillo et al. 2016; Kylili and Fokaides 2015; Lund et al. 2017).

Biofuels such as woody biomass have been widely discussed in the literature as useful in the generation of several energy services, or polygeneration (Kylili and Fokaides 2015; Proskurina et al. 2016; Jiang et al. 2017; IEA 2018; Arasto et al. 2017; Mangoyana and Smith 2011; Mancarella 2012). Utilizing the heat from woody biomass through CHP systems is important for enhanced energy and cost efficiency (Proskurina et al. 2016; Jiang et al. 2017; IEA 2018). For instance, biomass boilers installed onsite can locally generate power and heat, and potentially be combined in hybrid systems, such as with solar PV (Kylili and Fokaides 2015). Woody biomass-fueled polygeneration is comparable with the multi-generation capacities advocated in smart energy systems, as discussed by Lund et al. (2017) and Mohammadi et al. (2017). Mohammadi et al. (2017) further highlighted automated monitoring, optimization, communications and advanced applications as key elements in such energy systems. Smart CHP systems, for example, can be facilitated by smart grids, and optimized based on accumulators, district heating network flows, thermal storage, and heat/electricity from prosumers (Arasto et al. 2017). There is abundant literature on smart energy systems. However, there seems to be lacking of literature combining discussions on smart technologies throughout the woody biomass supply chain.

Socioeconomic dimension

While technological development is pivotal for decarbonization (Zhang et al. 2017), the deployment of smart technologies faces a series of challenges including regulatory barriers, economic incentivization (Mancarella 2012; Calvillo et al. 2016; Mangoyana and Smith 2011), and public management (Kylili and Fokaides 2015). As emphasized by Nam and Pardo (2011), while sustainability is not an implicit result of smart technologies, they can be drivers of sustainability when coupled with governance and institutional innovation. A form of institutional innovation and urban imaginary is the smart city concept. Yarime and Karlsson (2018) highlighted technological transformations of energy systems as a key component of smart cities in Japan. It is suggested that this concept is of interest to discuss in relation to the woody biomass supply chain.

Numerous authors described the smart city as a development process (Huber and Mayer 2012; Angelidou 2015; Lombardi and Vanolo 2015) which leverages smart technologies and citizen involvement in order to manage urban issues and create new services based on local contexts (Albino et al. 2015). Differing groups of technologies would be required based on various contexts (Yarime and Karlsson 2018; Carvalho 2012). It is suggested that this development process can also contribute to innovation and services in rural areas, facilitating regional development involving both cities and rural communities. Urban–rural linkages can contribute to symmetric economic relationships, knowledge-sharing, and sustainable regional development (Mayer et al. 2016). These linkages can facilitate rural development, thwart rural depletion, and connect rural areas to wider markets (Mayer et al. 2016). Urban–rural collaboration is therefore suggested as valuable in discussions on regional woody biomass supply chains.

Sustainability can be further enhanced with bioenergy systems designed based on local markets and conditions (Mangoyana and Smith 2011; He et al. 2013). For example, bioenergy can expand the market opportunities of local agricultural and forestry professionals (Malico et al. 2016). This may incur competition with existing food and timber production. However, it can be suggested that bioenergy pathways are leveraged to utilize waste such as forest residue, thereby expanding rather than substituting value creation. As noted by Tiilikainen and Birol (2018), forest residues and waste should be utilized for bioenergy after higher value timber products such as pulp and furniture are created. Discussion on the local context in terms of natural, economic and social circumstances would be important in considerations on woody biomass and for context-dependent investment (He et al. 2013).

Cascading and stakeholder synergies

The importance of cascading and stakeholder management across the wood supply chain is frequently discussed in literature. Cascading seems to have no universal definition, but may be referred to as the multiple use of wood resources by also utilizing residues and recycled wood (Mantau 2012) for value maximization in the biomass life cycle (Odegard et al. 2012). Proskurina et al. (2016) emphasized domestic resource use, cascading, and emphasis on logistics for sustainable woody biomass development, as this enables forest and bioenergy sector synchronization. Coupled with higher value products such as pulp and furniture, forest residues and waste should go to bioenergy (Tiilikainen and Birol 2018). For example, in an analysis on a wood supply chain in Maine (USA), harvesting and logging contractor profits were found to rise 34–70% and 3–7%, respectively, if roundwood and woodchip businesses were integrated.

While cascading requires information-sharing across the supply chain, discussion on the use of smart technologies in this context is not seen to a great extent in literature. Carvalho (2012) highlighted the importance of holistic energy supply chain management for downstream power and heat generation efficiency. Bioenergy success depends on stakeholder synergies to support feedstock supplies, finance, technical competence, policy, and technology availability (Mangoyana and Smith 2011). Such synergies may arise with agglomeration in local energy clusters, with benefits including lower transport costs, specialized services, and talent pools (McCauley and Stephens 2012). However, urban agglomeration may also incur a risk of spatial disparities and economic inequalities in rural areas if social and cultural attributes are not sufficiently reflected (Mayer et al. 2016). Nishida et al. (2014) commented on digital disparities between in urban and rural Japan. The authors found that rural areas in the north, mountainous center and coastal south of Japan show lower utilization of ICT (Nishida et al. 2014). This is at times due to poor digital infrastructure and often as a result of mountainous terrain which increases telecommunication investment costs (Nishida et al. 2014). Low density rural areas discourage investment, leading to disparities in Next Generation Access (NGA) networks, mobile phone coverage, and broadband (Salemink et al. 2017). A lack of connectivity impedes socioeconomic development as it prevents information-sharing and innovation in production processes (Salemink et al. 2017).

In decreasing the urban–rural digital dive, a community-based approach focusing both on increased connectivity and inclusion of societal members would be important (Salemink et al. 2017). Community engagement, for example, may be carried out via outreach, training, extension programs, and courses (Nishida et al. 2014; Salemink et al. 2017). Community engagement can also be critical for the supply chain linkages and synergies needed for bioenergy (Mangoyana and Smith 2011). Considering the stakeholder complexity and importance of stakeholder management in woody biomass supply chains (Whalley et al. 2017; Welfe et al. 2014), applications for smart technologies would be of interest to explore further. The increasing flow of data and knowledge is influencing social and economic relationships and interactions in new "sociotechnical configurations" (Del Giudice et al. 2016). ICT and capabilities such as cloud computing and social media applications are useful in supply chains, for knowledge-sharing, buyer–supplier relationship management, and digital electronic markets (Scuotto et al. 2016). ICT is increasingly enabling networked as opposed to linear supply chains (Kache and Seuring 2017), leveraging real-time data to connect stakeholders and integrate resources for improved services (Bifulco et al. 2016). There is at present a gap in this regard in biomass literature.

Methodology

The aim of this paper is to contribute to bioenergy discourse by highlighting opportunities for smart technologies to facilitate regional woody biomass supply chains. An exploratory, pragmatic approach was adopted due to the lack of published research on this topic. A simplified overview of this approach can be seen in Fig. 2. Structured interviews were carried out with 20 experts from academia, industry and government in the fields of forestry, woody biomass, and/or smart technologies. Expert interviews are useful in exploratory approaches to gather data and orientate in relatively uncharted fields (Bogner et al. 2009). An expert can be referred to as an individual with technical achievements or professional expertise, and that influences present material or social environments (Giddens 1990). The interviewees of this study and their affiliations can be seen in the Acknowledgments. Interviewees based in various parts of the world (Japan, Austria, Sweden, Germany, Italy, Denmark, Canada, Italy, and the United States) were selected to garner various perspectives. Initial selection was based on the network of the authors and on internet searches of experts with demonstrated knowledge (e.g. publications, presentations). Additional interviewee recommendations were also gathered from interviewees, in so-called snowball sampling, which is useful in accessing a broader circle of experts (Littig 2009). Potential limitations of the paper are the low number of interviewees and a lack of a more diverse expert network, for example from the African or South American continents. The number of interviewees sufficient for qualitative research depends on the research purpose, such as analyzing commonalities or contrasts (Baker and Edwards 2012). The purpose of the interviews was to gather experts' insights to form an initial understanding of the potential of smart technologies in the woody biomass supply chain. The 20 experts were considered sufficient in gathering such preliminary insights.

The interviewees were asked to discuss how smart technologies may contribute to woody biomass and to overcoming each of the five challenges of woody biomass in Japan identified by Ahl et al. (2018). A structured interview outline was used, with open-ended questions enabling interviewees to share detailed information, viewpoints and experiences (Turner 2010). The outline can be seen in Appendix 1. Six interviews were carried out face-to-face and, due to schedule and geographical limitations, nine via conference call and five via email correspondence. Email interviews potentially inhibited more in-depth communication and discussion. However, as noted by Meho (2006), email interviews can facilitate qualitative investigations, and be a good substitute when there are barriers to face-to-face and telephone interviews. Correspondences were in English.

There was a risk of interviewer and confirmation bias in this study. To reduce such biases, interviews were structured based on the same outline and with open-ended questions. Transcripts were analyzed based on an inductive, bottom-up coding approach. Codes extracted from qualitative data in open-ended interview transcripts can reflect various perspectives and reduce researcher bias as opposed to pre-coded interviews (Turner 2010). Content analysis benefits from both qualitative and quantitative approaches to avoid restricting to numerical representations of phenomena and to avoid bias through solely impressionistic interpretations, which is a common criticism of qualitative analyses (Krippendorff 2004). Operationalizing knowledge in qualitative data based on quantitative analysis can include identifying frequencies of concepts and words (Krippendorff 2004). In the current study, word frequencies were found in aggregated interviewee replies related to how smart technologies can be utilized in managing each of the five identified challenges of woody biomass. With stop words such as "a", "the", and "on" removed, words of frequencies above two were derived, shown in Table 2 in Appendix 2.

To complement this quantitative overview, qualitative analysis was carried out based on collocation and concordance. Collocation of key words and associated words in qualitative data is useful to explore meaning and create "textual and cognitive bridges" between the original statements and any developed theory (Mello 2002). This also facilitates

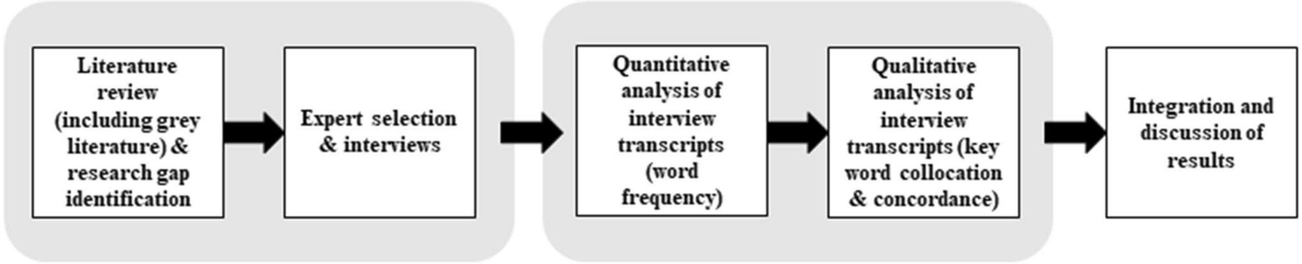


Fig. 2 Flow diagram illustrating the exploratory approach of this study

maintaining narrative integrity in analysis (Mello 2002). Concordance analysis involves identifying key words in context (KYIC), and is valuable in discussions on key concepts and identifying diverse word senses (Krippendorff 2004). The key words which were among the top five frequencies in aggregated interviewee responses for each challenge were identified. These key words were shown in collocation diagrams for each of the five challenges, and concordance was explored. In each collocation diagram (Figs. 3, 4, 5, 6, 7), black boxes were used to represent key words among the top five frequencies in interview results for each challenge, white boxes indicated associated words, thick lines showed links between key words and thin lines showed links between associated words. The collocation diagrams enabled a visual representation of interview results, and served as a basis for systemic analysis and discussion. Word frequency, collocation, and concordance analysis were done using the open source text-analysis and data-mining platform, Voyant Tools (Sinclair and Rockwell 2018). Similar methodologies for qualitative analysis and text-mining can be seen in Mårald et al. (2016) and Rasid et al. (2017). In addition, the interview transcripts were thoroughly read to identify similarities and dissimilarities of interviewee opinions and any further interpretations.

Results of exploratory analyses

Transportation infrastructure

The collocation of key words in responses to how smart technologies can be used for the challenge of transportation infrastructure related to harvesting and logistics in the upstream woody biomass supply chain can be seen in Fig. 3. The interview results center on forestry and digital services leveraging access to more accurate information. Examples of services include optimized route-planning leveraging mapping via drones and satellite imagery, and digital forest management leveraging virtual reality (VR) systems. Gingras and Charette (2017), and Roßmann (2011) similarly discussed VR and augmented reality (AR) for forestry support and training. For the long term, interviewees discussed the potential of increased access to data and mapping to facilitate partial or full automation in the supply chain, such as via robotics for fertilization and harvesting, and autonomous vehicles.

A step prior to automation may be to leverage digital technologies to optimize transportation tracks, routes and logistics. Information can be shared across the supply chain to increase the overall productivity of logistics, for example, by leveraging data on forest conditions, weather, and market demands in harvesting decisions. Drones and satellite imagery for improved GIS and 3D-mapping may facilitate accurate, digital depictions of the forest. This is progressing in some areas in Japan. For example, in the Gifu prefecture, open forest GIS data is available, such as on tree species and zones (Gifu Prefecture 2019). Data entered into GIS systems requires regular updating (FGIS 2019), and advances in remote-sensing may contribute in this regard. Improved forest-mapping may facilitate route-planning, harvesting and reforestation practices, and in the future potentially enable automation. For example, “digital technology can enable utilizing more capacity of transport tracks.” Transportation plans for drivers can be improved, and track-sharing among forest enterprises may be coordinated. Transportation costs are high for timber and “…we need a planning system for that, for routing optimization.”

Interview results indicate that digital depictions via remote-sensing can facilitate the identification of properties for more effective forest management even on an individual tree-level. In this way, digital services for forest owners would not only be on a broad forest level, but even with “fine-grained control on individual trees and their properties.” Accurate digital representations of reality can aid in harvest and transportation optimization based on both volume-trading and each tree’s quality—feeding back to biomass quality monitoring and control discussed further in “Biomass quality monitoring and control”. The potential of integrating optical and radar data for effective remote-sensing for forest-mapping was also highlighted by Lu et al. (2016) and Sinha et al. (2015)

With improved mapping, information-sharing and data analytics, automation is a potential next step for harvesting and transportation intelligence. “If robots can do it (bring timber from the forest) safely and at a low cost this can bring a lot of value to the supply chain.” Connected and autonomous machinery and vehicles can support route-planning, harvesting, and transportation efficiency, when integrated with accurate forest databases. One interviewee noted that “the world of autonomous vehicles is important… Connected vehicles allow you to look at larger infrastructure on how to do routing.” Automation may also enhance work safety among foresters.

While smart technologies have potential to contribute to harvesting and transportation, there may be socio-economic barriers to such deployment. One interviewee noted that there are several small-scale forest owners (2–5 ha = 0.02–0.05 km^2) in Japan, which are not actively engaged in forest management and may not have financial capacity nor skills to develop infrastructure. Forest associations may be one solution to aggregate forest owners for co-investment and co-learning. Educational communities may also contribute in this regard. For example, Forest GIS Forum is a community for knowledge-sharing among forest managers, forest researchers, and GIS experts across Japan (FGIS 2019). Collaborative learning is an important element for knowledge transfer in multi-stakeholder contexts

(McCauley and Stephens 2012; Barile et al. 2018). As put by one interviewee on the context of Japan, "to get things going we need to convince people to invest in something new, to manage the forest in more effective ways, or even just to think about conducting forestry business in the first place."

Biomass quality monitoring and control

The interview results for the challenge of biomass quality monitoring and control are illustrated in Fig. 4. These results centered on efficient woody biomass quality management throughout the supply chain by leveraging upstream to downstream assessment, tracking, and real-time information-sharing. Interview results indicated that when coupled with smart technologies for information-sharing, accountability and transparency, woody biomass can be more effectively controlled and managed for quality parameters. Open data on quality parameters can facilitate knowledge-sharing and management of quality variability across the supply chain. "Have them (parameter data) publicly available for knowledge-sharing of that variability… This comes back to communication and easily connecting." Interview results show that especially information on moisture content would be needed earlier in the supply chain and in real-time. "Drying is expensive. If we can monitor the moisture and quality of timber more effectively, we can optimize this process and make it more cost-efficient."

Smart technologies can contribute to quality assessment throughout the supply chain. Interviewees noted that data collected via satellite imagery and/or drones coupled with image analytics can also contribute to quality control by analyzing the forest, from tree ages to disease conditions. "Resource assessment technologies, such as laser-scanning, are useful to understand the forest resource conditions and terrain conditions." Multi-source remote-sensing systems, incorporating both optical and radar data, can contribute to efficient and accurate measurement of forest biomass parameters (Lu et al. 2016; Sinha et al. 2015). Especially radar data, such as SAR, or laser-scanning would be important for measurements on moisture content (Sinha et al. 2015). With the development of multispectral or hyperspectral drone images, the chemical and structural properties of individual trees, such as moisture content, may also be accurately mapped (Zhang et al. 2016). An interviewee similarly noted "satellite imagery or drone laser-scanning" for mapping forest resources in GIS systems.

Interviewees further noted image analytics for the measurements of size and volume of timber and biomass. "Measurement of logs is manual and paper-based in Japan. If we digitalize this, we can improve efficiency. If we utilize photos, based on image data we can calculate the diameter or volume, and this would be very helpful for us." Analytics can be further improved via AI for decision-making support, and via IoT for digital tracking, timber information-sharing across the supply chain, and decision-making guidance. Sensors and timber-tagging systems could lay a basis in such systems, which in turn can enhance accountability. "To prevent fraud you can use different types of due diligence and traceability…by reading sensor information on quality control points in biomass products." Smart technologies may simultaneously contribute to both quality control and trust.

Interview results indicate the importance of value traceability and classification at each point of wood conversion. "Having a classification system in place for biomass quality is necessary to properly assign a value to that biomass, establish the market structure, and reference values for different grades." Digital tracking and sharing of standards, certifications, and prices were noted as potential drivers of woody biomass quality control. This would benefit from an established market structure and price incentives. "We need price incentives for upstream suppliers to manage moisture content. This would need information-sharing and supply chain transparency." At present, "biofuel of varying quality can be sold at the same price on the market." A potential technology noted in the interview results for supply chain, contract, and certification traceability is blockchain.

It is important to also note that while smart technologies materialize several opportunities, education and know-how related to biomass quality and bioenergy plants would be necessary. "Of course it's (smart technologies) good for that, but here trained people is also an issue." ICT platforms would also need to be facilitated by community engagement, collaboration among stakeholders, and feedback on ICT tools (Mirembe et al. 2018). As shown in the interview results, the management and development of stakeholder skills in the supply chain would be important in digitalization efforts. As put by one interviewee, "…there might be guidance from IoT for work flow… but we need skills and a shift in education for any digital transformation in an IoT realm." Scuotto et al. (2016) similarly discussed a need for skill development if ICT is to be integrated in supply chain management, especially that of small and medium-sized enterprises.

Business model integration (cascading)

The interview results for the challenge of business model integration and cascading, as shown in Fig. 5, center on ICT leveraging remote-sensing and real-time data-sharing across the supply chain. Information-sharing on material flows and prices can facilitate traceability, trust, and even automation among businesses in the supply chain. "ICT… Sensors, robotics. We can have an automation process based on algorithms… Optimizing systems like this would help to build trust as well." For example, RFID-tagging can support automatic tracking, traceability, and wood supply chain management (Tzoulis and Andreopoulou 2013). Ciccarese et al. (2014) further noted the use of sensors as well as robotics for higher accuracy and speed in wood-, waste-, and residue-sorting. This may contribute to cascading of wood products in local or regional networks of enterprises (Ciccarese et al. 2014).

With supply chain transparency, interviewees noted that upstream suppliers may better understand downstream prices and demands (and vice versa), facilitating planning and operations. Several authors have noted the potential of cyber-physical processes to facilitate more agile responses based on upstream supplies and downstream demands, by leveraging IoT and cloud-computing (Gingras and Charette 2017; Kies and von Lengefeld 2018). Improved wood supply chain traceability can support production process improvements, business partnership developments, and stakeholder communication (Tzoulis and Andreopoulou 2013). "Individualized production" and maximized value creation among forest wood products may be possible with "high value components" more effectively targeted to "high value markets". One interviewee noted that, "bioenergy is a part of bio-based economy…there will be more and more products, and then at the end it (biomass) is used for heat and power." Via cascading in a broader wood market, a bio-based economy can enable cost-effectiveness, economic development, and climate change mitigation (Arasto et al. 2017; Brewer et al. 2018).

In interviewee discussions on potential bio-based economies, bioenergy was linked to local policy, local people, domestic forest resources, and wood markets. Local policies would be important as they can promote bioenergy in myriad ways, such as for local heating. For local people, "positive value needs to be recognized by local people, such as the beauty of local resources." This may be communicated via pictures and other methods of visualization of, for example, potential local effects of climate change. Pictures may tap emotional values to instigate change in rural areas (Mayer et al. 2016). Domestic forest resource management was discussed in terms of quality parameters, health, and reforestation processes. "Management of forest resources in Japan is still an underdeveloped area which would require further cooperation of forest owners, foresters, administrative agencies, and logistics companies". ICT platforms offer a potential pathway to enable cooperation via information-sharing, communication channels, and partnership-building. A key driver of bioenergy success is stakeholder synergies (Mangoyana and Smith 2011). Social networks and communication can support change in incumbent systems by identifying and supporting synergies (McCauley and Stephens 2012).

In terms of wood markets, interview results indicate that information transparency by leveraging ICT can improve and even automate decision-making as to picking the "right biomass pieces for right markets." With improved demand and price data, forest plantations, harvesting and reforestation practices may be planned in a more informed manner and gradually automated. Downstream, automated dispatch of biomass can also be coupled with other energy resources. "Using digital technology you can store woody biomass and in real-time you can channel that energy and reduce excess solar or coal." Similarly, Jiang et al. (2017) indicated the potential of backup biomass capacities to contribute to energy-balancing in urban renewable energy systems.

From the social perspective, the interviewees also indicated a need to initially expand on skills, such as of ICT, and entrepreneurship for innovation across the wood supply chain. Bioenergy was discussed as a sector which has somewhat lagged behind in data-processing and analytics. "Data and ICT can help bring up-to-date information to the market, and enable telling stories on what is happening." Another interviewee noted that "data on bioenergy is not collective, and without this we cannot have metadata and understand general trends to enable innovation." Data management and sharing may contribute to decision-making and innovation for woody biomass. However, the high dependence on paper in Japan may be an issue. In this context, rural entrepreneurs may aid in bridging divides for urban–rural linkages by facilitating innovation, maintaining knowledge on market developments, and evaluating assets (Mayer et al. 2016). Rural entrepreneurship involves creating a "new organization that introduces a new product, serves or creates a new market, or utilizes a new technology in a rural environment" (Wortman 1990). An example of such is Irodori, a local enterprise in Kamikatsu (Shikoku, Japan), which built a brand and market for decorative leaves to garnish traditional Japanese cuisine (Haga 2018). The local context and stakeholders in the forestry sector would be important initial considerations prior to decision-making on technological system advancements, discussed further as follows.

Building stakeholder respect, relationships and trust

The collocation of key words in responses to how smart technologies can be used for the challenge of building stakeholder respect, relationships and trust can be seen in Fig. 6. The interviews centered on ICT services for communication and increased transparency across the supply chain. Here transparency is linked to the tracking and availability of information of material flows and prices in the supply chain. This may in turn contribute to stakeholder trust between the supply and demand sides. "ICT can increase transparency. Transparency increases trust."

Forest is the most frequent word and is linked to people, forest owners, and wood for energy purposes. Interviewees indicated that GIS, a database of information related to the forest, and digital forest certification may increase accountability and visibility in wood material-tracking and monitoring. “Certification is traveling along the supply-chain. And bringing it digitally via ICT services, this could be very helpful for tracking services…”. Interviewees pointed out that largely paper-based tracking incurs higher risks of faulty data or fraud. With digital systems, increased transparency is suggested as a means to avoid fraud and enhance trust. Downstream players can be empowered via access to information on forest resources and material flows. For example, this transparency can shed light upon due diligence on sustainability practices and compliance across the supply chain.

The tracking and sharing of data related to fuel origins and sustainability compliance in electricity production was also noted. “Recently tracking systems for electricity have become important… for a Guarantee of Origin (GoO)…”. Several digital technologies may contribute to tracking across the supply chain. For example, cryptographic GoOs on blockchain platforms can enable more fraud-resistant certification and tracking of participants and balances (Castellanos et al. 2017). The Spanish government, for example, has set up an operating group called “ChainWood” to develop a cloud-based software leveraging blockchain, big data and machine learning for traceable and efficient wood supplies (FAO and ITU 2019). Interviewees noted that the tracking and sharing of wood information is limited in Japan. There has been no development, to the authors’ knowledge, of blockchain for wood supply chain traceability in Japan. However, this has been explored in other sectors. For example, private corporation iSiD (2016) is testing blockchain for enhanced traceability of organic agricultural products in the Miyazaki prefecture of Japan, to reassure customers of origin and food safety. Blockchain may be used in similar ways to provide GoOs for timber and biomass products. Enhanced information-sharing may facilitate compliance, coordination and transparency for a more interconnected supply chain. “The more you move into an industrial environment, you need to communicate easily between groups and understand issues and each step of the process because they are so interconnected.”

The interviews also emphasized the potential of supply chain transparency and price visibility to stimulate market competition. There is a price awareness gap between forest owners and the downstream wood supply chain in Japan. “Forest owners do not have the means to track their timber after production and sales. Owners should learn how the wood is used in the downstream and the real value of the wood.” With more visible supply chain material flows and prices, “forest owners may more easily find value on the market”. ICT may contribute to more uniform information across the supply chain and price transparency in a digital market platform. Such a platform could be leveraged for incorporation of market demands in harvesting decisions, discussed in “Transportation infrastructure”, and of price incentives for biomass quality control, discussed in “Biomass quality monitoring and control”. This may empower suppliers, and “this kind of transparency can also enable better relations among stakeholders.” Similarly in Europe, market transparency and price mechanisms have been important points for bioenergy development (Vinterbäck and Porsö 2011). Open availability of current and historical wood fuel prices can contribute to this transparency (Vinterbäck and Porsö 2011). Scuotto et al. (2016) found that inter-organizational ICT platforms or “electronic markets” can support communication, increase trust, and reduce coordination costs. Thereby, such platforms can facilitate stakeholder relationships, interaction, and knowledge-sharing (Scuotto et al. 2016; Lopez-Nicolas and Soto-Acosta 2010), as well as support new entrants and the creation of strategic partnerships (Scuotto et al. 2016).

While smart technologies can contribute to transparency, its implementation may face both technical and social issues. One interviewee highlighted that “having a solid network in place to guarantee real-time communication between forest operations and market demand is key to success.” Gingras and Charette (2017) similarly highlighted a potential lack of network coverage in more remote forest areas, inhibiting smart technology utilization. A possible solution is shared communication infrastructure jointly developed by telecom providers and energy companies for the creation of mutual benefits (Camarinha-Matos 2016). In addition to technical issues, there may also be social challenges related to the collaboration needed to integrate ICT and data-tracking across the woody biomass supply chain. Interviewees noted that ICT capacities are not proficient in rural areas, and that building trust cannot depend on digital solutions alone. “ICT can contribute and support this a lot but finally we cannot replace personal contact.” When discussing communication, some interviewees highlighted that stakeholders, especially in forestry, may prefer direct as opposed to digital communication. Lopez-Nicolas and Soto-Acosta (2010) further noted the difficulty of formalizing tacit knowledge, and that a potential way forward is to integrate face-to-face interaction with communicative and workflow-oriented ICT for knowledge-sharing among supply chain stakeholders.

Social challenges of smart technologies in the forest sector may also include traditional cultures and a weak use of ICT coupled with a lack of research and development (Kies and von Lengefeld 2018). Limited capacities in local firms alongside high-risk perceptions related to new technologies pose challenges to cyber-physical systems (Barile et al. 2018). In addition, issues of trust among diverse stakeholders could limit support for innovation in terms of niche activities and social practices (McCauley and Stephens 2012). Kache and Seuring (2017) highlighted governance, compliance, collaboration, trust and information security as challenges in digitalizing supply chains.

Such challenges emphasize a need for local community engagement to understand risk perceptions and co-develop new systems. The importance of community engagement can be seen highlighted in the interviews. “You need to build trust and a sense of connection… building better supply chains and show where they (community) impact the system. This could be through digital media.” Engagement may affect awareness and institutions which in turn can facilitate sociotechnical change (McCauley and Stephens 2012). A “buzz” of sustainable energy activities, meaning a collective learning process based on rumors, impressions, and recommendations, may also aid in trust-building (McCauley and Stephens 2012). As put by one interviewee, “To really bring projects further and mobilize people we need meetings, workshops…. Get people involved with discussion.”

Local community revitalization and socioeconomic development

The interview results on how smart technologies can facilitate local community revitalization and socioeconomic development are illustrated in Fig. 7. These results are centered on rural socioeconomic development leveraging local supply chains. Local bioenergy is tied to people and revitalization of rural economies. It was noted that regional woody biomass supply chains can contribute to avoiding costs of long-distance transportation, enable green energy, and increase value created in rural areas. Based on local heat demands, CHP was given as a pathway for local wood resource use, economic development, and energy security. On the community level, an interviewee highlighted that small-scale local wood supplies can be aggregated for either combined wood-chipping or mobile chipping upon harvest. Community ownership and investment models can indeed strengthen synergies among local stakeholders (Mangoyana and Smith 2011).

A key issue discussed by interviewees is how local resources can be effectively managed and create value, and how ICT can facilitate this. “Utilization of forest resources will lead to the promotion of autonomy by revitalizing regional economies. In the strategy for resource utilization, it is necessary to position ICT.” ICT can be useful to optimize supply chains and business practices for bioenergy, for example, based on the species, distribution, and quality of trees. Integrating material production and energy systems based on wood residues can enable more efficient value chains. In this integration, ICT can support decentralized systems via market platforms to connecting consumers to dispersed suppliers. “Local people (in Japan) do not have access to market tools, and can therefore not assess their value in their community”. It is suggested that digital market platforms would be useful when constructing local supply chains, and in enabling decision-making and connectivity among small-scale business owners. Such platforms, or “electronic markets”, can reduce management costs and encourage new entrants, including small and medium-sized enterprises (Scuotto et al. 2016). This is relatable to the discussions on digital market platform in “Building stakeholder respect, relationships and trust”. An example shared by an interviewee is the online platform eTree: an open wood market for small-scale manufacturers in Japan (eTree 2018).

Digitalization may contribute to innovation in the forest sector and revitalization of rural economies. “Currently Japanese startups or venture companies are not interested in the forestry sector… Digitalization can enable new innovative businesses to support socioeconomic development.” However, as noted by Nishida et al. (2014), there is an urban–rural divide in terms of digitalization and connectivity in Japan. This divide may obstruct socioeconomic progress if not overcome (Salemink et al. 2017). It would be important to develop connectivity in rural areas, as well as manage community engagement and digital skill-building (Salemink et al. 2017). Enhanced digital connectivity may also attract human capital to rural areas, and can be linked to regional economic development (Salemink et al. 2017). Several interviewees also commented on potential urban-to-rural migration of software engineers and other technical staff. “The future of work in urban and rural areas can be changed to a more dynamic city-rural interplay.” This is relatable to the potential of urban–rural linkages to facilitate economic relationships and sustainable development (Mayer et al. 2016).

How could such migration be incentivized? In a study by Melo and Ames (2016), an increase in wages coupled with technological development was given as key policy direction to encourage urban-to-rural migration for agriculture in China. Such mechanisms may also contribute to local socioeconomic development in Japan. Public–private biomass investment models can be effective in the long term for the pooling of human resources and capital (Mangoyana and Smith 2011). It would be necessary to “work with the community and also with the local government for infrastructure development as this depends on local management.”

Integrated overview and policy directions

Findings of expert interviews indicate smart technologies and mechanisms by which they can contribute to overcoming challenges in the woody biomass supply chain. An overview of the smart technologies and mechanisms by which they were suggested by experts to contribute to overcoming each challenge is shown in Table 1. At large, the interview results centered on forest resources, and value creation in

Table 1 Interview findings on smart technologies and mechanisms by which they may contribute to overcoming challenges in the woody biomass supply chain in Japan

Challenge	Mechanisms	Technology
Transportation infrastructure	Transparency, information-sharing, communication, process efficiency	ICT + sensors
	Value maximization, process efficiency (harvest and transport), safety, cost reduction	Robotics, autonomous machines
	Safety, efficiency, harvest planning, accurate assessment, 3D-mapping, route-planning and optimization, cost reduction	GIS + remote sensing (optical data + laser scanning from drones/satellites)
	Safety, awareness, learning, training, forest management	VR
Biomass quality monitoring and control	Transparency, information-sharing, communication, accountability, fraud prevention, digital certification, material-tracking, market platform, accurate assessment, process efficiency	ICT + sensors
	Accurate assessment, process efficiency	Image analytics
	Accurate assessment, process efficiency, forest management	GIS + remote-sensing (optical data + laser scanning from drones/satellites)
	Transparency, traceability, fraud prevention, material-tracking	Blockchain
	Material-tracking, accurate assessment, process efficiency	IoT
	Decision support, process efficiency	AI
Business model integration (cascading)	Transparency, information-sharing, communication, visibility, material-tracking, market platform, value maximization, traceability, collaboration, informed planning	ICT + sensors
	Accurate assessment, information-sharing, forest management, informed planning	GIS + remote-sensing (optical data + laser scanning from drones/satellites)
	Automation, value chain optimization, process efficiency	Robotics, autonomous machines
	Process efficiency, awareness, learning	Image analytics
	Material-tracking, collaboration, informed planning	IoT
Building stakeholder respect, relationships and trust	Transparency, information-sharing, communication, visibility, accountability, fraud prevention, digital certification, material-tracking, market platform	ICT + sensors
	Transparency, information-sharing, accurate assessment	GIS + remote-sensing (optical data + laser scanning from drones/satellites)
	Transparency, traceability, accountability, fraud prevention, material-tracking	Blockchain
Local community revitalization and socioeconomic development	Transparency, information-sharing, communication, accurate assessment, material-tracking, value maximization, process efficiency, market platform, informed planning, knowledge-sharing	ICT + sensors

AI artificial intelligence, *ICT* information and communication technology, *IoT* internet of things, *GIS* geographic information system, *VR* virtual reality

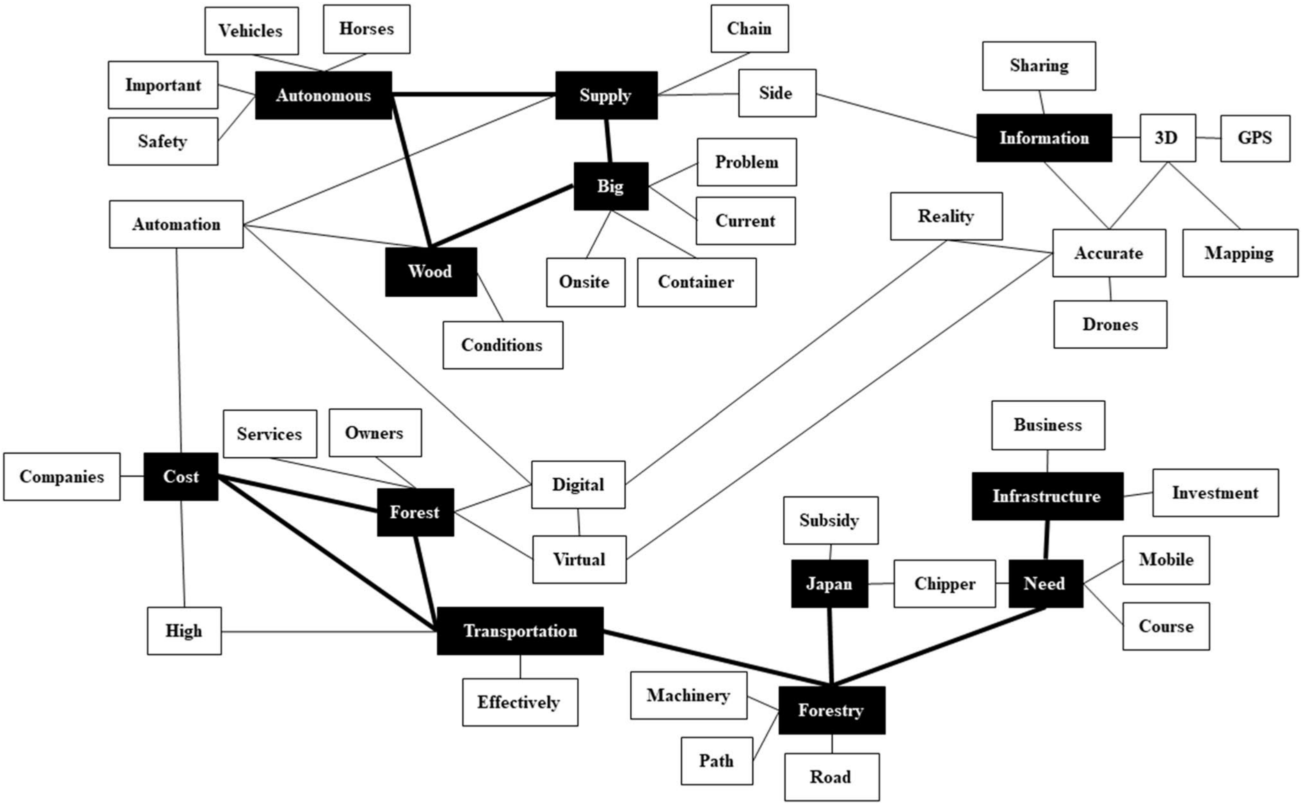


Fig. 3 Collocation diagram of responses to how smart technologies can contribute to overcoming challenge: transportation infrastructure (*GPS* global positioning system)

local supply chains leveraging data, ICT, and information-sharing. The development of a digital market platform was also mentioned as a mechanism to overcome multiple challenges, such as for cascading and trust-building. The smart technologies and mechanisms often overlap as applicable across both technical and social challenges. The technologies included in Table 1 are based on emphasis given by experts, with an aim to provide an initial overview of potential mechanisms for woody biomass supply chain development. The implementation of proposed technologies would depend on local context and would not be without challenges. Some technologies, such as GIS, are relatively developed. Others, such as blockchain or autonomous machines are emerging and pose technical, economic, and regulatory uncertainties. This calls for further studies, for example on technical or economic feasibility. In addition, the availability of personnel with skills to develop, implement and maintain new technical systems is of critical importance. The presence of such challenges indicate a need of an integrated and multi-faceted approach. Potential policy directions and change mediation are of interest to discuss further.

Attention to stakeholders, and their objectives and skills, was emphasized by experts. While approaches to sustainability tend to be techno-centric, key drivers include both technology and humans (Barile et al. 2018). When incorporating smart technologies, it would be important to consider local context and capacities, such as available infrastructure, social capital and skills. Renewable energy is dependent on political and societal aptitudes to adopt new technologies (Lund et al. 2017). There are several opportunities of smart technologies in the woody biomass supply chain. However, supporting domestic biomass prospects and innovation requires stable (Proskurina et al. 2016; Jiang et al. 2017; Brewer et al. 2018) and targeted policies to leverage opportunities and tackle challenges (Welfe et al. 2014).

Policy development is of relevance for Japan. As put by an expert, “Japanese forestry is highly subsidy dependent with forest management costing a lot.” Another expert noted a need for enhanced market competition for forestry and bioenergy: “We need to move away from subsidies and more to the private sector… The FITs are in the power market, and do not stimulate much market competition.” It

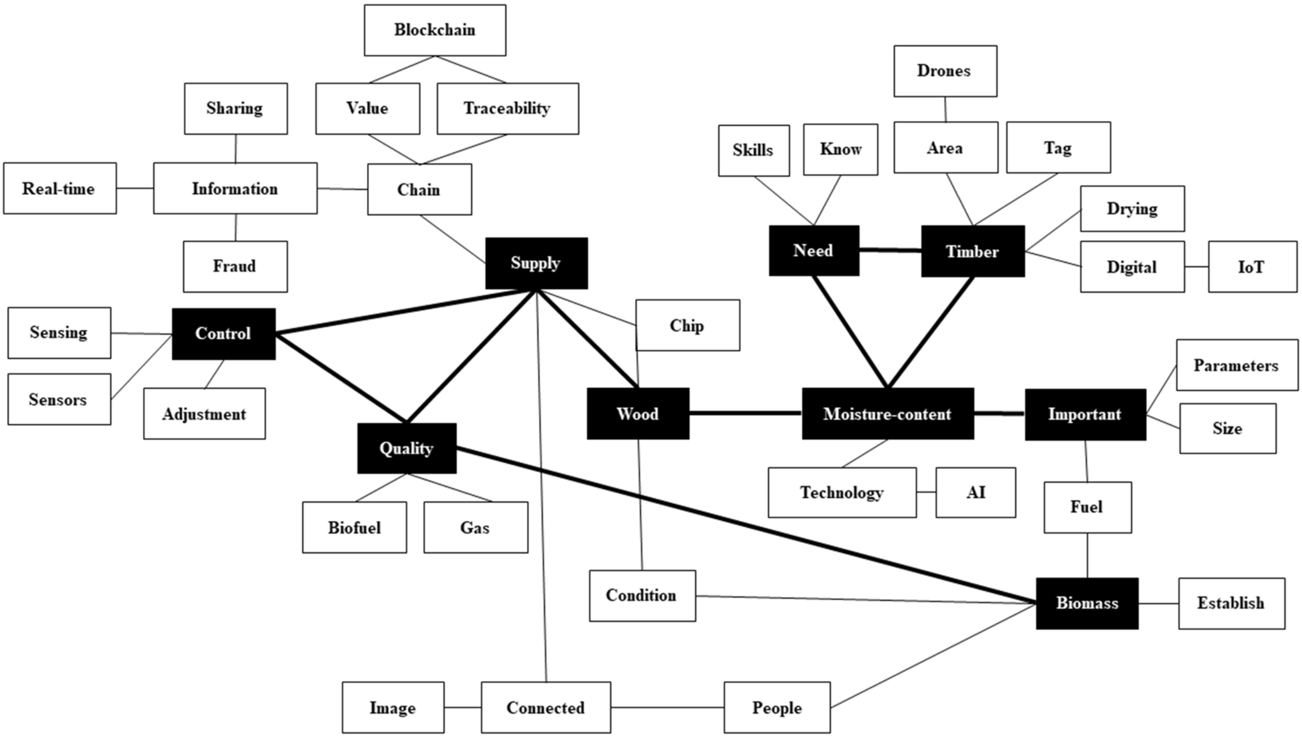


Fig. 4 Collocation diagram of responses to how smart technologies can contribute to overcoming challenge: biomass quality monitoring and control (*AI* artificial intelligence, *IoT* internet of things)

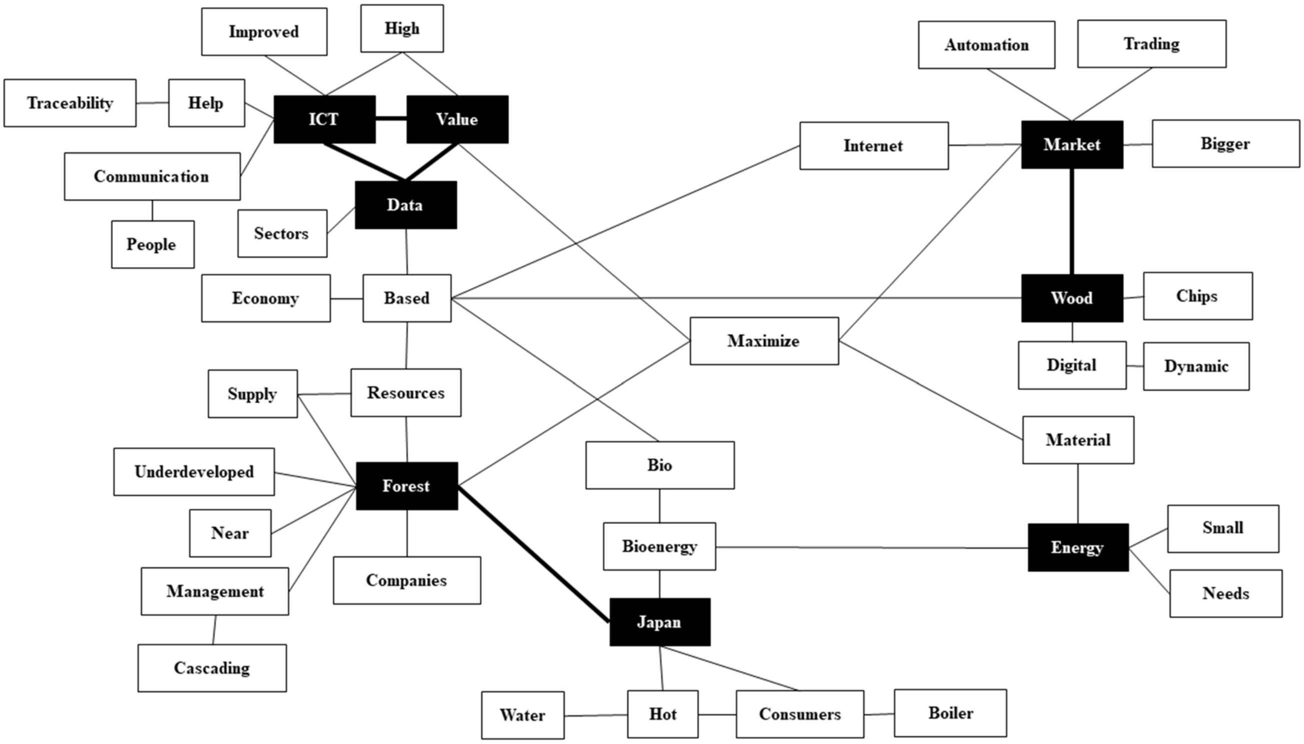


Fig. 5 Collocation diagram of responses to how smart technologies can contribute to overcoming challenge: business model integration (cascading) (*ICT* information and communication technology)

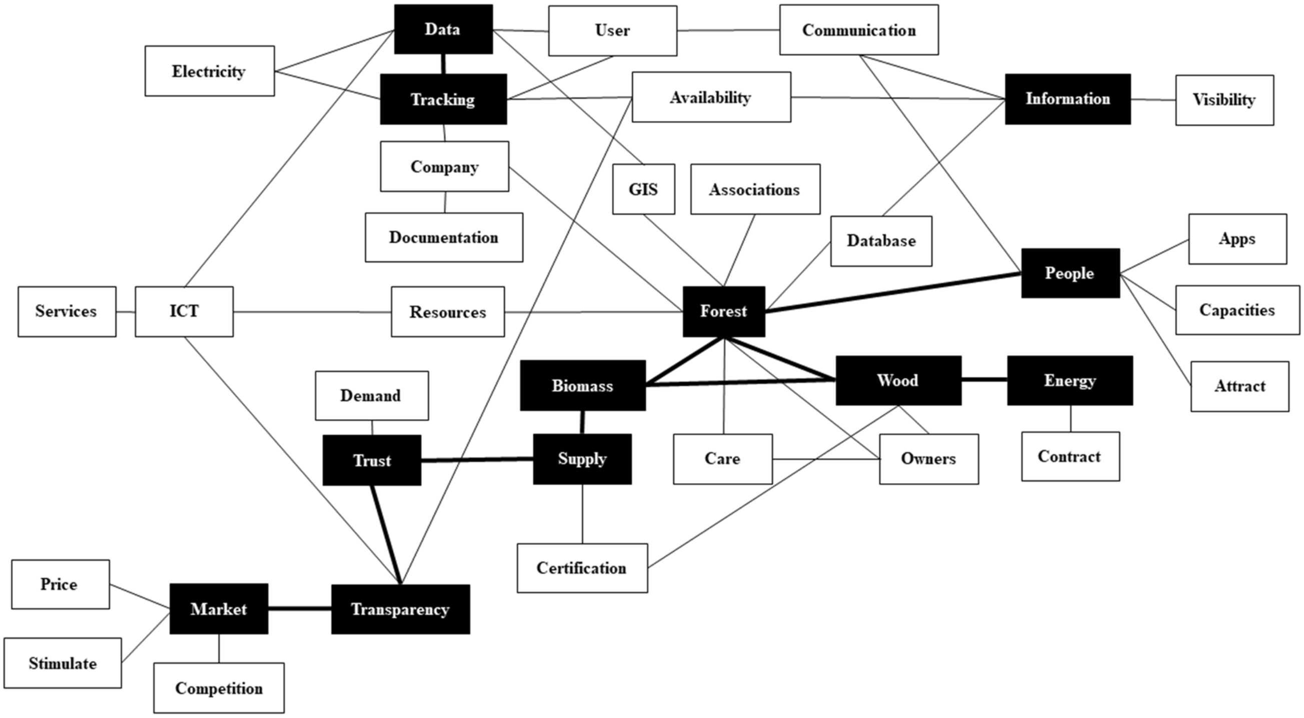


Fig. 6 Collocation diagram of responses to how smart technologies can contribute to overcoming challenge: building stakeholder respect, relationships and trust (*ICT* information and communication technology, *GIS* geographic information system)

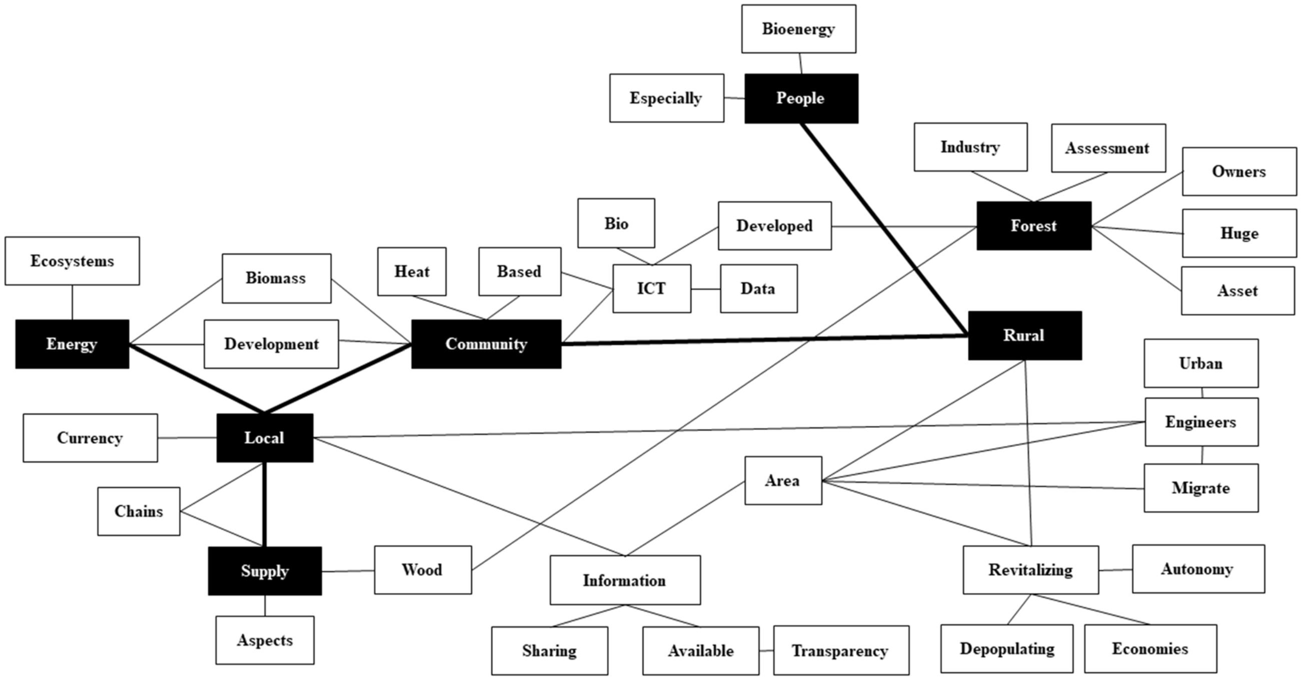


Fig. 7 Collocation diagram of responses to how smart technologies can contribute to overcoming challenge: local community revitalization and socioeconomic development (*ICT* information and communication technology)

can be suggested that increased competition can encourage innovation among woody biomass players, which may in turn lead to an increase in smart technology uptake. Entrepreneurial experimentation for energy innovation can be further promoted in Japan by advancing market liberalization, business models that are independent of public financing, capacity-building, and standard-setting for hardware and software (Yarime and Karlsson 2018). Supportive institutions would be important for woody biomass innovation via smart technologies.

For change mediation and smart technology innovation, the interviewed experts indicated a need for change agents and regional managers. Mediators, for example, may include rural entrepreneurs, communities, local governments, co-working spaces, and other relevant organizations such as forest associations. This will likely depend on the local stakeholder network and relations therein. Public incentives can be used to encourage rural entrepreneurship, such as tax concessions or employment provisions (Johnsrud 1991). Rural change agents are important both for rural activities and for urban–rural interplays, as they can leverage local knowledge, social capital, and market access (Mayer et al. 2016). In this context, rural entrepreneurs would need to stay updated and maintain contact with both urban and other rural areas, such as through networking events and study clubs (Mayer et al. 2016). It is suggested that such knowledge-sharing and networking can support the development of smart technology applications for domestic woody biomass. An interviewed expert also highlighted that bioenergy stakeholders in Japan "cannot share information of their experiences, whether bad or good," and that knowledge-sharing platforms would be important for the field and any smart technology innovation. In turn, smart technologies can also support such platforms as well as encourage rural entrepreneurs and change agents. In addition, extension agents, typically dispatched from universities to assist in community development, may support change. It can be suggested that agents with knowledge related to smart technologies as well as biomass can contribute to leveraging smart technology opportunities for domestic woody biomass. Agents' activities may involve knowledge-sharing, assisting the formation of local organizations, and acting as a link between the community and government (Oakley and Garforth 1985). For forestry extension programs, Clark (1982) highlighted the importance of bottom-up approaches via participatory planning with local communities, involvement of local organizations such as forest cooperatives, and personnel management.

Experts further noted that renewable energy ecosystems, including biomass, can benefit local economies and energy security. However, difficulties of small-scale energy systems in gaining grid access, transmission and distribution capacities were noted as challenges. Smart technologies offer several opportunities to support distributed energy systems at local levels, such as blockchain technology (Ahl et al. 2019). "Local efforts but also top-down regulation and support" are needed to facilitate regional woody biomass. It can be suggested that integrating bottom-up community-based, and top-down regulations may support socioeconomic development leveraging regional woody biomass and smart technology innovation. Public actor involvement and funding in innovative rural energy and environmental projects can be vital (Esparcia 2014). For example, Esparcia (2014) found that such projects in Europe tend to initially rely on local public institutions, external experts, and funding, and thereafter develop economic self-sustainability. Considering depopulation in rural Japan, bio-based economies supported by smart technology innovation and leveraging such public–private models may offer an opportunity to renew growth and revitalize local economies.

The findings of this paper indicate opportunities for smart technology innovation in the woody biomass supply chain. However, this exploratory approach is limited to previous case study findings in a Japanese region and to the interviews of this study. Woody biomass opportunities and challenges will vary in different contexts, and there is no "one-size-fits-all" solution for sustainable energy (Brewer et al. 2018; Arasto et al. 2017). It can be suggested that a toolbox of technologies based on local context and conditions would be important. The findings of this study can be valuable in exploring initial pathways for smart technologies based on concrete sociotechnical challenges. This study presents exploratory evidence regarding potential pathways for smart technologies in the woody biomass supply chain, with a need for further investigation of such directions in future studies.

Conclusion

As a renewable and dispatchable resource, woody biomass is valuable for energy supply stabilization in energy systems with increasing shares of intermittent resources. Woody biomass is highly dependent on supply chain management, which involves both technical and social challenges. The use of smart technologies is vividly debated among scholars for both supply chain management and stakeholder collaboration. However, potential applications of such technologies in woody biomass supply chains represent a research gap. This conceptual paper set out to explore this gap, and formulate initial implications on how smart technologies can contribute to overcoming challenges in woody biomass supply chains, exemplified by a case in Japan. On the one hand, it was found that smart technologies can incorporate processes of data collection and analysis, communication of the obtained information, and automation across the supply chain. This in turn has potential to contribute to overcoming both technical and social challenges, including transportation infrastructure, biomass quality management, business model integration (cascading), stakeholder relationship management, and local community revitalization and socioeconomic development. This can be facilitated by mechanisms supported by smart technologies, such as information-sharing, transparency, interconnectedness, and value maximization. On the other hand, several smart technologies are still developing with technical, economic, and regulatory uncertainties. A gradual development of a toolbox of technologies can be suggested, based on an integrated approach rooted in local contexts. It would be important to co-develop systems, engage with local communities, facilitate skill-building, and create supportive institutions for sustainable integration of technological systems. Potential policy directions include local participatory planning, public project-funding followed by economic self-sustainability, coordination of change mediator(s), the inclusion of both external experts and local actors, and rural entrepreneurship incentives. While this study presents exploratory findings and a first assembly of aspects, further research would be needed on the nexus of woody biomass and smart technologies. Such research may be related to how smart technologies can contribute to social, economic and environmental sustainability in regional woody biomass supply chains. It is proposed that sustainable development of woody biomass supply chains considering the prospective of smart technologies will be of interest for further investigation both in academia and by practitioners.

Acknowledgements The authors would like to thank the following interviewees for participation in this study (in alphabetical order): Boris Dudder (University of Copenhagen), Christoph Strasser (Bioenergy 2020 + GmbH), Daniel Buchner (DBFZ, Germany), Daniela Thrän (Helmholtz Centre for Environmental Research), David Chiaramonti (University of Florence), Edward Sumoto (Tata Group), Eric van den Huevel (studio Gear Up), Hironao Matsubara (Institute of Sustainable Energy Policies, Japan), Hiroyuki Akiba (Japan Woody Biomass Association), Jonas Brändström (Vinnova), Kohei Izutsu (Sonraku Corporation), Rachel Emerson (Idaho National Laboratory), Shintaro Chono (SymEnergy), Sylvain Volpe (FPI Innovations), Takanobu Aikawa (Renewable Energy Institute, Japan), Takeo Kato (Japan Woody Biomass Association), Tetsuya Maruta (NRI), Victor G. Walker (Idaho National Laboratory), Volker Lenz (DBFZ, Germany), Yoshiki Yamagata (National Institute for Environmental Studies, Japan).

Appendices

Appendix 1

Interview outline

(1) What are some technical challenges you have seen for woody biomass?
    (A) How can they be managed?
(2) What are some social challenges you have seen for woody biomass?
    (A) How can they be managed?
(3) How do you think smart technologies and ICT (information and communication technology) can contribute to woody biomass systems?
(4) Below is a list of challenges in the woody biomass supply chain. For each of the challenges, please discuss: How do you think smart technologies can contribute?

    (A) Building stakeholder respect, relationships and trust.
    (B) Biomass quality control (moisture content, size, etc.).
    (C) Business model integration for higher value creation.
    (D) Transportation infrastructure from forest.
    (E) Local community revitalization and socioeconomic development.

Appendix 2

See Table 2.

Table 2 Word frequency in interview responses for each of the five woody biomass supply chain challenges in Japan

Woody biomass supply chain challenge									
Transportation infrastructure		Biomass quality monitoring and control		Business model integration (cascading)		Building stakeholder respect, relationships and trust		Local community revitalization and socioeconomic development	
Word	*f*	Word	*f*	Word	*f*	Word	*f*	Word	*f*
Forest	20	Quality	19	Forest	14	Forest	26	Local	31
Transportation	13	Moisture-content	17	Data	12	Supply	12	Community	26
Infrastructure	11	Biomass	12	Value	10	Data	10	Supply	18
Need	11	Supply	10	Wood	10	Information	10	People	13
Big	9	Timber	10	Japan	8	Tracking	10	Rural	13
Cost	9	Wood	10	Energy	7	Biomass	9	Energy	12
Forestry	9	Control	9	ICT	7	Wood	9	Forest	12
Japan	9	Important	9	Market	7	Energy	8	Areas	11
Supply	9	Need	9	Area	6	Market	8	Good	11
Autonomous	8	Information	8	Bioenergy	6	People	8	Bioenergy	9
Information	8	Technology	7	Business	6	Transparency	8	Biomass	9
Wood	8	Condition	7	Material	6	Trust	8	Chain	9
Chain	7	Chain	6	Need	6	Forestry	7	Information	8
Timber	7	Chip	6	Power	6	Power	7	Need	8
Chipper	6	Digital	6	Resources	6	Communication	6	Resources	8
Road	6	Know	6	Sector	6	ICT	6	Wood	8
Route	6	Management	6	Apartment	5	Owners	6	Chains	8
Tree	6	Parameters	6	Companies	5	Value	6	Economic	7
Digital	5	Controlled	5	Consumers	5	Contract	5	Help	7
Europe	5	Fuel	5	Digital	5	Important	5	Important	7
Harvesting	5	Gas	5	Enable	5	IoT	5	Value	7
Help	5	People	5	Help	5	Resources	5	Renewables	7
Important	5	Sensors	5	Important	5	Stakeholders	5	Heat	6
Low	5	Side	5	People	5	Certification	4	Regions	6
Mobile	5	Users	5	Production	5	Chain	4	Use	6
Owners	5	Analysis	4	Side	5	Company	4	Behavior	5
Robotics	5	Condition	4	Technology	5	Industry	4	Business	5
Way	5	Conversion	4	Timber	5	Local	4	Incentive	5
Automation	4	Forestry	4	Use	5	Management	4	Infrastructure	5
Base	4	Human	4	Biomass	4	Operation	4	Small	5
Density	4	Measure	4	Bio	4	Owners	4	Socioeconomic	5
GPS	4	Price	4	Paper	4	Visibility	4	Contribute	5
Machines	4	Sensing	4	Problem	4	Business	3	Development	5
Mountain	4	Sharing	4	Properties	4	Customers	3	Economy	4
Onsite	4	Size	4	Public	4	Database	3	ICT	4
Side	4	Components	3	Trading	4	Difficult	3	Industry	4
Small	4	Count	3	Trust	4	Digital	3	Large	4
Systems	4	Data	3	Big	3	Direct	3	Owners	4
Technology	4	Drones	3	Cascading	3	Downstream	3	Power	4
Transport	4	Efficiency	3	Chemicals	3	Electricity	3	Trust	4
Trucks	4	Forest	3	Communication	3	Fuel	3	Agriculture	3
Business	3	Fraud	3	Demand	3	Issues	3	Biofuel	3
Chipping	3	Image	3	Develop	3	Network	3	Bad	3
Develop	3	Good	3	Education	3	Photo	3	Circulation	3
Difficult	3	IoT	3	Electricity	3	Price	3	Community	3

Table 2 (continued)

Woody biomass supply chain challenge									
Transportation infrastructure		Biomass quality monitoring and control		Business model integration (cascading)		Building stakeholder respect, relationships and trust		Local community revitalization and socioeconomic development	
Word	*f*	Word	*f*	Word	*f*	Word	*f*	Word	*f*
Drivers	3	Japan	3	Forestry	3	Registration	3	Connect	3
Satellite	3	Market	3	Future	3	Relationship	3	Cost	3
Sharing	3	Skills	3	Government	3	Truck	3	Creation	3
Tracks	3	Standards	3	High	3	Upstream	3	Developed	3
Virtual	3	Tag	3	Improved	3			Currency	3
Weather	3	Thinning	3	Industry	3			Digital	3
Drones	3	Tracking	3	Information	3			Digitalization	3
Future	3	Time	3	Local	3			Directive	3
Germany	3	Trust	3	Management	3			Ecosystems	3
Government	3	Trees	3	Needs	3			Forestry	3
GIS	3	Value	3	Optimized	3			Germany	3
Impact	3	Work	3	Picture	3			Government	3
Industry	3			Products	3			Interesting	3
Japanese	3			Plants	3			Issue	3
Logging	3			Quality	3			Japan	3
Long	3			Risks	3			Jobs	3
Optimize	3			Supply	3			Manufacturers	3
People	3			Traceability	3			Model	3
Roads	3			Transparency	3			New	3
Soil	3			Trees	3			Production	3
Subsidy	3			Utilized	3			Products	3
Support	3							Promote	3
Vehicle	3							Regional	3
								Regulations	3
								Scale	3
								Sharing	3
								Social	3
								Solar	3
								Support	3
								Systems	3
								Transparency	3
								Villages	3
								Work	3

f frequency

References

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

Ahl A, Yarime M, Tanaka K, Sagawa D (2019) Review of blockchain-based energy: implications for institutional development. Renew Sustain Energy Rev 107:200–211

Aikawa T (2018) Restructuring Japan's bioenergy strategy—towards realizing its true potential. Renewable Energy Institute. https://www.renewable-ei.org/en/activities/reports/img/pdf/20180628_01/REI_BioenergStrategy_EN_180628.pdf

Albino V, Berardi U, Dangelico RM (2015) Smart cities: definitions, dimensions, performance, and initiatives. J Urban Technol 22(1):3–21

Angelidou M (2015) Smart cities: a conjuncture of four forces. Cities 47:95–107

Arasto A, Chiaramonti D, Kiviluoma J, van den Huevel E, Waldheim L, Maniatris K, Sipilä K (2017) Bioenergy's role in balancing the electricity grid and providing storage options—an EU perspective. International Energy Agency (IEA) Bioenergy. https://www.ieabioenergy.com/wp-content/uploads/2017/02/IEA-Bioenergy-bio-in-balancing-grid_master-FINAL.pdf

Baker SE, Edwards R (2012) How many qualitative interviews is enough? Discussion paper. National Centre for Research Methods Review Paper. http://eprints.ncrm.ac.uk/2273/4/how_many_interviews.pdf

Barile S, Orecchini F, Saviano M, Farioli F (2018) People, technology, and governance for sustainability: the contribution of systems and cyber-systemic thinking. Sustain Sci 13:1197–1208

Bifulco F, Tregua M, Amitrano CC, D'Auria A (2016) ICT and sustainability in smart cities management. Int J Public Sect Manag 29(2):132–147

Bifulco F, D'Auria A, Amitrano CC, Tregua M (2018) Crossing technology and sustainability in cities' development. Special feature: people, technology and governance for sustainability: the contribution of systems and cyber-systemic thinking. Sustain Sci 13:1287–1297

Bogner A, Littig B, Menz W (2009) Introduction: expert interviews—an introduction to a new methodological debate. In: Bogner A, Littig B, Menz W (eds) Interviewing experts research series. Palgrave Macmillan, UK, pp 1–13

Brewer JP II, Vandever S, Johnson JT (2018) Towards energy sovereignty: biomass as sustainability in interior Alaska. Sustain Sci 13:417–429

Calvillo CF, Sanchez-Miralles A, Villar J (2016) Energy management and planning in smart cities. Renew Sustain Energy Rev 55:273–287

Camarinha-Matos LM (2016) Collaborative smart grids—a survey on trends. Renew Sustain Energy Rev 65:283–294

Caputo F, Buhnova B, Walletzky L (2017) Investigating the role of smartness for sustainability: insights from the Smart Grid domain. Sustain Sci 13(5):1299–1309

Carvalho MG (2012) EU energy and climate change strategy. Energy 40:19–22

Castellanos JA, Coll-Mayor D, Notholt JA (2017) Cryptocurrency as guarantees of origin: simulating a green certificate market with the Ethereum Blockchain. The 5th IEEE International Conference on Smart Energy Grid Engineering (SEGE) 367–372

Chuahan PS, Tewari A (2014) Using smart grid for efficient utilization of biomass based fuels: scope and challenges. Int J Eng Res Technol 3(7):187–190

Ciccarese L, Pellegrino P, Pettenella D (2014) A new principle of the European Union forest policy: the cascading use of wood products. Ital J For Mt Environ 69(5):285–290

Clark GC (1982) Policies, design and organization of forestry extension programmes. Report of the FAO/SIDA Seminar of Forestry Extension, FAO, Rome, Italy, pp 123–128

Clement J (2018) Blockchain biofuel application. Arch Chem Res 2:22

Del Giudice M, Caputo F, Evangelista F (2016) How are decision systems changing? The contribution of social media to the management of decisional liquefaction. J Decis Syst 25(3):214–226

DOE (2015) Enabling modernization of the electric power system. Quadrennial technology review Ch. 3. United States Department of Energy (DOE). https://www.energy.gov/sites/prod/files/2015/09/f26/QTR2015-3D-Flexible-and-Distributed-Energy_0.pdf

Dudder B, Ross O (2017) Timber tracking reducing complexity of due diligence by using blockchain technology. SSRN

Eisenbies MH, Volk TA, Patel A (2016) Changes in feedstock quality in willow chip piles in winter from commercial scale harvest. Biomass Bioenerg 86:180–190

Elwood SA (2008) Embedding ubiquitous technologies. In: Tomei LA (ed) Encyclopedia of information technology curriculum integration. Information Science Reference 279–285

Esparcia J (2014) Innovation and networks in rural areas. An analysis from European innovative projects. J Rural Stud 34:1–14

eTree (2018) What is eTree? https://etree.jp/html/page1.html. Accessed 11 Dec 2018. **(In Japanese)**

FAO, ITU (2019) E-Agriculture in action: blockchain for agriculture: opportunities and challenges. Sylvester G (ed) Food and Agriculture Organization (FAO) of the United Nations, International Telecommunication Union (ITU) of Bangkok

FGIS (2019) Forest GIS Forum (FGIS). http://fgis.jp/. Accessed 29 Apr 2019

Fujiwara T (2003) Public participation in Japan's forest planning system. In: Inoue M, Isozaki H (eds) People and forest—policy and local reality in southeast Asia, the Russian Far East, and Japan. Springer, Dordrecht

Giddens A (1990) The consequences of modernity. Polity Press, UK

Gifu Prefecture (2019) Gifu forest navigator (in Japanese). https://www.pref.gifu.lg.jp/sangyo/shinrin/shinrin-keikaku/11511/index_9948.html. Accessed 29 Apr 2019

Gingras JF, Charette F (2017) FPInnovation Forestry 4.0 Initiative. Council on Forest Engineering, Proceedings. http://cofe.org/files/2017_Proceedings/FPInnovations%20Gingras%20Charette%20Forestry%204.0%20for%20COFE%202017.pdf

Gold S, Seuring S (2011) Supply chain and logistics issues of bioenergy production. J Clean Prod 19(1):32–42

Guo ZX, Ngai EWT, Yang C, Liang X (2015) An RFID-based intelligent decision support system architecture for production monitoring and scheduling in a distributed manufacturing environment. Int J Prod Econ 159:16–28

Haga K (2018) Innovation in rural Japan: entrepreneurs and residents meeting the challenges of aging and shrinking agricultural communities. J Innov Econ Manag 1(25):87–117

He G, Bluemling B, Mol APJ, Zhang L, Lu Y (2013) Comparing centralized and decentralized bio-energy systems in rural China. Energy Policy 63:34–43

Huber A, Mayer I (2012) Smart cities: an emerging city concept to frame sustainable transitions? 3rd International conference on sustainability transitions, sustainable transitions: navigating theories and challenging realities. August 29–31 Copenhagen, Denmark

IEA (2017) Japan—feed-in tariff for renewable electricity and solar PV auction. International Energy Agency. https://www.iea.org/policiesandmeasures/pams/japan/name-30660-en.php. Accessed 22 Jan 2019

IEA (2018) Renewables 2018 analysis and forecasts to 20123—executive summary. International Energy Agency. https://webstore.iea.org/download/summary/2312?fileName=English-Renewables-2018-ES.pdf

IIED (2019) Rural urban linkages. International Institute for Environment and Development (IIED). https://www.iied.org/rural-urban-linkages. Accessed 29 Apr 2019

Inray (2018) FuelControl—solid fuel quality control system. http://www.inray.fi/index-s.php?page=22&lang=en. Accessed 16 Aug 2018

IPCC (2018) Summary for policymakers of IPCC special report on global warming of 1. 5°C approved by governments. Intergovernmental Panel on Climate Change (IPCC), Press release. https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf

iSiD (2016). Press release (In Japanese). Informational Services International Dentsu (iSiD). https://www.isid.co.jp/news/release/2016/1019.html. Accessed 29 Apr 2019

JETRO (2016) Electricity and renewble energy. Japan external trade organization (JETRO). Available at: https://www.jetro.go.jp/

ext_images/en/invest/attract/pdf/en_2016_Energy.pdf. Accessed 30 Aug 2019

Jiang Y, van der Werf E, van Ierland EC, Keesman KJ (2017) The potential role of waste biomass in the future urban electricity system. Biomass Bioenerg 107:182–190

Johnsrud MD (1991) Entrepreneurship in the development of a rural area. 4th FAO/REU International Rural Development Summer School, Mikkeli, Finland

Kache F, Seuring S (2017) Challenges and opportunities of digital information at the intersection of big data analytics and supply chain management. Int J Oper Prod Manag 37(1):10–36

Kenney KL, Smith WA, Gresham GL, Westover TL (2013) Understanding biomass feedstock variability. Biofuels 4(1):111–127

Khansari N, Motashari A, Mansouri M (2013) Impacting sustainable behaviour and planning in smart city. Int J Sustain Land Use Urban Plan 1(2):46–61

Kies U, von Lengefeld AK (2018) Digitisation in the forest-based sector. State of technology and opportunities for innovation. Club du Bois at the European Parliament, Brussels

Kimura K, Ninomiya Y (2017) Wood biomass power generation target for 2030: impact on biomass fuel supply in Japan. The Institute of Energy Economics, Japan. https://eneken.ieej.or.jp/data/7194.pdf

Koch B (2010) Status and future of laser scanning, synthetic aperture radar and hyperspectral remote sensing data for forest biomass assessment. ISPRS J Photogramm Remote Sens 65(6):581–590

Krippendorff K (2004) Content analysis—an introduction to its methodology, 2nd edn. SAGE Publications, Thousand Oaks

Kylili A, Fokaides PA (2015) European smart cities: the role of zero energy buildings. Sustain Cities Soc 15:86–95

Littig B (2009) Interviewing the elite—interviewing experts: is there a difference? In: Bogner A, Littig B, Menz W (eds) Interviewing experts research series. Palgrave Macmillan, UK, pp 98–113

Lombardi P, Vanolo A (2015) Smart city as a mobile technology: critical perspectives on urban development policies. In: Rodriguez-Bolívar MP (ed) Transforming city governments for successful smart cities, public administration and information technology. Springer, Switzerland, pp 147–161

Lombardi P, Giordano S, Farouh H, Yousef W (2012) Modelling the smart city performance. Innov Eur J Soc Sci Res 25(2):137–149

Lopez-Nicolas C, Soto-Acosta P (2010) Analyzing ICT adoption and use effects on knowledge creation: an empirical investigation on SMEs. Int J Inf Manag 30:521–528

Lu D, Chen Q, Wang G, Lui L, Li G, Moran E (2016) A survey of remote sensing-based aboveground biomass estimation methods in forest ecosystems. Int J Digit Earth 9(1):63–105

Lund H, Ostergaard PA, Connolly D, Mathiesen BV (2017) Smart energy and smart energy systems. Energy 137:556–565

MAFF (2016) Annual report on forest and forestry in Japan. Ministry of Agriculture, Forestry and Fisheries, Japan. http://www.maff.go.jp/e/data/publish/attach/pdf/index-64.pdf

MAFF (2018) Biomass town. Ministry of Agriculture, Forestry and Fisheries, Japan. http://www.maff.go.jp/e/policies/tech_res/biomass.html. Accessed 19 Dec 2018

Malico I, Carrajola J, Pinto Gomes C, Lima JC (2016) Biomass residues for energy production and habitat preservation. Case study in a montado area in Southwestern Europe. J Clean Prod 112(5):3676–3683

Mancarella P (2012) Distributed multi-generation options to increase environmental efficiency in smart cities. IEEE Power and Energy Society General Meeting, San Diego, CA, 1–8

Mangoyana RB, Smith TF (2011) Decentralised bioenergy systems: a review of opportunities and threats. Energy Policy 39(3):1286–1295

Mantau U (2012) Wood flows in Europe (EU27). Confederation of European Paper Industries (CEPI) and European Confederation of Woodworking Industries (CEI-Bois). http://www.cepi.org/system/files/public/documents/publications/forest/2012/CEPIWoodFlowsinEurope2012.pdf

Mårald E, Langston N, Sténs A, Moen J (2016) Changing ideas in forestry: a comparison of concepts in Swedish and American forestry journals during the early twentieth and twenty-first centuries. Ambio 45(Suppl 2):74–86

Mayer H, Habersetzer A, Meili R (2016) Rural–urban linkages and sustainable regional development: the role of entrepreneurs in linking peripheries and centers. Sustainability 8(8):745

McCauley SM, Stephens JC (2012) Green energy clusters and sociotechnical transitions: analysis of a sustainable energy cluster for regional economic development in Central Massachusetts, USA. Sustain Sci 7:213–225

Meho LI (2006) E-mail interviewing in qualitative research: a methodological discussion. J Am Soc Inf Sci Technol 57(10):1284–1295

Mello RA (2002) Collocation analysis: a method for conceptualizing and understanding narrative data. Qual Res 2(2):231–243

Melo G, Ames GCW (2016) Driving factors of rural-urban migration in China. Agricultural & Applied Economics Association, Annual Meeting, Boston, Massachusetts, USA, July 31–August 2

METI (2014) 4th Strategic energy plan (Provisional Translation). Ministry of Economy, Trade & Industry, Japan

Miglietta MM, Huld T, Monforti-Ferrario F (2017) Local complementarity of wind and solar energy resources over Europe: an assessment study from a meteorological perspective. J Appl Meteorol Climatol 56:217–234

Mirembe DP, Mukasa SB, Lubega JT (2018) An ICT based platform to track and monitor the certification and distribution of clean cassava planting material. RUFORUM. https://blog.ruforum.org/2018/05/31/an-ict-based-platform-to-track-and-monitor-the-certification-and-distribution-of-clean-cassava-planting-material/. Accessed 15 Dec 2018

Mohammadi M, Noorallahi Y, Mohammadi-ivatloo B, Hosseinzadeh M, Yousefi H, Khorasani ST (2017) Optimal management of energy hubs and smart energy hubs—a review. Renew Sustain Energy Rev 89:33–50

Nakagawa T, Chisaka H, Notoji Y (2018) A novel SMART energy system for using biomass energy effectively. Renew Energy 116:492–499

Nam T, Pardo TA (2011) Conceptualizing smart city with dimensions of technology, people, and institutions. In: Proceedings of the 12th annual international digital government research conference: digital government innovation in challenging times (dg.o'11). ACM, New York, NY, USA, pp, 282–291. https://doi.org/10.1145/2037556.2037602

Nishida T, Pick JB, Sarkar A (2014) Japan's prefectural digital divide: a multivariate and spatial analysis. Telecommun Policy 38:992–1010

Nishiguchi S, Tabata T (2016) Assessment of social, economic, and environmental aspects of woody biomass energy utilization: direct burning and wood pellets. Renew Sustain Energy Rev 57:1279–1286

Oakley P, Garforth C (1985) Guide to extension training. Issue 11 of Food and Agriculture Organization (FAO) training series. Food & Agriculture Organization

Obayashi Y (2017) Fuel shortage looms as Japan fires up biomass energy. Japan Times. Available at: https://www.japantimes.co.jp/news/2017/09/27/national/fuel-shortage-looms-japan-fires-biomass-energy/#.XWjg9yj7SUk. Accessed 30 Aug 2019

Odegard I, Croezen H, Bergsma G (2012) Cascading of biomass: 13 solutions for a sustainable bio-based economy—making better choices for use of biomass residues, byproducts and waste. Delft, CE Delft

Pambudi N, Itaoka K, Chapman A, Hoa ND, Yamakawa N (2017) Biomass energy in Japan: current status and future potential. Int J Smart Grid Clean Energy 6(2):119–126

Paredes-Sanchez JP, Gutiérrez-Trashorras AJ, González-Caballín JM (2013) Bio-smartcity: biomass supply to a smartcity. A case study. International conference on new concepts in smart cities: fostering public and private alliances (SmartMILE), Gijon 1–4

Proskurina S, Sikkema R, Heinimö J, Vakkilainen A (2016) Five years left—how are the EU member states contributing to the 20% target for EU's renewable energy consumption; the role of woody biomass. Biomass Bioenerg 95:64–77

PwC (2017) Clarity from above: leveraging drone technologies to secure utilities systems. https://www.pwc.com/hu/hu/kiadvanyok/assets/pdf/clarity-from-above-leveraging-drone-technologies-to-secure-utilities-systems-pwc.pdf

Rasid N, Nohuddin PNE, Alias H, Hamzah I, Nordin AI (2017) using data mining strategy in qualitative research. International visual informatics conference, Bangi, Malaysia

Roßmann J (2011) From space to the forest and to construction sites: virtual testbeds pave the way for new technologies. In: Ma D, Fan X, Gausemeier J, Grafe M (eds) Virtual reality & augmented reality in industry. Springer, Berlin, pp 39–54

Salemink K, Strijker D, Bosworth G (2017) Rural development in the digital age: a systematic literature review on unequal ICT availability, adoption, and use in rural areas. J Rural Stud 54:360–371

Scuotto V, Caputo F, Villasalero M, Del Giudice M (2016) A multiple buyer–supplier relationship in the context of SMEs' digital supply chain management. Prod Plan Control 28(16):1378–1388

Sinclair S, Rockwell G (2018) Voyant tools. http://docs.voyant-tools.org/. Accessed 19 Dec 2018

Sinha S, Jeganathan C, Sharma LK, Nathawat MS (2015) A review of radar remote sensing for biomass estimation. Int J Environ Sci Technol 12(5):1779–1792

Skogforsk (2018) (In Swedish) New project to develop self-driving forest machines. Available at: https://www.skogforsk.se/nyheter/2018/nytt-projekt-ska-utveckla-sjalvstyrande-skogsmaskiner/. Accessed 14 Jan 2019

Skogstekniska Klustret (2014) Smart crane control. https://www.skogstekniskaklustret.se/projekt/smart-crane-control. Accessed 14 Jan 2019 **(in Swedish)**

Soares N, Martins AG, Carvalho AL, Caldeira C, Du C, Castanheira E, Rodrigues E, Oliveira E, Skogforsk (2018) New project to develop self-driving forest machines. https://www.skogforsk.se/nyheter/2018/nytt-projekt-ska-utveckla-sjalvstyrande-skogsmaskiner/. Accessed 14 Jan 2019 **(in Swedish)**

Tiilikainen K, Birol F (2018) Modern bioenergy is critical to meeting global climate change goals. Climate home news. http://www.climatechangenews.com/2018/10/11/modern-bioenergy-critical-meeting-global-climate-change-goals/. Accessed 19 Dec 2018

Turner DW III (2010) Qualitative interview design: a practical guide for novice investigators. Qual Rep 15(3):754–760

Tzoulis I, Andreopoulou Z (2013) Emerging traceability technologies as a tool for quality wood trade. Proc Technol 8:606–611

Velodyne Lidar (2019). https://velodynelidar.com/industry-drone.html. Accessed 29 Apr 2019

Vinterbäck J, Porsö C (2011) WP3—Wood fuel price statistics in Europe—D 3.3. European Commission. https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/eubionet_iii_wood_fuels_price_statistics_in_europe_en.pdf

Welfe A, Gilbert P, Thornley P (2014) Increasing biomass resource availability through supply chain analysis. Biomass Bioenerg 70:249–266

Whalley S, Klein SJW, Benjamin J (2017) Economic analysis of woody biomass supply chain in Maine. Biomass Bioenerg 96:28–49

Wortman MS Jr (1990) Rural entrepreneurship research: an integration into the entrepreneurship field. Agribusiness 6(4):329–344

Yanagida T (2015) System evaluation for sustainable bioenergy production. The 3rd ACMECS Bioenergy Workshop, Future development of ACMECs Bioenergy/Regional Plan and Standardization, 8–11 December

Yarime M (2017) Facilitating data-intensive approaches to innovation for sustainability: opportunities and challenges in building smart cities. Sustain Sci 12:881–885

Yarime M, Karlsson M (2018) Examining the technological innovation systems of smart cities: the case of Japan and implications for public policy and institutional design. In: Niosi J (ed) Innovation systems, policy and management. Cambridge University Press, Cambridge, pp 394–417

YellowScan (2019). https://www.yellowscan-lidar.com/. Accessed 29 April 2019

Yoshida H, Nomiyama T, Aihara N, Yamazaki R, Ara S, Enomoto H (2014) Local activity of biomass use in Japan. In: Tojo S, Hirasawa T (eds) Research approaches to sustainable biomass systems, pp 347–371

Zhang J, Hu J, Lian J, Fan Z, Ouyang X, Ye W (2016) Seeing the forest from drones: testing the potential of lightweight drones as a tool for long-term forest monitoring. Biol Cons 198:60–69

Zhang Y, Chen W, Gao W (2017) A survey on the development status and challenges of smart grids in main driver countries. Renew Sustain Energy Rev 79:137–147