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Redesigning a sustainable bioenergy system using a multi-platform application

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Abstract. This article is a concept that arranges and expands the bioenergy system paradigm that has been widely published by renewable energy experts. The new paradigm is based on the principle of the energy system where all factors must be identified and included because they affect the sustainability of the system's process, performance and results. The target of this concept is structuring a more holistic and effective analytical technique to guide policymakers, entrepreneurs, and researchers in making decisions and implementing bioenergy projects. The literature review is used as an analytical tool to build this concept and the results of a study indicate that the bioenergy system is all key components that can be grouped into policy and regulation subsystems; the subsystem of the production and bioenergy utilization chain, the bioenergy management subsystem; and the bioenergy infrastructure subsystem. To get sustainability, bioenergy system is necessary to link and identify key materials that are related and interact with the economic, social and environmental pillars that support the sustainable development system. Future prospects are translating the concept of bioenergy system and their constituent components into mathematical models, making a research guide in the future based on agro-industry and regional agro-bioenergy system in Indonesia.

1. Introduction

Provision of energy supply is the main need of humans to support various activities and comfort and lifestyle. The transition of energy supplies from fossil fuels (oil, gas, and coal) to renewable energy is triggered by a number of reasons such as a decrease in the number of fossil energy reserves, fluctuations and increases in fossil energy prices, and concern to preserve the global environment and build a country's energy security [1,2]. The contribution of six renewable energy sources (solar, hydro, wind, geothermal, bioenergy, and marine) has developed well along with the advancement of technological innovation, decreasing costs and increasing the diversity of products from the hard work of researchers in research institutions and universities [3-5]. Based on data from the World Bioenergy Association 2016 in Lang et al., although fossil energy supplies still dominate the supply of world energy contributions, renewable energy has increased its contribution from 17.6% in 2000 to 18.3% in 2013 with bioenergy as the largest contributor (14%). It is expected that the bioenergy contribution will continue to grow in the future [6].

From the six renewable energy sources, bioenergy allows to meet human energy needs because it can be provided in the form of gas, liquid, and solid and has characteristics resembling fossil energy [7].

The three forms of bioenergy products make it easier to move to locations that need them more. The availability of biomass which is a bioenergy feedstock is abundant and spread in various places sourced from agricultural, plantation, forestry and marine waste and residues, as well as settlements. However, the raw material has a weakness because of its high water content, low energy content, non-uniform shape and size, and scattered location. This condition requires a holistic framework in order to be able to utilize and increase the contribution of bioenergy as one of the renewable energy sources in the future.

The structure of this article begins with the understanding that bioenergy is an energy system designed to supply energy services to end users [8], then all components involved and influencing the system must be identified, analyzed, and included in concepts as key material according to the IPCC criteria [9]. There are four key questions that must be sought through this literature review, then outlined in the form of schemes and matrices containing key material grouped and becoming the conceptual constructors of sustainable bioenergy systems. The application of mathematical models, analysis of potential and strategies to increase bioenergy contributions is a prospect offered to be a further step of this concept

Various scientific publications that include the term bioenergy system did not explain thoroughly the key material that has a direct or indirect effect on the implementation of the system. The explanation of the publication is only limited to some key material or part of the interaction of key material from the constituent subsystem, then does not relate it to the factors that influence the sustainability of the bioenergy system. The following are given three examples of scientific publications, then followed by an explanation of four types of weaknesses from understanding the concept.

Mitchell et al., included the title of the article "Bioenergy System" but in its discussion only able to identify the supply chain of bioenergy production which consists of components of production, transportation, pre-treatment, conversion, and generation of energy [10]. Disagreements occur even though they are noted in the same book, because Bridgwater and Boocock say that bioenergy systems should range from pre-treatment to end users with increasing attention to the benefits and problems of the environment due to the application of the system [11].

Although McCormick and Kaberger [12] used the definition of a bioenergy system initiated by Sims [13] to reveal the success of the application of bioenergy in the city of Enkoping, Sweden, however, schematically, the definition only presents the production subsystem. Sims states that bioenergy systems consist of biofuel resources, supply systems, conversion technology, and energy needs. Then the definition is combined with an analysis from Roos et al. [14] to give birth to a new concept in the form of a scheme as in figure 1. where system controllers are issues of sustainability, relations between institutions, and market conditions.

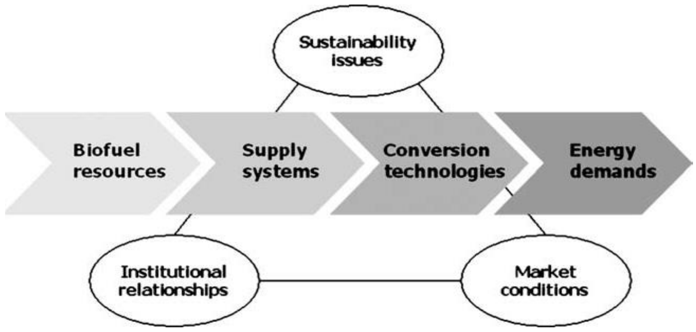

Figure 1. Bioenergy system scheme according to McCormick and Kaberger [12].

Sanches-Pereira has fully translated the bioenergy system by adding a scheme by involving constituent subcomponents consisting of policy, infrastructure, production chains, and institutional capacity [15]. However, the driving factor only involves the market needs of the economic aspects and has not involved social and environmental aspects so that it will experience difficulties in implementing the sustainability of the system.

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Based on this literature review, four major weaknesses have been identified about the bioenergy system that has been adopted so far. The three weaknesses of this understanding are as follows:

- The bioenergy system is only understood as a production chain that processes biomass raw materials, starting from harvesting, collecting, transporting, storing, pre-treating, and changing the shape of energy, and its utilization [10]. This understanding implies that there are restrictions on the involvement of key material from the environmental, social and economic components of the system.
- The determinants of the success of the bioenergy system such as the availability of infrastructure, technological advances, management by involving human resources in various professions, and government regulations and policies are only separate discussion material. so that it has not been able to provide a thorough explanation of an energy system.
- Explanation of bioenergy as an energy system in the form of a scheme is only related to the partial interaction of the key material that composes the energy system [12].

This gap in understanding of the bioenergy system makes it a reason to propose the development of new concepts. A concept that gives the perspective that the energy system must be holistic and and can be presented in the form of a schema of thought, then explains the use of the algorithm and the case examples from the citations.

To find a solution to the gap in the bioenergy concept as an energy system, four questions are presented, namely: What material is the key determinant of bioenergy if it is considered an energy system? Can these key material be grouped with specific criteria? What is the interaction of key material and the interaction of constituent groups in the bioenergy system? How is the link between the bioenergy system and the concept of sustainability supported by three pillars, namely economic, social and environmental?

2. Method

2.1. Workflow

The stages of work for analyzing this concept are presented in figure 2, beginning with a literature review which gave birth to a problem finding where there were gaps and differences in perceptions because there was no holistic explanation and scheme of the bioenergy concept as an energy system. The literature sought and selected is then grouped based on the discussion material into seven groups, namely an understanding of biomass and bioenergy; identification of raw materials, transportation processes, conversion and storage technology; bioenergy products; utilization of bioenergy products; infrastructure; management; policies and regulations, and their relevance to the pillars of sustainability or sustainable development to obtain a holistic concept in the form of a sustainable bioenergy system scheme.

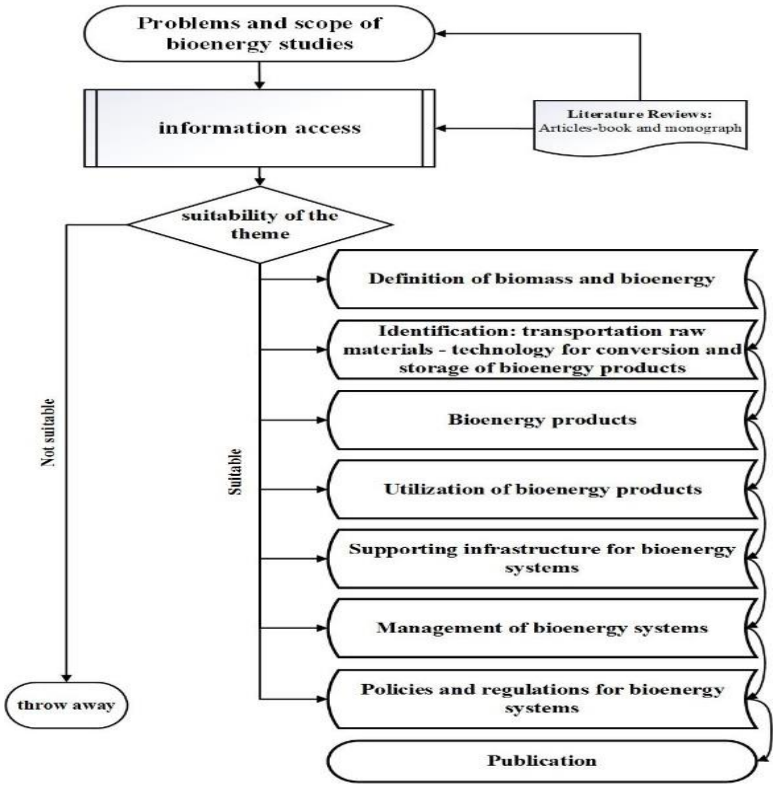

Figure 2. The flow of thought in the preparation and rearrangement of the concept of the bioenergy system.

2.2. Assumptions

To fulfill the concept of an energy system, all key components that have a direct or indirect effect on bioenergy planning, implementation and evaluation as a system must be identified and included to obtain a holistic understanding [9,16].

To do this, six assumptions are used:

- Key material is the factors that are involved and influential in a bioenergy system based on a study or discussion of publications that are available from scientific journals.
- The key material can be grouped based on similar themes.
- Explanation of interaction is only based on the interaction between components in the bioenergy production subsystem, as well as the interaction of the bioenergy system with the three pillars of sustainability.
- Details of the key material in the subcomponents are presented in the form of a bioenergy compilation matrix that can be further developed by interested people in this theme.
- This system produces bioenergy products that use biomass raw materials from waste or waste from agro-industry. The bioenergy products produced are grouped according to their forms, namely artificial, liquid and solid gas.
- Three pillars of sustainability: economic, social and cultural, and environmental are part of the pillars of sustainable development that can be applied to bioenergy systems.

3. Results and discussion

3.1. Bioenergy system

The definition of an energy system is a system designed to supply energy services to end users [16]. Bioenergy systems cover from pre-treatment to end-users with increasing concern for the benefits and environmental impacts of implementing the system [11]. If associated with the Fifth Assessment Report of the IPCC which defines energy systems as "all components related to production, conversion, shipping and energy use" [10], then all constituent and direct or indirect components should be assessed and included to achieve a comprehensive understanding of the system. These three analyses can be presented in the form of a general scheme as in figure 3 where the energy system represented by the bioenergy system will interact with all components of the economic, social, and environmental pillars that support sustainable development.

The bioenergy system is built by a series of key materials that can be grouped as components of regulation and policy, management, supply chain and production, and infrastructure. Interaction will occur between key material and the components of the bioenergy system if regulations and policies provide opportunities based on the interests of an institution or region. The same conditions will also occur in the interaction of the components of the bioenergy system with the three pillars of sustainable development as presented in the form of a general scheme (figure 3.), and details of the key material are presented in table 1.

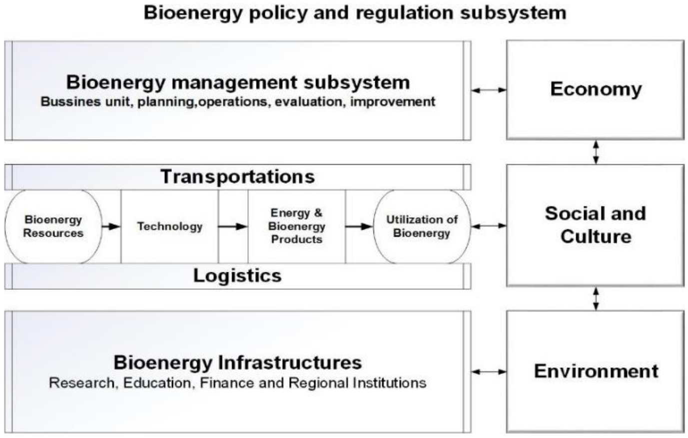

Figure 3. Scheme of the key components of the bioenergy system and its interaction with sustainable pillars

The key components in the bioenergy system are divided into four subsystems, namely:

3.1.1. Bioenergy production subsystem. This subsystem includes several activities consisting of raw material selection, harvesting, transportation, pre-treatment, biomass conversion technology, storage and packaging of bioenergy products, utilization of bioenergy products. Various biomass sources have been widely known through studies of commodity potential in an agriculture-based, plantation area, marine, and forestry. Identification of biomass sources can come from crop residues, industrial waste or energy crops. The main consideration is using waste or residues even energy crops so that they do not conflict with the interests of providing food in an area.

Pre-treatment is a determining factor to get the quality and quantity of raw materials that are in accordance with factory needs and production targets according to the standards of bioenergy products. The various treatments that will be applied include physical, thermal, chemical, and biological treatment by paying attention to product targets, quality and quantity of raw materials, selection of biomass conversion trajectories, consideration of availability and mastery of conversion technology, as well as economic, social and environmental aspects in the production area.

The conversion path is divided into three paths namely physical, thermal, and biochemical by providing several choices of conversion technologies such as combustion, gasification, liquefaction, and fermentation to convert biomass into various energy products. Another consideration is the priority of products targeted as main products without forgetting the by-products of the conversion process. The product selection strategy supported by technological advancements has shifted the position of traditional biomass utilization to a single product into multiple energy products. The stages towards multi-energy products are started from co-generation, tri generation to polygene ration so that conversion efficiency continues to grow and provides additional benefits in terms of economy and utilization of raw materials [17-19].

In this conversion trajectory, the role of technology greatly determines the level of investor confidence to invest their capital. The stages of technological development are divided into six stages, namely: 1) Basic Research and Development; 2) Applied Research and Development; 3) Demonstrations; 4) Pre-commercialization; 5) Market Gap and Commercial Support; and 6) Commercial. In the fourth to sixth stages, the role of investors will be more assured because of the risk of failure in terms of technology will decrease [20,21].

The mode of transporting biomass and bioenergy products may only use one type such as trucks or transport trains in the production area dominated by the plains. However, the transportation modes and programs will vary in their needs if the production area consists of rivers, sea and land such as in Indonesia, the Philippines and Malaysia. Adaptation of modes and transportation programs will follow the types of bioenergy products that will be moved from other locations. For example, for land transportation, biodiesel will be more efficient using tank trucks while wood pellet products will be more efficient using large plastic bags and containers transported by truck.

Variations in the use of bioenergy products are highly dependent on the variety of needs of the community and industry in a region. Its uses include lighting, cooking, power for electrical and electronic equipment, fuel engines and vehicles. The form of energy commonly used by the public is electricity for lighting, electrical and electronic equipment. Meanwhile, bioenergy products in the form of solid are used for heating or raw materials for electricity generation. Liquid bioenergy products are more widely used for transportation facilities (cars, motorcycles, ships, and airplanes) and diesel engines that become power plants.

The packaging of bioenergy products is determined by the shape of the product, the location of transportation, the mode and program of transportation, and the end target users. Optimization of these four factors is one of the management strategies needed in achieving increased production efficiency, marketing strategies and expanding the market for bioenergy products.

3.1.2. Bioenergy infrastructure subsystem. An important requirement for a bioenergy infrastructure is synergizing and supporting system performance, does not cause environmental pollution, low operational costs and low energy consumption. This subsystem consists of two parts, namely physical and non-physical infrastructure subsystems, where the presence of both complement each other so that the bioenergy production system can run well.

Physical infrastructure sub-subsystems for bioenergy include the availability of electricity networks from the generating system to dividing substations to the network to consumers, communication systems and networks, ports, and road infrastructure used for the process of transporting raw materials and bioenergy products. The physical infrastructure that needs to be available in bioenergy production locations may be almost the same as other industrial activities such as offices, parking lots, and security signs, as well as a realtime monitoring system of production processes in factories or energy plants.

The non-physical infrastructure sub-subsystem for bioenergy in a production area can generally be identified as an institutional and work program that focuses on education and training activities for human resources such as the vocational training centre and university; financial institutions such as banks, securities, and insurance; research and development institutions to obtain innovations, studies, inventions, techniques for implementing bioenergy related systems and technologies.

Provision of infrastructure for bioenergy systems is adjusted to the conditions of the area that is the work location, rural areas will be different from urban locations. The implementation of the Mandiri E3i Village concept (Energy, Economy, Environment Improvement) is one example of a program to provide renewable energy infrastructure for rural areas [22], while for urban use the concept was initiated by Ling Ng [23].

3.1.3. Bioenergy management subsystem. This subsystem is closely related to strategies, techniques and programs to manage all natural, human, equipment, technology and financial resources as well as information on government policies and regulations related to the bioenergy system. Management of human resources involved in bioenergy systems with various professional stratifications such as investors who become project owners, project implementation teams (project planners, implementers and evaluators), consumers or end users, researchers, and communities become one of the material in the management subsystem this bioenergy. In addition to the involvement of human resources, this subsystem also requires management rules that will divide the program and work targets, work time, work safety and security, and the rules for managing a business unit based on standard operational procedures (SOP) steps continuation of strategies, techniques and work programs.

Bioenergy management determines the position of the economic, social and environmental pillars as a driver or target for implementing this energy system. Efforts to fulfill the income target based on a feasibility study on a bioenergy project are part of the target in the economic pillar, and the driver is the fulfillment of energy supplies based on sales contracts that have been carried out by the marketing team. This bioenergy management will also utilize business units that are in the form of companies or cooperatives that are working partners and mobilize all the interests of farmers' groups to ensure the continuity of raw material supply.

3.1.4. Bioenergy policy and regulation subsystem. Understanding of policies and regulations (rules) is based on the presence of written rules in the form of laws, presidential regulations, ministerial regulations, up to the lowest hierarchical rules such as governor regulations or mayor regulations located at provincial and district or city levels for cases in the regulatory system in Indonesia.

Policies and regulations will regulate all components in each management sub-system, infrastructure, raw material resources, technology, energy products, utilization related to markets and marketing, as well as the direction and efforts to achieve them in a country's national development. Included in achieving sustainable development targets. The aim is to provide legal certainty and confidence for business people that this business provides a sense of security and comfort and benefits. Then evaluation of decision-making policies can be seen from the impact on these constituent components.

Singh and Setiawan reviewed five indicators similar to bioenergy system components, namely technology, infrastructure, regulation and institutions, human resources and knowledge development, as well as stakeholder development for analysis of comparative biomass energy potential in India and Indonesia based on the effectiveness of each policy the country [24]. The next step of policy and regulation on the bioenergy system will be followed by certification to ensure that the operation of the energy system is in accordance with the rules.

Buyx and Tait, states that in the framework of preparing policies and regulations related to bioenergy, it is better to fulfill the rules, not to sacrifice basic human rights and must recognize the rights of people to give compensation; must be environmentally friendly and not contribute to total greenhouse gas (GHG) emissions and not worsen global climate change, and bioenergy costs and benefits must be distributed fairly [25]. Likewise, with the advances in bioenergy conversion technology innovation, it must be at an acceptable stage and provide investment security for investors [20,21,26].

Changes in policies and regulations will change all the performance of the components of the bioenergy system. The policy of replacing foodstuffs with waste and the remainder of the agricultural industry that is a marker of the second generation of biofuels will lead to changes in the needs and techniques of raw material collection, technology, R & D support, including consumer responses in markets at local, regional and international levels. A new balance will occur in the bioenergy system when all its constituent components have experienced adjustments to the policy. Examples of this case occurred in Europe which led to the use of waste and residual crops so that the supply of energy does not conflict with the provision of food [26–31].

3.2. Sustainable pillars and bioenergy system

The basic principle of sustainability refers to the definition that the ability to get the needs of a generation without forgetting the ability of future generations to meet their needs. In the proposed bioenergy system scheme, the three pillars of sustainable development are controlling motion, purpose, and at the same time being the recipient of the impact. The three roles are carried out by the key material that forms the economic, social and environmental pillars. Its role is carried out independently and in synergy with other components of the bioenergy system. The scope of the study starts from the project scale up to the regional scale. Issues relating to bioenergy systems and sustainable development, which also include sustainable energy systems, have been of concern to Elghali et al. [27–30] with identification as follows:

3.2.1. Economy

- Security and stability of the bioenergy supply chain, using fuel both domestically and imported;
- Extracting potential bioenergy systems to fulfill the energy supply of a region/country;
- Pathways for the introduction of bioenergy on different business scales to various types of consumers;
- Potential innovation strategies and optimization techniques to produce a more efficient and effective bioenergy chain;
- Reducing investment risk in the bioenergy sector based on the scale of the project, availability of raw materials, financing, availability of technology, and markets, as well as the policies of a country.

3.2.2. Social and culture

- Community acceptance of the bioenergy system as a priority choice that is able to meet its energy supply needs;
- Policy measures to promote bioenergy, including policies in the agricultural and waste sectors,
- The right approach to get guaranteed supplies from raw material suppliers; guarantee of providing transportation services, social and cultural guarantees on project implementation;
- Opening business fields and employment for the people around the project
- Play a role in mobilizing young generation initiatives in entrepreneurship in the bioenergy sector.

3.2.3. Environment

- Environmental impacts (not limited to greenhouse gas emissions) during the full fuel cycle;
- The potential of biomass to reduce greenhouse gas emissions in various sectors, including hot fuel, electricity and transportation;

The acceptance of this new concept of bioenergy systems for biomass-based renewable energy scientists still requires further analysis and research. To fulfill this matter, this concept needs to be studied further through several research activities such as application of mathematical models and interaction schemes in the analysis of palm oil, coconut, sago, forestry, and municipal bioenergy systems in an area; use of this new concept of bioenergy system to analyze potential and implementation strategies and increase the contribution of sustainable biomass-based energy supply; Utilizing this concept by integrating the regional agro-bioenergy system initiated by Arodudu et al. for cases in Indonesia [32].

4. Conclusion

The bioenergy system consisting of raw material selection, harvesting, transportation, pre-treatment, biomass conversion technology, packaging of bioenergy products, and utilization of bioenergy products is an old paradigm that has been widely understood by biomass-based renewable energy experts. This understanding is limited to the bioenergy production subsystem in the new paradigm.

The bioenergy system in the new paradigm is based on the principle of an energy system where all factors must be identified and included because they affect the sustainability of the process, the performance and results of the system. Bioenergy systems are all key material that can be grouped into a system of policies and regulations; the chain of production and utilization of bioenergy subsystems, the bioenergy management system; and bioenergy infrastructure subsystem. To get a guarantee of continuity in the bioenergy system, a link and identification of key material related to and interacting with the economic, social and environmental pillars is needed to support the sustainable development system.

The prospects that will be carried out using this new paradigm are: a) the application of mathematical models and interaction schemes in the analysis of oil palm, coconut, sago, forestry, and municipal bioenergy systems in an area; b) utilization of this new concept of the bioenergy system to analyze potential and implementation strategies and increase the contribution of sustainable biomass-based energy supplies; c) utilize this concept with the regional agro-bioenergy system as an effort to integrate the two concepts of food and energy based for the region.

References

[1] Lund H 2007 Renewable energy strategies for sustainable development *Energy* **32** 912–9
[2] Kaiser S and Segerborg-Fick A 2014 Biomass Technology Roadmap European Technology Platform on Renewable Heating and Cooling Renew *Heating&Cooling* 1–44
[3] McCormick K and Kåberger T 2014 An Innovative Bioenergy System *In Action Proceedings of the International Conference on Environmental Protection*
[4] Junginger M, de Visser E, Hjort-Gregersen K, Koornneef J, Raven R, Faaij A and Turkenburg W 2006 Technological learning in bioenergy systems *Energy Policy* **34** 4024–41
[5] Sarwani M, Nurida N L and Agus F 2013 Greenhouse gas emissions and land use issues related to the use of bioenergy in *Indonesia J. Penelit. dan Pengemb*. **32** 56–66
[6] Lang A, Bradley D and Gauthier G 2016 Global Bioenergy Statistics, *World Bioenergy Association*
[7] Berndt C C and Hodzic A 2007 Bagasse Fibre for Sustainable Manufacturing *J. Biobased Mater. Bioenergy* **1** 289–300
[8] Groscurth H M, Bruckner T and Kümmel R 1995 Modeling of energy-services supply systems *Energy* **20** 941–58
[9] Burke E J, Brown S J, Christidis N, Eastham J, Mpelasoka F, Ticehurst C, Dyce P, Ali R, Kirby M, Kharin V V., Zwiers F W, Tilman D, Balzer C, Hill J, Befort B L, Godfray H, Beddington J, Crute I, Conforti P, IPCC, Dore M H I, Arnell N and Huntington T G 2008 Climate Change 2014 *Synthesis Report* **403**
[10] Mitchell C P, Bridgwater A V and Mackie K L 1997 *Bioenergy Systems Developments in Thermochemical Biomass Conversion* (Dordrecht: Springer Netherlands) pp 1509–24
[11] Bridgwater A V and Boocock D G B 1997 *Developments in Thermochemical Biomass Conversion* (Dordrecht: Springer Netherlands)
[12] McCormick K and Kaberger T 2010 Exploring a pioneering bioenergy system: The case of Enkoping in *Sweden J. Clean. Prod.* **13** 1003–14
[13] Sims R E H 2003 Bioenergy to mitigate for climate change and meet the needs of society, the economy and the environment *Mitig. Adapt. Strateg. Glob. Chang*. **8** 349–70
[14] Roos A, Graham R L, Hektor B and Rakos C 1999 Critical factors to bioenergy implementation *Biomass and Bioenergy* **17** 113–26
[15] Sanches-Pereira A 2012 Assessment of Sustainability within Bioenergy Supply Chain

Management 91
[16] Groscurth H M, Bruckner T and Kümmel R 1995 Modeling of energy-services supply systems *Energy* **20** 941–58
[17] Ünal A N, Ercan S and Kayakutlu G 2015 Optimisation studies on tri-generation: a review *Int. J. Energy Res.* **39** 1311–34
[18] Mancarella P 2014 MES (multi-energy systems): An overview of concepts and evaluation models *Energy* **65** 1–17
[19] Rong A and Lahdelma R 2016 Role of polygeneration in sustainable energy system development challenges and opportunities from optimization viewpoints *Renew. Sustain. Energy Rev.* **53** 363–72
[20] Wüstenhagen R and Menichetti E 2012 Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research *Energy Policy* **40** 1–10
[21] Bürer M J and Wüstenhagen R 2009 Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international cleantech investors *Energy Policy* **37** 4997–5006
[22] Abdullah K 2008 The E3i Village Concept *Jurnal Ilmiah Energi*, **1**(6) 67–74
[23] Ng T L 2014 Infrastructure Support for Bioenergy Development in *Cities Curr. Sustain. Energy Reports* **1** 111–20
[24] Singh R and Setiawan A D 2013 Biomass energy policies and strategies: Harvesting potential in *India and Indonesia Renew. Sustain. Energy Rev.* **22** 332–45
[25] Buyx A and Tait J 2011 Ethics. Ethical framework for biofuels *Science* **332** 540–1
[26] Mola-Yudego B, Arevalo J, Kortelainen J and Halder P 2014 Bioenergy: From Local Conflicts to Global Governance Oil *Gas Energy Law* **12**(4)
[27] Rimppi H, Uusitalo V, Väisänen S and Soukka R 2016 Sustainability criteria and indicators of bioenergy systems from steering, research and Finnish bioenergy business operators' perspectives *Ecol. Indic.* **66** 357–68
[28] Mohr A and Raman S 2013 Lessons from first-generation biofuels and implications for the sustainability appraisal of second-generation biofuels *Energy Policy* **63** 114–22
[29] Robledo-Abad C, Althaus H J, Berndes G, Bolwig S, Corbera E, Creutzig F, Garcia-Ulloa J, Geddes A, Gregg J S, Haberl H, Hanger S, Harper R J, Hunsberger C, Larsen R K, Lauk C, Leitner S, Lilliestam J, Lotze-Campen H, Muys B, Nordborg M, Ölund M, Orlowsky B, Popp A, Portugal-Pereira J, Reinhard J, Scheiffle L and Smith P 2017 Bioenergy production and sustainable development: science base for policymaking remains limited GCB *Bioenergy* **9** 541–56
[30] Tomei J and Helliwell R 2016 Food versus fuel? Going beyond biofuels *Land use policy* 56 320–6
[31] Scott J A, Ho W and Dey P K 2012 A review of multi-criteria decision-making methods for bioenergy systems *Energy* **42** 146–56
[32] Arodudu O T, Helming K, Voinov A and Wiggering H 2017 Integrating agronomic factors into energy efficiency assessment of agro-bioenergy production–A case study of ethanol and biogas production from maize feedstock *Applied energy* 198 426-439