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Svetlana Proskurina

INTERNATIONAL TRADE IN BIOMASS FOR ENERGY PRODUCTION: THE LOCAL AND GLOBAL CONTEXT

LUT
Lappeenranta
University of Technology

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INTERNATIONAL TRADE IN BIOMASS FOR ENERGY PRODUCTION: THE LOCAL AND GLOBAL CONTEXT

Thesis for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium of the Student Union House at Lappeenranta University of Technology, Lappeenranta, Finland, on the 31st of August, at noon.

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Abstract

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Biomass is an important source of renewable energy in the global energy mix. International trade in biomass is increasing. It is stimulating global use of biomass for energy and promoting development of bioenergy in many regions of the world. The markets for solid and liquid biofuels are developing rapidly. In the last ten years, international trade in energy biomass has increased considerably, especially direct trade, which grew from 200 PJ in 2004 to 600 PJ in 2015. However, despite the importance of trade in biomass for energy production, considerable uncertainty exists about many issues. What is the extent of trade required to meet European Union (EU) member states future bioenergy requirements? Where can this biomass be sourced and transported? Can the projected increase be done sustainably? What are the factors affecting terms of biomass trade?

The main aim of the thesis is to increase knowledge, insights and understanding of trade of biomass, and how is it developing, in order to facilitate the growth of biomass markets globally and locally. The thesis focuses on the status of biomass trade for energy in the global and local EU-Russia context. Within in the local EU-Russia context it is possible to show the international biomass trade streams in details. Europe is currently the major player in global biomass trade and Russia is one of the leading exporters of wood pellets to the EU. Wood pellets are the main traded solid biofuel, thus its market can be studied in more detail. The thesis presents a global overview of trade in solid and liquid biofuels, particularly wood pellets, biodiesel, and bio-ethanol, and biomass products such as industrial roundwood. The thesis presents the main production, export and import volumes of studied products as well as global trade streams including potential developments of emerging trade streams such as torrefied biomass. In addition, the thesis describes the role of bioenergy in renewable energy development in the EU, and in the local context, wood pellet markets in Finland and Russia.

The findings presented in the thesis are the outcome of seven articles presented in the second part of the work. The thesis comprises an introduction providing the background to the research questions, followed by individual papers considering various aspects of biomass in renewable energy, the wood pellet business, and the global trade in biomass.

The findings from the work indicate that due to the variety of available biomass resources and continuing supportive policy and regulation in many countries, biomass trade will continue to be an important aspect of renewable energy markets for the foreseeable future. Despite slow progress in bioenergy development encountered in several EU countries, currently the EU remains a leader in biomass utilization and trade. Based on the example of the Finnish and Russian markets, it is evident that wood pellet markets vary considerably in different countries and have different orientations. Thus, the study concludes that fertile ground exists for further development of international trade in biomass for energy production.

Keywords: bioenergy, biomass trade, EU renewable energy targets, wood pellets, biomass transportation, Russia, Finland

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The work presented in this doctoral dissertation was carried out in the Laboratory of Renewable Energy Systems, LUT School of Energy Systems, Lappeenranta University of Technology, Finland, between 2013 and 2018. The work has been motivated by issues considered as part of collaboration with IEA Bioenergy Task 40: Sustainable International Bioenergy Trade. My time at the Copernicus Institute of Utrecht University, Netherlands, in 2016–2017 enabled completion of a significant amount of research work, and I would like to express my thanks to all colleagues at the Copernicus Institute for an interesting and motivating atmosphere and excellent support.

I want to thank my co-authors – Richard, Martin, Eija, Mirja, Heli, Julia, Anton, Raghu, and Beysin – for their enthusiasm, contribution and support. I am also very grateful to Peter Jones from LUT Language Centre for help with the mysteries of the English language. Thanks are also due to our indispensable secretary, Piipa Virkki, who was always happy to help me with all work-related issues and administrative troubles.

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Thank you. Kiitos. Danke vel. Спасибо.

Svetlana Proskurina
18 July 2018
Lappeenranta, Finland

This work is dedicated to renewable energy.

Contents

List of publications

This thesis is based on the following papers. The rights have been granted by the publishers to include the papers in the dissertation.

I. Proskurina, S., Sikkema, R., Heinimö, J., and Vakkilainen, E. (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 and Bioenergy*, 95, pp. 64–77.

II. Proskurina, S., Heinimö, J., Mikkilä, M., and Vakkilainen, E. (2015). The wood pellet business in Russia with the role of North-West Russian regions: Present trends and future challenges. *Renewable and Sustainable Energy Reviews*, 51, pp. 730–740.

III. Proskurina, S., Rimppi, H., Heinimö, J., Hansson, J., Orlov, A., Raghu KC., and Vakkilainen, E. (2016). Logistical, economic, environmental and regulatory conditions for future wood pellet transportation by sea to Europe: The case of Northwest Russian seaports. *Renewable and Sustainable Energy Reviews*, 56, pp. 38–50.

IV. Proskurina, S., Alakangas, E., Heinimö, J., Mikkilä, M., and Vakkilainen, E. (2017). A survey analysis of the wood pellet industry in Finland: Future perspectives. *Energy*, 118, pp. 692–704.

V. Proskurina, S., Heinimö, J., Schipfer, F., and Vakkilainen, E. (2017). Biomass for industrial applications: The role of torrefaction. *Renewable Energy*, 111, pp. 265–274.

VI. Proskurina, S., Junginger, M., Heinimö, J., and Vakkilainen, E. (2017). Global biomass trade for energy – Part 1: Statistical and methodological considerations. *Biofuels, Bioproducts and Biorefining*, Accepted. In Press.

VII. Proskurina, S., Junginger, M., Heinimö, J., Tekinel, B., and Vakkilainen E. (2018). Global biomass trade for energy – Part 2: Production and trade streams of wood pellets, liquid biofuels, charcoal, industrial roundwood and emerging energy biomass. *Biofuels, Bioproducts and Biorefining*, Accepted. In Press.

In the thesis, these publications are referred to as *Publication I, Publication II* and so on.

Author's contribution

The author is the principal investigator and corresponding author of all the publications. The author generated the ideas and conclusions that are presented in the publications.

The regular co-authors, Esa Vakkilainen and Jussi Heinimö, significantly helped to guide the ideas into more precise and comprehensible forms and reviewed the papers prior to submission to the journals for publication.

The work presented in Publication I was carried out in collaboration with Richard Sikkema, who helped to provide data about bioenergy development in EU countries, including latest news, and reviewed drafts of the paper. Mirja Mikkilä helped with paper structure and reviewed drafts of the paper in Publication II and Publication IV.

In Publication III, Heli Kasurinen (née Rimppi) was responsible for the environmental management aspects of the study. She provided Section 6 Environmental conditions and 7 Regulatory conditions (excluding the review of DINplus and ENplus pellet quality certifications). Julia Hansson and Raghu KC helped with the later stages of the work by providing valuable comments and suggestions. Anton Orlov helped with finding up-to-date data about the Russian wood pellet industry.

In Publication IV, Eija Alakangas helped with data collection about Finnish wood pellets, including standardization techniques, and reviewed drafts of the paper. Fabian Schipfer helped with data collection and paper structure in Publication V. In Publication VI and VII, Martin Junginger helped with data collection and reviewed the papers prior to submission to the journals. Beysin Tekinel helped with data collection at the beginning of the study in Publication VII. Publication VI and Publication VII present results of a study linked to IEA Task 40 entitled "Update Study of International Energy Biomass Trade".

Related publications (not included in the thesis)

During work on this thesis, the author was involved in the projects of Task 40 – Sustainable International Bioenergy Trade: Securing supply and demand, IEA Bioenergy, 2016–2017, and participated in the following publications:

Wild, M., Deutmeyer, M., Bradley, D., Hektor, B., Hess, JR., Nikolaisen, L., et al. (2016). Possible effects of torrefaction on biomass trade. *IEA Bioenergy Task 40*. 68 p.

In this report, the author contributed mainly Chapter 8 titled "Possible new industrial users of torrefied biomass."

Thrän, D., Peetz, D., Schaubach, K., Backéus, S., Benedetti, L., Bruce, L., et al. (2017). Global Wood Pellet Industry and Trade Study 2017. *IEA Bioenergy Task 40*. 243 p.

In this report, the author was responsible for chapters about wood pellet markets in Baltic countries (Estonia, Latvia and Lithuania), Ukraine, Finland, Poland and Russia.

Proskurina, S., Heinimö, J., Mikkilä, M., and Vakkilainen, E. (2017). Data demonstrating the Finnish wood pellet industry and future perspectives. *Data in Brief*, 10, pp. 41–43.

Proskurina, S., Heinimö, J., and Vakkilainen, E. (2018). Policy forum: Challenges of forest governance: biomass export from Leningrad oblast, North-West of Russia. *Forest Policy and Economics*, 95, pp. 13–17.

Conference proceedings

Proskurina, S., Vakkilainen, E., Heinimö, J., and Mikkilä, M. (2014). The Russian wood pellet business: exports to the Nordic Area. 22nd European Biomass Conference and Exhibition, 23–26 June. Hamburg, Germany.

Proskurina, S., Heinimö, J., Mikkilä, M., and Vakkilainen, Esa. (2015). The wood pellet business in Finland. 23rd European Biomass Conference and Exhibition, 1–4 June. Vienna, Austria.

Proskurina, S., Heinimö, J., Mikkilä, M., and Vakkilainen, E. (2015). The wood pellet business in Finland: future perspective. Book of Proceedings Bioenergy 2015, 4–9 September. Jyväskylä, Finland.

Proskurina, S., Heinimö, J., and Vakkilainen, E. (2016). Challenges of Russian forests and its impact to the export. Book of Proceeding Bioenergy from Forest 2016, 1–2 September. Jämsä, Finland.

Proskurina, S., Heinimö, J., and Vakkilainen, E. (2017). Wood pellet export from Russia: review of main importers. Young Researchers Conference: Energy Efficiency & Biomass, 1–3 March. Wels, Austria.

Thrän, D., Peetz, D., Schaubach, K., Trømborg, E., Pellini, A. Lamers P., et al. (2017). Global wood pellet industry and market - current developments and outlook. 25th European Biomass Conference and Exhibition, 12–15 June. Stockholm, Sweden.

Proskurina, S., Sikkema, R., Heinimö, J., and Vakkilainen, E. (2017). How are the EU Member States contributing to the 27% target for EU's renewable energy consumption - the role of woody biomass. 25th European Biomass Conference and Exhibition, 12–15 June. Stockholm, Sweden. (EUBC&E 2017 Student awards)

Proskurina, S., Junginger, M., Heinimö, J., and Vakkilainen, E. (2017). Trade of energy biomass - an overview of the global status. 25th European Biomass Conference and Exhibition, 12–15 June. Stockholm, Sweden.

Abbreviations

CO_2	Carbon dioxide
EU	European Union
EIA	The U.S. Energy Information Administration
IEA	International Energy Agency
IEA ETP	International Energy Agency- Energy Technology Perspectives
MS	Member state of the European Union
NREAP	National Renewable Energy Action Plan, submitted by a Member State according to article 4 of directive 2009/28/EC in 2010 to the European Commission
RE	Renewable energy
REN21	The Renewable Energy Policy Network for the 21st Century
RES	Renewable energy sources
UNEP	The United Nations Environment Programme
USA	The United States of America
WBA	World Bioenergy Association
WEC	World Energy Council
WWF	World Wildlife Fund

1. Introduction

> "In a sense, the fossil fuels are a onetime gift that lifted us up from subsistence agriculture and eventually should lead us to a future based on renewable resources."
>
> (Kenneth Deffeyes, 2001)

Global energy consumption has increased by at least 35% since the year 2000, reaching 567 EJ in 2013 (BPstat, 2015; WBA, 2016; IEA, 2016), with growth forecast to continue (EIA, 2017). Renewable energy sources (RES) accounted for about 15% (72 PJ) of total energy consumption in 2013 (IEA, 2015). For comparison, in 2008, this share of renewables was 13% (67 PJ). The importance of RES has grown due to increasing demand for CO_2-free energy, concerns about environmental sustainability, and a desire to decrease dependence on fossil fuels. Moreover, renewable energy (RE) projects have increased in popularity in many parts of the world due to the localized economic benefits such developments bring (WWF, 2011; REN21, 2017; UNEP, 2017).

One of the important renewable and sustainable energy sources is biomass. In addition to direct burning to obtain energy, biomass can also serve as a feedstock to be converted into various liquid (or gas) and solid fuels (biofuels). Biofuels can be transported and stored, and allow for heat and power generation on demand, which is essential in an energy mix with a high dependence on intermittent sources such as wind (Ellabban et al., 2014; Guo et al., 2015).

In world renewable energy supply, solid biofuels are by far the largest renewable energy source, representing approximately 66% of global renewables. This large share can be explained by the widespread non-commercial use of biomass in developing countries (traditional biomass use), for example, for residential heating and cooking (IEA, 2016; Kaygusuz et al., 2017). In the heating sector, approximately 95% of total RE is derived from biomass (WBA, 2016; IEA ETP, 2017; REN21, 2017).

The modern use of biomass for energy production has grown in the past decade, especially in the developed countries. Great interest is shown in the opportunities offered by bioenergy, particularly in view of the gradual development of more modern and efficient bioenergy production systems (modern biomass use). Many countries are building new heat and power plants, and boiler stations that use solid and liquid biofuels, and existing plants are being converted to enable the combustion of biofuels. However, in many developed countries, the internal biomass potential and domestic biofuel production capacity is insufficient to meet the energy needs of the country. Thus, international trade in biomass and biofuel products is becoming increasingly important and traded volumes are rising (Junginger et al., 2014).

Despite its importance, studies of biomass trade are still limited and many uncertainties exist (Lamers, 2013; Junginger et al., 2014; Brack, 2017). This thesis focuses on several knowledge gaps, such as finding reliable up-to-date data about traded volumes and motivations for trade. Moreover, this thesis studies the implementation of bioenergy trade in the EU-Russia context for wood pellets in terms of economic impact and regional development of policy side conditions that can significantly increase the understanding of biomass trade in general.

1.1 Aim

International biomass trade includes many different regions and biomass products. It is impossible to cover all possible biomass products, exporting and importing countries. Thus, this thesis focuses only on main tradeable ones with the focus on the EU, the main player in biomass trade. The EU imports biomass products from different countries such as the Southeastern United States, Russia and Canada. Globally, the main tradable biomass products are wood pellets, biodiesel and bioethanol. Some trade streams are more studied that others, for example, the biomass trade between the EU and the USA, mainly Southeast region (for example, Dwivedi et al., 2016; Fingerman et al., 2017). Whereas, in comparison, the trade between the EU and Russia has received less attention.

The main aim of this thesis is to increase knowledge, insights and understanding of trade in biomass in order to facilitate the development of biomass markets for the whole world and concrete regions such as the EU and Russia. This thesis focuses on biomass used for energy production purposes. Figure 1 presents the major research areas of this thesis, superimposed on the global map of main biomass products trade for energy purposes.

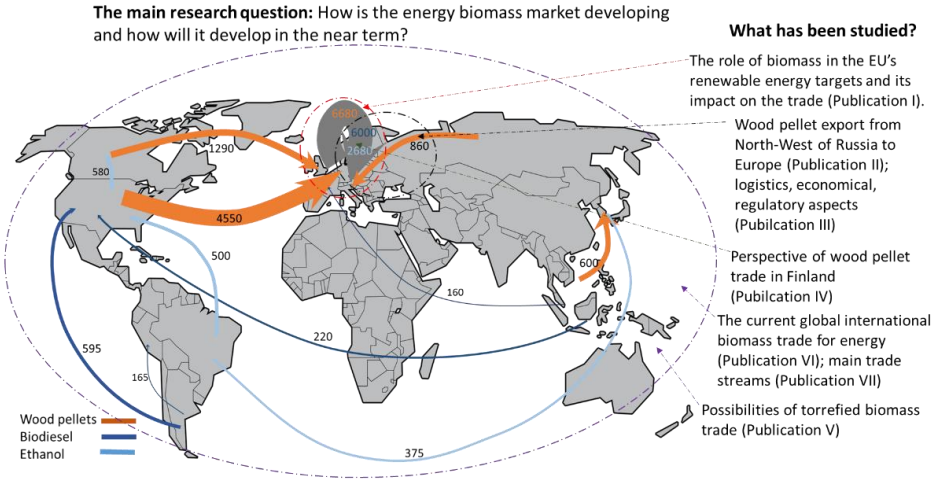

Figure 1: International trade in wood pellets, biodiesel and bioethanol, in ktons, in 2015 (for source see Publication VII) and research areas addressed in the study.

1.2 Outline of the thesis

This doctoral thesis is composed of seven scientific publications fully or partly investigating biomass trade for energy production. The publications are appended in the thesis not in chronological order of publication but following the logic of topic disclosure.

Following an introduction to the work, Chapter 2 “International trade in biomass for energy” describes the main characteristics of international biomass trade for energy production and presents the role of the EU and wood pellets by collecting and reviewing the latest and most important available studies.

Chapter 3 “Research goal and methodology” gives an overview of the research topics, research questions, objectives and methods, and the scope of the study. The chapter assists understanding by placing the research questions addressed in each individual publication within the context of the work as a whole.

Following the description of the research area, Chapter 4 “Overview of the publications” summarizes the key findings of the papers included in the thesis. Chapter 5 “Conclusions” closes the thesis by highlighting the scientific contribution of the thesis and making suggestions for future work.

2 International trade in biomass for energy

Potential for development of bioenergy varies greatly in different countries and regions depending on geographical terrain, agricultural productivity, industrial structure and other factors. Some countries have limited biomass resources, insufficient to satisfy their own needs for bioenergy, whereas other countries, such as Russia, have an abundance of biomass resources. For example, in the Netherlands and Belgium, current use of biomass exceeds local renewable biomass resources (Scarlat et al., 2015; Dafnomilis et al., 2017). While, in Russia, only 12% of bioenergy potential is currently utilized. Due to the availability of fossil fuel resources, and for policy and economic reasons, Russia is not very active in bioenergy development (Pristupa and Mol, 2015; Namsaraev et al., 2018). The geographical distribution of biomass resources and a misalignment between supply and demand for biomass has led to the development of international trade in biomass in solid and liquid forms. This market is undergoing rapid change and is becoming increasingly international, with progressively more regions and countries participating in biomass trade.

2.1 Biomass trade for energy production

Biomass for energy production can be classified as directly and indirectly traded biomass for energy. Indirect trade is defined as trade of the fraction of biomass traded primarily for a material purpose (e.g. roundwood to be processed into sawnwood in the destination country) that ultimately ends up being utilised for energy production through the use of processing residues (e.g. sawdust). With such indirectly traded biomass, bioenergy is usually only produced as a by-product, yet the amounts of bioenergy produced can be substantial. For example, Finland imports large amounts of raw wood products such as logs, pulpwood and chips from Russia for production of processed materials, and during the manufacturing processes of the primary products, a significant part ends up in energy production or is converted into by-products that are utilized in energy production (Heinimö and Junginger, 2009; Heinimö, 2011).

Wood pellets and bioethanol are typical examples of biofuels that are widely traded worldwide directly for energy production. Markets for liquid biofuels (e.g. bioethanol and biodiesel) are closely related to agricultural commodities, and such fuels are mostly used as transport fuels. Solid biofuels (e.g. wood pellets) mainly originate from the forestry and wood processing sectors and are predominantly used in renewable electricity and heat production. In comparison with liquid biofuels, markets for solid biofuels are less complex and the trade dynamics are more straightforward (Junginger et al., 2014).

International biomass trade is growing. The question of where to find biomass resources will continue to be important. In the long term, it can be one of the most challenging questions. Woody biomass is likely to remain overwhelmingly the biomass fuel of choice for electricity generation and heat, at least in the short and medium term.

Agricultural wastes and residues, which are important sources of biomass energy in China, India and Brazil, have considerable uncertainty over the likely availability of land for their cultivation, among other factors. Woody biomass use is popular in Europe, North America and Japan. The EU wood demand has been increasing and, as a result, import from countries such as the USA and Canada increased (Brack, 2017). It seems that in the long-term, the EU import from all possible places such as Russia will be crucial.

International biomass trade is a complex topic that includes many different issues and challenges, such as the interaction between policies and market forces. It is possible to see, for example, on the study by Lamers (2013) which investigates issues regarding sustainable international bioenergy trade, evaluating the impact of sustainability criteria and policy on past and future bioenergy supply and trade, as well as their impact on the global bioenergy trade. Thus, it is important to investigate sustainable aspects of international bioenergy trade, including analysis of feedstock-specific environmental risks to define potential future environmental criteria for EU bioenergy trade. These environmental requirements may significantly influence future woody biomass trade in a globally competitive market.

In addition to methodological aspects of direct and indirect biomass trade and its estimation, Heinimö (2011) focuses on bioenergy in Finland as a local case study, and sustainability schemes for international bioenergy flows. Using a questionnaire based approach the study develops scenarios for international markets for energy biomass. The main finding of these scenarios is that the market for biomass will diversify and grow rapidly by 2020. Assessing the perspective of international bioenergy trade for the medium (2030) and long-term (2070), Kranzl et al. (2014) compare scenarios of possible biomass trade that was done by different organizations including research institutions. Scenarios have been compared in terms of global bioenergy demand and production, in addition to comparing the bioenergy demand, bioenergy production and net trade balance of bioenergy in 20 world regions. Scenarios focus on the biophysical trends and observed historic behaviour under certain conditions and assumptions rather than making predictions. The study concludes that almost all scenarios indicate that trade in bioenergy will experience a huge increase in the coming decades. As bioenergy trade is increasing, it is important to study the future role of Russia to supply e.g. pellets to the EU.

2.2 Role of the EU in international biomass trade

The European Union has set a target of raising the share of EU energy consumption produced from renewable resources from 20% by 2020 to 27% by 2030 (European Commission, 2016). The EU has ambition to become the world leader in renewable energies. In 2010, all member states had to submit national renewable energy action plans (NREAP) (European Commission, 2012). These NREAP indicate that many EU countries consider increasing use of bioenergy crucial to achieving their renewable

energy targets. In the EU, among RES, wood and other solid biofuels as well as renewable wastes accounted for 49.4% of primary renewables production in 2016. Although the rate of bioenergy increase is less than solar and wind, the increase in bioenergy use will be important in the RE mix of the EU (Eurostat, 2018). Wood and solid biomass remains the biggest source of RE in the EU (AEBIOM, 2017; Eurostat, 2018).

Assessing international biomass trade for bioenergy in the context of RE deployment scenarios for the EU-27, Hoefnagels et al., (2014) suggest that the share of imported biomass will increase in order to achieve the 20% renewable energy target in 2020. Presenting, for EU-27, three different scenarios of future biomass development in the heat, electricity and transport markets, and evaluating the role of biomass in NREAP, van Stralen et al. (2013) concluded that the share of imported biomass, mainly wood pellets and biofuels, is high in all the scenarios. Theoretically, the overall sustainable biomass potential is large enough to cover projected total bioenergy demand by 2020 and 2030 (Panoutsou et al., 2015). The EU has other unused biomass potential, such as manure, roundwood and straw; however, its usage for energy production is expensive.

The EU is the main player in international trade in solid and liquid biofuels (Figure 1). Based on calculations of total EU biomass demand and potential, Scarlat et al. (2015) suggest that biomass can feasibly contribute almost 60% of the EU Renewable Energy target and about 12% of final energy use in the European Union by 2020. Import and intra-EU trade of biomass will be vital to match biomass supply and demand in different regions in Europe and for reaching EU renewable energy targets (Scarlat et al., 2015; Sanchez et al., 2016). Thus, looking at development of international biomass trade for energy production, and the role of the EU in it, will continue to be important.

2.3 Role of wood pellets in international biomass trade

The most commonly found and most widely used energy pellets are wood pellets, often made from side streams from sawmilling and wood products manufacture. Globally, the importance of wood pellets in the energy mix is increasing, and a large number of countries are using wood pellets in old and new heating plants and thermal power stations (Cocchi et al., 2011; Kuparinen et al., 2014). Wood pellets, unlike raw wood, contain very low levels of moisture and produce little ash, so virtually all of the material is burned and converted to heat. Compared with other solid biomass fuels, pellets are easy to handle, store and transport. Moreover, standards and certifications were developed for wood pellets (Duca, et al., 2014).

In light of these benefits, wood pellets have become one of the fastest-growing internationally traded bioenergy-based commodities (Junginger et al., 2011; Olsson et al., 2011; Thrän et al., 2017). Global production of wood pellets increased from 27 million tons (2014) to about 36 million tons (2016) of which about 13.5 million tons and 14 million tons were produced in the EU in 2014 and 2016 respectively. All EU-domestic wood pellet production was consumed in the EU, plus an additional 5.3

million tons (2014) and 14 million tons (2016) imported from non-European countries respectively (Searcy et. al., 2016; AEBIOM, 2017).

The study by Sikkema (2014) had as one of its research questions consideration of market changes in woody biomass markets as regards future suppliers and supply logistics, including mobilization of woody biomass for energy. The study concluded that wood pellets imported from outside the EU will have a significant impact on expected future growth (2020 and beyond) in woody biomass use by the EU energy sector (Sikkema, 2014).

Interest in the use of wood pellets in the EU drives the wood pellet production (mainly for export) in several non-EU countries with weak bioenergy development such as Russia. Russia, in common with many other former Soviet republics, has very large biomass resources, and the region has great potential for increased bioenergy exports. Solid biofuels (mainly wood pellets) trade is the mainstay of such exports. There are almost no exports of liquid biofuels. Wood pellet production increased greatly in North-West Russia and in the Russian Far East (aiming to feed East Asian markets) in 2010–2012 (Matzenberger et al., 2015). After the USA and Canada, Russia is the third largest exporter of wood pellets to the EU. However, due to fast-growing global wood pellet markets, Russia's share of the EU market dropped from 16% in 2009 to 11% in 2015 (Sun and Niquidet, 2017).

One of the reasons for popularity of global wood pellets trade is its suitability to long distance transportation thanks to attractive technical characteristics. However, there are solid biofuels products with even more attractive technical characteristics. Discussing international biomass trade and wood pellet markets, several studies (e.g. Alakangas et al., 2012; Goh et al., 2013) note that torrefied biomass may become a new traded commodity between different countries, such as the EU and the USA. Torrefaction is a mild pre-treatment of biomass at a temperature of between 200 and 300°C, which improves the fuel quality for combustion and gasification applications and, in combination with palletisation, significantly improves logistics. The key advantage of pressing torrefied biomass into pellets and briquettes is a higher energy density per volume. In case of torrefied wood, the bulk density can be increased from 200–400 kg/m^3 for the torrefied wood chips to about 650–720 kg/m^3 for torrefied pellets (approximately 600 kg/m^3 for conventional wood pellets), depending on species and processing conditions (Wild et. al., 2015). Torrefied pellets have substantially lower costs for handling and storage than traditional pellets. Their use increases the potential share of co-firing with coal (higher end-use efficiency) and reduces both cost and greenhouse gas emissions (Nunes et al., 2014; Chen et al., 2015).

3 Research goals and methodology

The international biomass trade is changing and developing. This thesis addresses several research questions related to international trade in biomass for energy. Examination of these issues aims to increase understanding of biomass markets and their current and future development. The work in this thesis uses several different methodological approaches. In each publication, the research method was selected based on its suitability for the research issue at hand.

3.1 Research questions and objectives

Despite the importance of the biomass trade, many questions remain insufficiently investigated and inadequately understood. This doctoral thesis attempts to address some of these gaps. In the large context of international biomass trade, a few important aspects were chosen for study (Figure 2). The overall objective of this thesis is to analyse recent developments in international biomass trade for energy production especially in the EU-Russia context and to explore the potential future evolution of such biomass trade. The starting point of this thesis has been the uncertainties in a number of issues connected with energy biomass markets: the role of bioenergy in renewable energy development in the EU, development of bioenergy wood pellet markets in the EU and Russia, challenges related to identifying the current status of international trade of biomass for energy purposes and the role of Russia in global bioenergy trade.

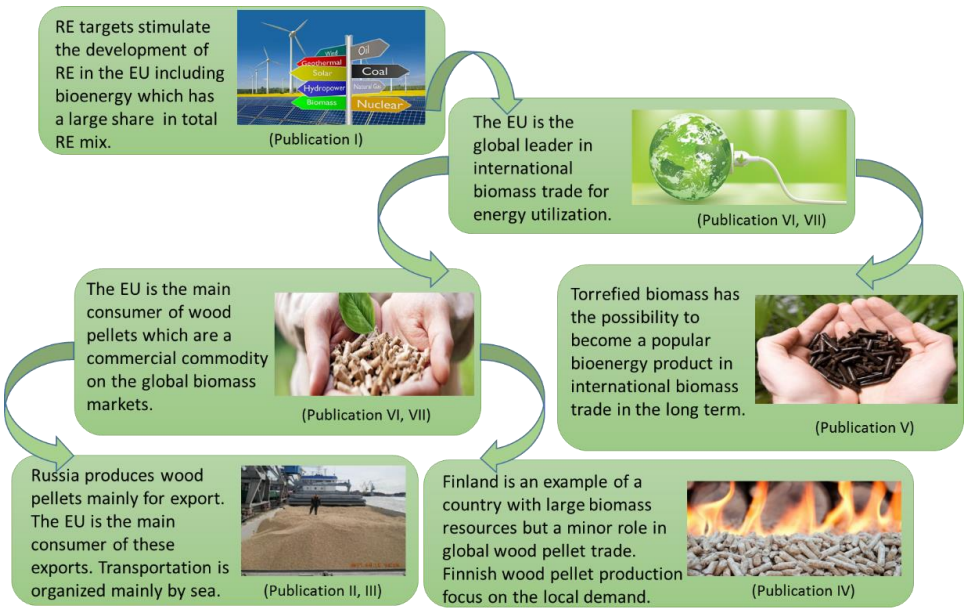

Figure 2: The main studied statements and their relations.

The major research questions of this thesis are:

Q1. What efforts have been made by each EU member state to achieve the national biomass targets set in their NREAPs and how much of the biomass target in their overall RE target is covered by the international biomass trade?

Q2. What are the prospects for Russian wood pellet production, development and wood pellet export from North-West Russia to the EU? What role will the Russians play in the EU wood pellet markets?

Q3. What are the prospects for Finnish wood pellet production, development and consumption as well as participation in global wood pellet trade? What role will the Finns play in the wood pellet markets?

Q4. What can be said about the role of a new emerging solid biofuel, torrefied biomass, on global biomass markets?

Q5. How has the current comprehensive status of global trade in biomass developed since 2004?

Although, the questions cover slightly different focus areas, they are closely connected, as can be seen in Figure 3. For example, the second and third questions are oriented to issues related to wood pellet markets, and the first four questions form part of the subject studied on the final question.

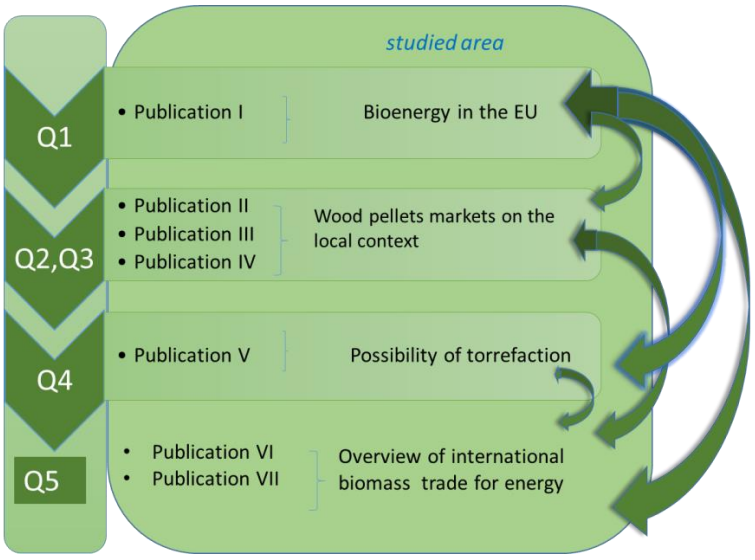

Figure 3: Relationships between the research questions studied.

3.2 Research methods

The first question was posed to gain a better understanding of the role of biomass in total RE targets (Section 2.2) and to acquire improved knowledge of the impact of international trade in biomass on bioenergy development in the EU. It was found that, in order to help identify differing trends and developments, the 28 EU member states could be divided into groups based on performance as regards attainment of local biomass targets: leading, intermediate and lagging countries. The division is based on the difference of the share of biomass consumption and progress towards their, often ambitious, 2020 bioenergy targets. It seemed that this division clarified the individual country position so the research question could be addressed more specifically. The study also included a sub-section reviewing related literature and listing the most recent and relevant studies (Publication I).

In order to better understand the challenges of bioenergy export to the EU, trade of wood pellets from North-West Russia to Europe was investigated. The Russian wood pellet industry was first described based on a review of the literature (Publication II) and then deeper analysis of sea transportation of wood pellets considering logistical, economic, environmental and regulatory factors was performed, including observations based on expert communications (Publication III).

Using the example of Finland, the third research question aimed to improve understanding the reasons why some countries with an abundance of biomass resources do not hold a significant position in the global trade in wood pellets. To collect comprehensive information about the current situation of the Finnish wood pellet industry and perspectives for future development, Publication IV used a survey method. The questionnaire contained thirteen different questions about closely related issues, which were grouped thematically to make the responses easier to analyse and interpret. In addition to findings about the Finnish wood pellet industry, Publication IV includes discussion of challenges and advantages of the research method applied.

The aim of the last question was to construct an up-to-date overview of international trade in biomass at a global level. Changes in trends that have occurred over the past decade are addressed and previous studies regarding international trade in biomass updated. Based on literature review and personal communications with experts, methodological challenges related to global biomass trade evaluation (Publication VI) and emerging biofuel trade streams (Publication VII) were investigated. Torrefied biomass is identified as one of several emerging biomass trade streams that can be expected to see development in the long term. To identify the technical potential of torrefied biomass, optimistic, pessimistic and mostly likely scenarios are discussed (Publication V). Table 1 summarizes the main research methods applied in the respective publications.

Table 1: Cross reference table indicating which Question (Q) does each Publication (P) answer, what was the method used to answer and what were the data sources used to reach the answers.

P	Q	Title of Publication	Method	Data source
I	1	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.	Literature review, division EU countries into groups.	Literature data, personal communication.
II	2	The wood pellet business in Russia with the role of North-West Russian regions: Present trends and future challenges.	Literature review.	Literature data, personal communication.
III	2	Logistical, economic, environmental and regulatory conditions for future wood pellet transportation by sea to Europe: The case of Northwest Russian seaports.	Case study, literature review, interviews.	Literature data, personal communication.
IV	3	A survey analysis of the wood pellet industry in Finland: Future perspectives.	Survey method, literature review.	Literature data, interviews, structured questionnaire.
V	4	Biomass for industrial applications: The role of torrefaction.	Scenarios method, literature review.	Literature data.
VI	5	Global biomass trade for energy - Part 1: Statistical and methodological considerations.	Literature review.	Literature data, personal communication.
VII	5	Global biomass trade for energy - Part 2: Production and trade streams of wood pellets, liquid biofuels, charcoal, industrial roundwood and emerging energy biomass.	Literature review.	Literature data, personal communication.

3.3 Research limitations

International biomass trade for energy is a very broad topic involving different countries, different legislative environments, and different biofuel products. This study covers both global and local contexts, focusing on the EU, Finland and Russia. This thesis focuses mostly on wood pellets as the most tradable solid biofuel product on the international biomass markets. The two publications that highlight liquid and solid biofuels (Publication VI and Publication VII) focus on industrial roundwood, wood chips, fuel wood, wood pellets, biodiesel, bio-ethanol, and palm oil used for energy purposes. Other products such as used cooking oil, wood waste, municipal solid waste, biochar, bio-jet fuel and pyrolysis oil are omitted from consideration because of the difficulty of differentiating whether they are traded for energy or other purposes, and because of an absence of reliable data.

The study excludes many products that can be part of indirect trade in biomass for energy. For example, exported paper or cardboard can return to the producing country within packaged products and later be utilised in energy production as recovery fuel or biogas. A large amount of agro-residues such as rice husks, potato peelings, coconut shells, banana peel, and shells of all kinds of nuts (peanuts, walnuts, cashews etc.) can end up being used for bioenergy in an importing processing country. However, the volumes traded are difficult to assess, and they can be assumed to be minor in comparison with, for example, roundwood trade. Such products with potential for use in bioenergy production are thus excluded from this thesis. Of the products studied, wood chips and particles as well as industrial roundwood are considered as indirect trade for bioenergy. Trade in wood chips is primarily for pulp and paper production. Figure 4 presents limitations of the study.

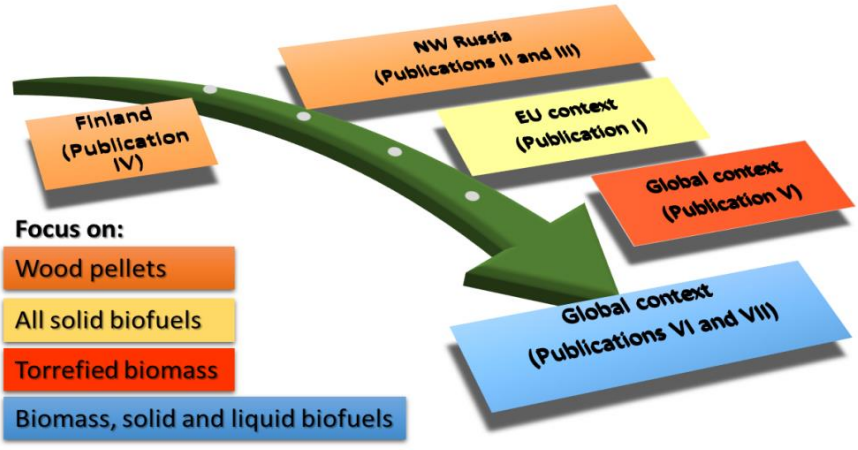

Figure 4: Limitations of the study.

Indirect trade evaluation volumes presented in this thesis have an approximate estimation. Firstly, national statistics of most countries do not differentiate between imported roundwood used as raw material for wood processing industry production and for energy production. For example, statistics of the Food and Agriculture Organization of the United Nations (Faostat, 2017) allocate products to different product groups and present volumes for logs and pulpwood that are assumed to be entirely for use as raw material, and simultaneously for fuel wood and waste wood. Secondly, there are often no statistics in literature resources about the use of by-products from different material applications. Thirdly, it is difficult to estimate the degree of utilization for energy purposes of wood residues from imported roundwood and from roundwood produced domestically (Publication VI).

In addition to the above limitations, it should be noted that not all trade streams are fully analysed by the research community. For example, biomass trade between Canada, the USA, as well as Asian countries is presented in Publications VI and VII but without detailed discussion, as such discussion would extend the scope of the study to an unmanageable degree.

The study focuses mostly on current biomass trade and presents relatively short-term perspectives. Publication I includes recommendations for further development of biomass for energy in the EU excluding detailed scenarios of future bioenergy development. Publication II and Publication III consider to some extent future possibilities of Russian wood pellet industry development, and Publication IV presents perspectives for Finnish wood pellet markets focusing on the current status. In Publication VI and Publication VII, detail analysis of possible future scenarios of global biomass trade for energy is outside the scope of the study. Publication V is more oriented to a long-term perspective and presents predictions of possible future markets of torrefied biomass.

3.4 Reliability and validity

The study is mostly empirical and descriptive, where the valuation of reliability and validity is not easy task. Getting the similar results by using different instruments such as a survey, personal communication and literature review increases the reliability of the study (Shank, 2006). Thus, to increase the reliability of research, in this study different methods have been used. The main data collection methods employed in the study were a survey, a literature review and discussions with experts. Data on different available resources including statistics by different organizations were collected and compared.

In order to improve the comparability of different data sources, the study tries to be explicit in training and rechecking. For example, data about wood pellets exports, production and consumption (Publication II and Publication III) varies depending on the source. A large amount of work was done to compare the sources including finding the possible personal interest of each data sources. This study tries to draw from available resources for the most accurate and honest view without any personal interest. Included

publications in this thesis were rewritten many times in order to be as exact as possible. For example, Publication III covers the very fuzzy area of Russian wood pellet logistic; therefore, several revisions were needed, based on updated data. Different experts including a large number of co-authors read and commented on this data, which helped to clarify the various items.

Data about Finnish wood pellet production, consumption, export and import is mostly similar in all literature sources for Finland (Publication IV). However, the future perspective of wood pellets and the main factors inhibiting and stimulating wood pellet industry developments seems unclear. In order to achieve a better view, literature review is combined with survey method. Survey method has strengths and weaknesses that are discussed in methods section of Publication IV. Moreover, discussion includes how the weaknesses were treated. For example, the first two questions were about participants themselves and provided an overview of the background of the respondents and their familiarity with wood pellets and bioenergy in general. This information helped to ensure the validity of the answers. Avoiding missing answers, all questions were compulsory for respondents. To avoid misunderstandings of questions by respondents and false answers, the survey includes different kinds of questions and has similar questions posed at different context related to similar (single) issues. To ensure accuracy each question was treated as if it was a tiny version of the test. Thus, a series of questions are combined to give a picture of one complex concept of the wood pellet industry (Publication IV).

4 Main findings and results

This chapter presents an overview of the research publications included in the thesis. The appendix part of the thesis includes full publications, which are journal articles. For each of the publications, the objectives, results and their relation to the thesis as a whole are briefly discussed. The relationship of each publication to the research area studied can also be seen from Figure 3 in Section 3.1.

4.1 Publication I: 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

4.1.1 Research objectives

In addition to the overall EU RE target (Section 2.2), each EU member state has its own local renewable energy target. In most cases, countries divided this into categories and thus set a specific target regarding bioenergy development expressed in their NREAPs. The objective of Publication I is to examine the overall expected contribution of biomass to total RE in each EU country up to 2020 and, more specifically, to evaluate the impact of solid biomass on EU energy consumption derived from renewable resources.

4.1.2 Results

Many EU members have actively contributed to meeting EU RE targets and a trend of increasing renewable energy usage in gross final energy consumption can be observed throughout the EU. Interest in bioenergy development varies between EU countries. Some countries are very progressive in bioenergy sector development, such as Finland and Sweden, whereas others are less dynamic, for example Belgium, Italy and Spain. The differences can be explained by a combination of historical factors, biomass resources potential and policy focus on bioenergy. Of the EU countries the Netherlands and the United Kingdom are the most likely to face the prospect of not meeting their own biomass targets.

The expected share of biomass in the EU is expected to be in 2020 about 45.1% from total renewable share, followed by wind (17.2%), hydropower (12.9%), biofuels (11.9%) and solar (6.2%) by 2020. This means that biomass is going to remain a significant and even dominant renewable energy source for some time.

EU's biomass primary demand is expected to increase from 5.3 EJ in 2013 to 7.4 EJ in 2020. This has already created live debate on how this increase can be sustainably sourced. The international biomass trade will be a significant part of the answer.

In the study the EU was divided into three groups based on their progress toward self-determined 2020 biomass usage target.

For countries that already reach their national biomass targets or have a difference less than 15% (Group 1), woody biomass plays an important role for electricity generation and heating and cooling sector, mostly for Finland, and Austria. For Romania, for example, wind and solar are more priority RE sources and biomass is lagging behind. However, this country has a potential for solid biomass use in heating and cooling sectors. Romania and Austria with Lithuania (from 2 Group), have woody biomass potential higher than demand. Thus, woody biomass development is very promising and supply from these countries to other European Members will take place. Finland, Romania, Austria and Sweden have a large biomass potential. For Poland and Slovenia woody biomass supply from other EU countries is important. Germany has seen promising development of biomass.

Intermediate countries (Group 2) are countries whose biomass still needs to increase from 15% to 30%. They have a realistic likelihood of reaching their own local biomass targets and will probably increase the share of woody biomass more rapidly than in previous years, thanks to policy support of RE promotion in heat and electricity production. Latvia and Lithuania has seen promising development of biomass and may soon match the performance of Group 1. Italy and Slovakia are likely to increase woody biomass use for heat and electricity production. Italy will be a key importer of woody biomass in the EU.

Lagging countries (Group 3) are countries whose required biomass share increase is more than 30% (Group 3). France and the United Kingdom (with Germany from 1 Group) have huge domestic energy consumption; thus, the development of renewables in these countries is crucial and their success will significantly influence the overall EU share of renewables. Solid biomass use in electricity and heat production is therefore important in France and the United Kingdom. If these countries can further increase biomass share in gross final energy consumption, it will positively affect their national RE targets and, as a result, the total RE share of the EU-28. France (with Germany from Group 1) have large unused potential of solid biomass, while for the United Kingdom , development of solid biomass imports, mainly wood pellets, will play a crucial role. Despite the RE support in the electricity and heat sectors, France and the United Kingdom will still not comply with their own RE target due to a large difference between current and expected share of renewables by 2020. For France and Belgium, solid biomass will play a crucial role in electricity from RES and a smaller role for heat from RES by 2020.

4.1.3 Contribution to the overall picture

In most EU countries, biomass trade plays an important role in bioenergy development. For example, the Netherlands, the United Kingdom and Belgium, which have limited biomass resources and biomass demand greater than technical biomass potential, rely on biomass imports.

The greatest problems achieving bioenergy targets are found in EU member states having relatively high energy consumption: France and the United Kingdom. It is unlikely that these countries can comply with expected renewable energy demand through bioenergy, unless they engage more in bioenergy trade. Similarly, Finland, which has an abundance of biomass resources, imports a large amount of biomass from Russia for energy purposes.

Estimation of bioenergy contribution to EU RE targets helps to understand the role, actual and potential, of the EU on global international biomass markets (Publication VI and Publication VII). One of the measures that can increase the likelihood of EU member states reaching their bioenergy targets is to improve biomass logistics within the EU and with nearby regions such as North-West Russia (Publication II and Publication III).

4.2 Publication II: The wood pellet business in Russia with the role of North-West Russian regions: Present trends and future challenges

4.2.1 Research objectives

Russia is one of the main exporters of wood pellets to the EU (Section 2.3). The majority of Russian wood pellet production plants (approximately 60%) are concentrated in the North-West regions of Russia. Denmark and Sweden are the main importers of Russian wood pellets. The objective of Publication II is to present an overview of the status of the Russian wood pellet market including production and export with particular emphasis on pellet exports to the EU. Publication II aims specifically to determine wood pellet market development in Russia, to identify the main pellet suppliers by regions and volumes, to examine domestic demand for wood pellets, and to discuss challenges facing the Russian wood pellet industry.

4.2.2 Results

Providing a comprehensive overview of the Russian wood pellet industry and Russian wood pellet markets is complicated due to limited available knowledge. For example, data of production volumes and domestic consumption is very contradictive. In addition to an absence of reliable and clear statistical data, the Russian pellet industry faces a number of other serious challenges, such as lack of significant domestic demand and an

absence of domestic standards. The industry is currently not very profitable due to high price for biomass, lack of a local pellet market and lack of subsidies for energy production from biomass. Russia has a substantial number of pellet production projects, both planned and operational, but only a small share have been successfully implemented (Figure 5).

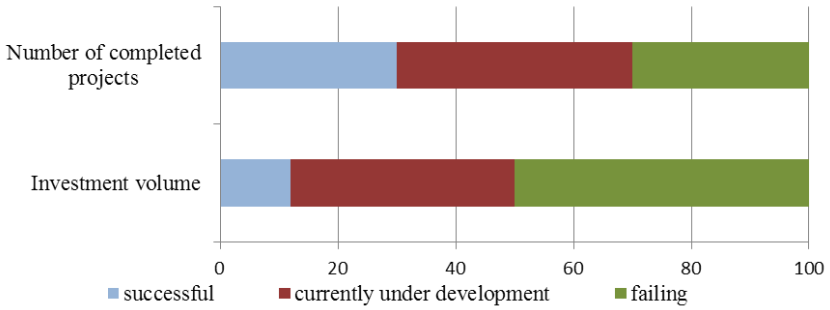

Figure 5: Successfully implemented pellet production projects in Russia in %, 2011.

There are no specific targets for wood pellets, and no large interest from the Russian government in wood pellet development. Only local programs for stimulation of pellet production can be found in several regions. For example, Arkhangelsk Oblast has a program that stimulates wood pellet production and policy targets have been set to increase pellet production and biomass use. In spite of the local-use policy, pellet exports will likely increase from that region. For comparison, development in Leningrad Oblast does not seem promising. The local government does not support renewable energy at all and there is lack of a systematic approach for wood pellet industry development.

New players on the Russian pellet market face restricted opportunities. For instance, they lack guaranteed access to raw materials, have problems producing large volumes of high quality pellets, and are unable to negotiate reduced transportation costs for regular shipments of large quantities. Consequently, a few large companies dominate wood pellet production in Russia and account for almost all Russian wood pellet exports.

The USA and Canada are the leading volume producers of pellets for export, with Russia lagging far behind. The lead consumers of pellets in Europe are Sweden, Germany, Italy, and the Netherlands, where, excluding Sweden, the share of Russian pellets is negligible.

4.2.3 Contribution to the overall picture

There is general consensus that the future of the Russian pellet industry remains unclear. Increase in local wood pellet demand is uncertain and the wood pellet industry will continue to be export-oriented. EU demand alone cannot sustain increases in the

Russian wood pellet industry, although EU climate and RE targets (Publication I) will continue to stimulate the industry.

The USA and Canada will likely continue to be in a leading positions regards wood pellet exports to the EU (Publications VI and Publication VII). In 2012–2013, exports from the United States nearly doubled from 1.6 million tons to 3.2 million tons, of which 98% was delivered to the EU. It is unlikely that Russian trade volumes will be close to these two leading exporters of pellets in the foreseeable future.

4.3 Publication III: Logistical, economic, environmental and regulatory conditions for future wood pellet transportation by sea to Europe: The case of Northwest Russian seaports

4.3.1 Research objectives

Russian wood pellets are mainly transported to the EU by sea. The largest volume of wood pellets produced in North-West Russia passes through the ports of Vyborg and St. Petersburg with approximately 50% and 30% of total seaborne wood pellet exports, respectively. The objective of Publication III is to analyse Russian wood pellet sea logistics through the three important north-western seaports: Vyborg, St. Petersburg, and Ust-Luga. In addition, Publication III aims to map conditions for future development of wood pellet transportation by sea in the northwest of Russia, focusing on economic, environmental, and regulatory perspectives.

4.3.2 Results

The majority of Russian wood pellet producers exist to serve demand from Europe. Thus, improvement in the logistics of Russian wood pellets can play a major role in the future of the Russian wood pellet industry. In describing the transportation of Russian wood pellets, including economic, environmental and regulatory perspectives, it is evident that Russian wood pellet exports may have difficulties in fulfilling expectations due to a number of challenges in transportation. Weak sea port infrastructure is one of the bottlenecks in wood pellet exports.

Lack of good infrastructure has a clearly detrimental effect on the Russian pellet industry. Russian ports do not generally have specialized infrastructure for handling wood pellets. A further issue facing the Russian wood pellet industry is certification of sustainability. The Russian wood pellet industry needs to prepare for the possibility of adoption of sustainability criteria for wood pellets from European customers. Utilization of existing international certification systems applicable to the pellet production chain could be beneficial, as well as early compliance with future standards and legislative requirements, which would ensure the continuance of business in the European market area and competitiveness against other major pellet exporters, such as the USA and

Canada. To ensure fully traceable pellets of consistent quality, Russian wood pellet producers intending to operate on the EU market need to take under their control both the supply chain of raw material and the transportation stage, that will allow to increase the export of wood pellets in the long term perspective.

Significant growth in wood pellet transportation through the three ports studied is not guaranteed, although the prospects of Ust-Luga port seem quite promising. Successful realization of the Ust-Luga development plan could significantly increase the wood pellet turnover of the port. One of the competitive advantages of Ust-Luga port is the relatively long distance from settlements and the absence of severe restrictions on the expansion of the port and related infrastructure. A factor negatively affecting the prospects of Ust-Luga is that transport by large vessels is not possible in the Ust-Luga port. The depth of the river is 6–8 m, so the port is only suitable for ships with a capacity of 800 to 4 million tons. St. Petersburg port, which is able to handle large vessels, is focusing more on other products, and thus large pellet shipments, as found from Canada and the USA, are difficult to foresee.

The Port of Vyborg might not be able to increase the volume of wood pellet transportation due to the lack of growth in exports by "Vyborg Timber Corporation," which is not operating stably. In the current economic situation, an increase in wood pellet supply through the Vyborg port by other producers is not foreseeable. Thus, the turnover of wood pellets in the port could be unchanged or even decline.

4.3.3 Contribution to the overall picture

Publication III is a continuation of Publication II with a focus on Russian wood pellet transportation issues. The example of Russian wood pellet transportation shows that logistical, economic, environmental and regulatory conditions significantly influence trade in biomass for energy purposes.

The establishment of a both economically and logistically attractive pellet supply chain is a crucial issue in the pellet trade and current practices require constant improvement and development. Other words, it is necessary, for Russia, to focus on comprehensive optimization of the entire supply chain, from raw material acquisition and granulating lines in the plant to the large boiler furnaces in industrial installations or small boilers in private houses where the pellets are fired.

In addition, the political situation in Russia, including the ongoing conflict in Ukraine and the impact of sanctions on the EU-Russia relationship, make predictions regarding the future development of wood pellet transportation through Northwest Russian seaports uncertain. Without significant improvements in port infrastructure, the Russian wood pellet industry might disappear from the global wood pellet market.

4.4 Publication IV: A survey analysis of the wood pellet industry in Finland: Future perspectives

4.4.1 Research objectives

Although having abundant forest resources, Finland is not a leader on global wood pellet markets. In Finland, wood pellets are locally produced and distributed essentially to domestic markets. Publication IV analyses related market and production issues by presenting the main factors stimulating and inhibiting development of the wood pellet industry in Finland. Publication IV aims to present the status of the Finnish wood pellet industry and its main opportunities and challenges.

4.4.2 Results

The results, shows that currently, wood pellets play a relatively minor role in Finnish bioenergy. The main obstacles to Finnish wood pellet industry development can be explained by low fossil fuel prices, competition from other solid biofuels such as wood chips, which have a long history of use in Finland, lack of government actions supporting wood pellet use, and the high price of raw material, for which there are competing uses.

Based on responses from about 60 industry actors it can be concluded that the Finnish wood pellet industry is more oriented to medium-scale and large power plants, and households have lower priority. Private consumers tend not to be very interested in wood pellets, primarily because wood pellets are not very competitive economically with other fuels. However, most experts believe that the prospects for the wood pellet industry can be considered promising (Figure 6).

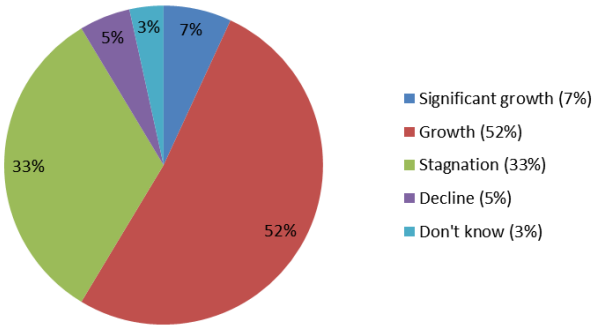

Figure 6: Opinions of 58 experts about future prospects of the Finnish wood pellet industry over the next 5–10 years, in %.

In view of the target of increasing biomass consumption, the good availability of forest resources and innovations in combustion technology, this optimism about the future of the wood pellet industry in Finland does not seem misplaced. In general, the prospects for the wood pellet industry can be considered promising and wood pellets could play a more important role in the future Finnish energy mix as part of efforts to increase bioenergy utilization in the country.

An interesting finding is that respondents whose location is outside Finland have a very optimistic view about the future of the Finnish wood pellet industry. 60% and 30% of such respondents expect growth or significant growth in the Finnish wood pellet industry, respectively. This finding seems to suggest that Finnish wood pellets have an attractive and solid reputation in other countries.

4.4.3 Contribution to the overall picture

Wood pellets are environmentally friendly and locally produced, promoting local employment, and European targets (Publication I) of increasing renewable energy are driving factors for increased utilization of wood pellets. In Finland the consumption of wood pellets is growing and may increase considerably in coming years, depending on factors such as policy regulation and investments, as well as reduced raw material prices and greater promotion of pellets.

The findings allow comparison of Finnish (Publication IV) and Russian (Publication II and Publication III) wood pellet markets and support the idea that different countries have significantly different wood pellet markets. The Finnish wood pellet industry is mostly concentrated on domestic bioenergy development, whereas the Russian wood pellet industry is almost fully export-oriented. Considering international trade in wood pellets, large changes in export and import volumes of wood pellets are not foreseeable in the short- and medium-term in Finland. Finnish wood pellet producers are planning to increase capacity to satisfy local demand.

4.5 Publication V: Biomass for industrial applications: The role of torrefaction

4.5.1 Research objectives

A number of emerging biomass streams for energy production exist, one of which is torrefied biomass (Section 2.3). Torrefied biomass is very attractive for long distance transportation thanks to its higher density and heating value, which makes transportation easy and cheap. Torrefaction can be attractive for pellet upgrading technology. The objective of Publication V is to evaluate the potential of torrefied biomass use in industrial applications focusing on technical possibilities, and presents predictions based on the scenario method of potential torrefied biomass demand in a number of industrial sectors, including both power and non-power industries.

4.5.2 Results

Evaluation of future torrefied biomass demand is very complicated. There is little accessible data about the current use of torrefied biomass in industrial applications and limited knowledge is available regarding its utilization in industries such as the chemical and petrochemical industry, and pulp and paper production. In addition, the market for torrefied biomass is at a relatively early stage of development and its future seems unclear.

Based on information on current biomass use and technical possibilities of torrefied biomass use in industry, this study roughly estimates torrefied biomass prospects for all the industrial sectors studied based on a series of likely scenarios.

In optimistic scenario, in the light of technical benefits, if the market of torrefied biomass will significantly develop, the torrefied wood pellets can compete with wood pellets and shows lightly similar trade streams. Torrefied biomass demand can reach roughly 15–18 million tons by 2030 (Scenario 1). Might be optimistic scenarios seem very ambitious. However, if to glance the large progress of wood pellet trade during the last 5–10 years the torrefied pellets can show the similar progress due to attractiveness of torrefied biomass use in power industry and non-power such as iron and steel and non-metallic minerals industries as well as logistic.

Although the significant technical progress of torrefaction was done, torrefaction technology commercial market introduction appears slower and more difficult than initially anticipated. In the pessimistic scenario (Scenario 2) of the study torrefied biomass demand can reach roughly 2–5 million tons by 2030.

Generally, these two scenarios estimate that torrefaction use will increase and the increase will depend on many factors such as market conditions, technical and economical possibilities. In the “likely scenario” (Scenario 3) torrefied biomass demand can reach roughly 8–10 million tons by 2030. The feasibility, from a technical standpoint, of more extensive use of biomass in non-metallic minerals and iron and steel industries has been demonstrated, and use of torrefied biomass in the biomass usage mix would seem attractive. The pulp and paper industry currently uses a large amount of biomass and technical possibilities for the use of torrefied biomass seem also very attractive. In these industries the complete replacement of fossil fuel by torrefied biomass technically would seem possible.

Torrefied biomass demand may increase due to the development of new torrefied biomass production facilities, stricter control of emissions, and a decrease in fossil fuel use by industry. The power generation sector has been, thus far, the leader in testing torrefied biomass use with other industrial demand lagging behind. There are promising technical possibilities for greater torrefied biomass use in a number of other areas such as the steel, non-metallic minerals, as well as the pulp and paper industries. Although a large increase in torrefied biomass consumption by industry is not immediately

foreseeable, industrial use by actors outside the energy generation sector could increase demand for torrefied biomass in general and, as a result, stimulate development of global torrefied biomass markets.

4.5.3 Contribution to the overall picture

Torrefied biomass has a possibility to be visual on the global biomass trade in long term perspective. Its growth will likely make an impact on international biomass markets development. A number of countries, such as Canada and the USA, have relatively strong positions in torrefied biomass production and development and could become the main future suppliers on torrefaction product markets. The projected streams of torrefied biomass can be expected to be rather similar to wood pellet trade streams. Torrefied biomass can replace or dominate the current wood pellet trade (Publication VI and Publication VII).

In the long term, new trade streams of biomass for energy can emerge. Torrefied biomass can be one of them. It is very attractive as a solid biofuel product for long-distance transportation. Torrefied biomass has a greater density and heating value than raw wood, which makes transportation easier and more economic.

4.6 Publication VI: Global biomass trade for energy - Part 1: Statistical and methodological considerations

4.6.1 Research objectives

International biomass trade has increased and changed considerably in recent years. There is a need to update previous work and develop a contemporary overview of international trade in biomass. Publication VI examines a number of methodological issues related to assessment of direct and indirect biomass trade (Section 2.1). In addition, Publication VI aims to update total figures on direct and indirect international trade of biomass for energy production by showing estimated scope of international trade for 2004–2015.

4.6.2 Results

During 2004–2015, world production of most of the studied products increased, especially production of solid and liquid biofuels. International trade in biomass for energy has almost doubled from around 800 PJ in 2004 to 1300 PJ in 2015. This is about 5 % of total bioenergy use globally. Indirect trade has slightly increased and direct trade increased threefold, from about 200 PJ (2004) to 600 PJ (2015). Thus, in the last five years of the period studied, direct trade of biomass for energy started to approach the volume of indirect trade. This is a significant change in comparison with previous studies. Table 2 presents the estimated scope of international trade of the studied products, which is the key result of the study.

Table 2: Estimated scope of international trade of studied products in 2004–2015, in PJ (Derived from world import and import numbers).

Year / product	2004	2008	2011	2012	2013	2014	2015
Indirect trade (end up for energy):*a*	585	610	575	550	650	625	640
· Industrial roundwood *a,b*	450	435	390	375	470	440	450
· Wood chips and particles *a,c*	135	175	185	175	180	185	190
Direct trade:	200	385	560	580	615	610	610
· Charcoal *d*	30	40	50	50	50	55	65
· Fuel wood *e*	35	40	65	65	70	70	50
· Wood pellets *f*	30	55	135	125	170	200	220
· Biodiesel *g*	20	25	80	85	75	45	50
· Ethanol as biofuel *h*	60	155	150	160	140	130	120
· Palm oil for bioenergy use *i*	25	70	80	95	110	110	105
Total (end up for energy)	785	995	135	130	1265	1235	1250

Changes in trade volumes for almost all studied products can be explained by changes in production and/or traded volumes of the main exporter and importer countries. For example, global ethanol market development depends on ethanol production in the USA and Brazil, because they account for about 75% of the world's ethanol production and are the main global exporters, and on imports into the EU as the main bioethanol importer.

The development of international trade and international markets in biomass for energy production is at a relatively early stage. The study focuses on trade volumes and does not consider production data and agricultural products. However, most agricultural products have much larger volumes of production and trade than solid and liquid biofuels. As an indicator of relative market size, the trade of wheat and soybeans was about 150 and 130 million tons respectively in 2015. Paper and paperboard trade with about 110 million tons is larger than, for example, trade in wood pellets with 16 million tons in 2015.

4.6.3 Contribution to the overall picture

The study shows that wood pellets and ethanol are typical examples of biofuels that are widely traded and have commodity type markets. The other studied products do not have the same commodity status on world markets.

Wood pellets showed significant growth, attaining 25% of total direct biomass trade for energy purposes. The trade in ethanol and biodiesel peaked in 2013 and then decreased. Trade in palm oil for energy purposes increased in the last decade of the period studied due to greater usage of palm oil for energy purposes in the EU. International biomass

markets are developing rapidly, and trade in biomass for energy will continue to be an important aspect of global bioenergy development.

Publication VI together with Publication VII extends knowledge about global biomass trade and markets. As can be seen from Figure 3 in Section 3.1, Publication VI and Publication VII are partly connected with the previous five publications.

4.7 Publication VII: Global biomass trade for energy - Part 2: Production and trade streams of wood pellets, liquid biofuels, industrial roundwood, charcoal and emerging energy biomass

4.7.1 Research objectives

Generally, more and more countries now participate in biomass trade. International trade includes a significant number of cross-border streams. The objective of Publication VII is to identify and highlight the main producing countries, as well as to quantify export and import streams of liquid and solid biofuels, including industrial roundwood, wood pellets, biodiesel and bio-ethanol. A further aim is to discuss changes in trends that have occurred over the past decade, and to investigate trade streams in emerging biofuels.

4.7.2 Results

In recent years, Asian markets have developed rapidly, for example, China (industrial roundwood), South Korea, Thailand, Vietnam (wood pellets), Malaysia and Indonesia (palm oil). The EU is the leader in biomass utilisation for energy production, and as a result, the main importer for most types of biomass products. Overall, mostly all solid and liquid biofuels have shown increases in production volumes and present maximum values in 2015. It can be concluded that trade stream volumes have potential to continue their growth. Interestingly, the use of palm oil for energy production has increased in the EU. Moreover, it can be argued that emerging bioenergy trade flows will develop further over the long term.

It seems that Asian wood pellet markets will continue development thanks to policy support and the global trend of wood-pellet market development. In South Korea, widespread interest in wood pellets started from a renewable portfolio standard that became effective in 2012 and had the goal of reaching 10% energy generation from renewable resources in the 2022 to 2027 timeframe. Japan is also expected to increase wood pellet imports quite substantially over the next five years. The abundance of primary forest feedstock and by-products from forest products manufacture, as well as relatively low production costs, make Vietnam a very promising country for wood-pellet market development. Malaysia, Indonesia, and Thailand also have potential for

further development. Indonesia almost doubled production and export during 2013–2014. Thailand increased wood pellet production from 20 000 tons in 2013 to 115 000 tons in 2015.

Ethanol trade increased during the last ten years. The slight declined in last few years can be explained by different reasons. The relatively low levels of ethanol exports from the United States to Europe can be explained by an antidumping duty on bioethanol imports from the United States imposed by the European Commission. In Brazil, the stagnation of ethanol production between 2009 and 2014 had multiple causes. The economic crisis of 2008 delayed sugar cane replanting for 2009, and combined with unfavorable weather conditions the crisis had a highly negative impact on ethanol production. Lastly, in 2009–2014, ethanol became less competitive due to the government's reduced support for ethanol production and the introduction of price freezes, which favoured fossil fuels. This unfavourable business environment led to the closure of some ethanol production facilities and fewer facilities being built.

Like bioethanol production, global biodiesel production has increased significantly over the last ten years. In the United States, a peak of biodiesel production occurred in 2013 due to increased consumption, which can be explained by factors such as the need to satisfy total renewable fuel standards, biodiesel tax credits, growing access to foreign biodiesel, mostly from Argentina, and favourable blending economics. The United States was a net exporter of biodiesel from 2007 to 2012 and then became a net importer from 2013 to 2015. Export of biodiesel from many non-European countries to the EU is relatively small due to EU anti-dumping policy. The EU-28, production of biodiesel is mainly based on imports. In 2015, the EU imported about 53% of feedstocks (vegetable oils mainly from rapeseed, palm and soya) used to produce crop biodiesel in EU installations. The EU-28 consumed about 12.9 Mt of biodiesel in 2015.

4.7.3 Contribution to the overall picture

Trade stream volumes have potential to continue their growth. There is possibility of new emerging biomass products such as torrefied biomass, cooking oil, biochar and aviation biofuels. In the long term, additional significant bioenergy trade flows, both as regards the products traded and the trading routes used, can be expected to emerge and establish their own niche in international biomass trade in biomass for energy.

The biomass trade for energy covers many different countries and many different products. In recent years, Asian markets have developed considerably. Further increasing demand on Asian markets will play an increasingly important role in the global wood pellet trade, which can be expected to change current global trade streams. In Europe, the Baltic countries Estonia, Latvia, and Lithuania have made much progress in the export of wood pellets. The EU is the main leader in biomass utilization and the main importer of most biomass products. Divergent policy regulation and large price differentials have led to complex wood pellet trade streams within the EU.

Publication VII is as a continuation of Publication VI with a focus on global biomass trade streams and discussion of emerging biomass trade including torrefied biomass. Both publications extend knowledge of international biomass trade and they are connected with the previous five publications (Section 3.1, Figure 3).

5 Conclusions

The main purpose of this work was to increase knowledge, insights and understanding of development in international trade in biomass for energy purposes. This doctoral dissertation studied several issues related to the international trade in biomass. Key observations in response to the research questions presented at the beginning of the thesis (Section 3.1) are summarized in the following sections.

5.1 Main findings of the study

Q1. What efforts have been made by each EU member state to achieve the national biomass targets set in their NREAPs and how much of the biomass target in their overall RE target is covered by the international biomass trade?

Taking into consideration progress in RE development and usage in the EU as a whole, most countries of the EU are making serious efforts to reach the 20% renewable energy target for 2020, and all EU states show a trend of increased RE usage in gross final energy consumption towards the new targets for 2030 of 27% share RE consumption. Although, the majority of countries are close to attaining their own domestic RE targets, some member states will face serious problems reaching their 2020 RE targets. The greatest problems are found in countries with relatively high energy consumption, such as France, the United Kingdom and Germany. It is unlikely that these nations can comply with anticipated renewable energy demand, unless they mobilize more woody biomass from their available domestic potential (France, Germany) or considerably increase their woody biomass imports (mostly wood pellets) from elsewhere (the United Kingdom) (Publication I).

It seems that the role of international biomass will increase in the future for the EU. Biomass resources are varied in different members states and for many of them biomass is crucial in achieving RE targets. Woody biomass plays an important role for electricity and heat production in many EU countries such as Finland and Austria. Some EU countries such as Latvia and Lithuania have seen promising development of biomass. Development of bioenergy will likely depend on the trade in EU countries such as Belgium and the Netherlands. Sustainable biomass logistics and trade within the EU and with non-EU countries seems crucial in achieving bioenergy targets and increasing RE share in the EU.

Q2. What are the prospects for Russian wood pellet production, development and wood pellet export from North-West Russia to the EU? What role will the Russians play in the EU wood pellet markets?

Generally, the export from Russia is not seen to be problematic. Russia successfully exports fossil fuels such as oil and natural gas to the EU. Export of wood pellets with raw biomass does not seem as profitable as fossil fuel export. Russia is unlikely to transition from a fossil fuel based exporter to a biomass exporter. However, as a part of

efforts to balance its economy, Russia has a need to diversify its exports portfolio away from too exclusive a focus on oil and gas.

Wood pellets show considerable potential on global bioenergy markets and wood pellet trade is increasing due to their advantageous heating characteristics, and the ease with which they can be efficiently handled, stored and transported, in comparison with raw biomass. Based on the example of North-West Russian wood pellet exports to the EU, it is evident that growing demand in the EU for wood pellets only partly motivates Russian wood pellet industry development. The Russian wood pellet industry is constrained by an absence of reliable and clear statistical data, high prices for biomass, lack of a local pellet market, underutilization of forest resources, and weak wood pellet project implementation (Publication II). Moreover, infrastructure for seaborne transportation of Russian wood pellets requires significant improvement. Otherwise, the Russian wood pellet industry might disappear from the global wood pellet market, especially exports to the EU (Publication III).

A small number of players are participating in trade of wood pellets in Russia. About 17 Russian enterprises have 70% of total pellet exports of the country. 80% of total wood pellet imports from Russia belong about 16 large companies. Denmark, Sweden and South Korea are the main leaders of Russian wood pellet imports. In Russia, new players, especially small producers, on the wood pellet market face problems with finding raw materials, a high price of certification, being unable to negotiate reduced transportation costs for regular shipments etc. Mainly large companies organize wood pellet production and export and it seems that this trend will continue to take place next 5–10 years.

Q3. What are the prospects for Finnish wood pellet production, development and consumption as well as participation in global wood pellet trade? What role will the Finns play in the wood pellet markets?

Unlike Russia, wood pellet consumption in Finland has increased steadily and is close to matching local production levels. To increase wood pellet usage, Finland should improve policy support, especially support for small-scale households, and make wood pellets compatible with other fuels such as wood chips. Significant growth of the wood pellet industry is not forecast (opinions of 7% from 60 respondents) but continuation of current growth patterns seems reasonable (opinions of 52% from 60 respondents). Finnish wood pellet producers are planning to increase capacity to satisfy local demand, and thus, the role of Finland on global wood pellet markets will continue to be minimal (Publication IV).

The trend of increasing wood pellet use by large CHP plants in Finland seems to continue. In Tampere, the 33 MW capacity thermal power plant has used wood pellets since 2012. Another example of wood pellet use is the Salmisaari pellet-fired heating plant with 92 MW of the district heat output in Helsinki. Wood pellets in the plant have

replaced coal since 2016. There are also plans for future wood pellets use in other old and new CHP plants in Helsinki.

The price of Finnish wood pellets is higher compared with the price of wood pellets, for example, in Central Europe. Moreover, due to the high price of Finnish wood pellets, they are not commonly used in Finnish households. It seems that Finland needs many years or decades to become prominent on the global wood pellet market. There is a need more players in the market from the production and consumption side in Finland and neighbouring countries. Competition from different players with policy regulations can be one of the options to decrease the price and, as a result, increase the role of wood pellets within and outside of Finland.

Q4. What can be said about the role of a new emerging solid biofuel, torrefied biomass, on global biomass markets?

Due to its technical characteristics, torrefied biomass has the potential to replace regular wood pellets and even coal in some cases. Torrefacion has attractive technical possibilities in the power generation sector, which can be the leader in torrefied biomass use, and in other areas such as the steel and iron industries as well as non-metallic mineral industries. The high price of torrefied biomass production can be compensated by reduced transport and logistic costs. Torrefied biomass has the opportunity to replace or complement conventional wood pellet production and supply. The same trade logistics and infrastructure which is used for conventional wood pellets can also be used for torrefied biomass. Different elements, such as biomass recourse availability, investments, guaranteed performance of technology and cost benefits, influence the future of torrefied biomass market creation.

There is currently no market in place for torrefied biomass and its future seems unclear. The future of torrefied biomass, as with most other emerging biomass products, will depend upon the price. Currently, little practical experience exists of the whole production chain of long-haul torrefied biomass trade. Considerable investment will be required before torrefied biomass can gain a significant place in global energy biomass markets. In light of the increased investment in technology development and commercialization, it can be assumed that torrefaction will become commercially available within the next 5–10 years.

Torrefied biomass consumption by non-power generation industry is not foreseeable in comparison with the power sector, however, industrial use by actors outside the energy generation sector could increase demand for torrefied biomass in general and, as a result, stimulate development of global torrefied markets. Non-power generation industries such as iron and steel production, pulp and paper, can be seen as the bridge towards the large markets e.g. the power sector. If the market of torrefied biomass is created, the trade of torrefied biomass could be mostly oriented to the EU. In addition, South Korea and Japan are also developing infrastructure for torrefied biomass consumption (Publication V).

Q5. How has the current comprehensive status of global trade in biomass developed since 2004?

Total trade in biomass for energy purposes increased almost two times from around 800 PJ in 2004 to 1300 PJ in 2015. This is about 5% of total bioenergy use globally. Indirect trade has slightly increased and direct trade increased threefold, from about 200 PJ (2004) to 600 PJ (2015). In the last five years, direct trade volumes have started to become close to those of indirect trade. Wood pellet usage has shown significant growth, and accounts for 25% of total biomass trade for energy (Publication VI). In recent years, Asian markets have developed rapidly, for example, China (industrial roundwood), South Korea (wood pellets), and Malaysia and Indonesia (palm oil). The EU is the world leader in biomass utilisation and, as a result, the main importer of most types of biomass products (Publication VII).

International biomass trade is not a goal of its own. However, it expected that significant global bioenergy progress seems unachievable without biomass trade, especially between world regions. The global biomass trade is likely to continue to grow. The scale of this growth depends on many factors such as historical bioenergy development, availability of biomass resources, policy regulations, logistics improvements, global economic situation, fossil fuel use and ecological and technology development.

Currently, the EU is a leader in biomass utilization and biomass imports, and EU renewable energy targets will continue to stimulate bioenergy development in the EU (Publication I). Due to differing biomass resource potential, policy support and regulation in countries of the EU, biomass trade will continue to be an important aspect of bioenergy production. Wood pellets are set to continue to be one of the main commodities on international biomass markets (Publication VI and Publication VII). Transportation of wood pellets from Russia to Europe seems unclear in the long-term, due to many contributing factors (Publication II) including logistical issues (Publication III). Some countries, such as Finland with wood pellets, are mostly independent of direct international biomass trade, yet have strong bioenergy development (Publication IV). Market prospects for emerging biomass products such as torrefied biomass (Publication V) seem unclear.

5.2 Scientific contribution

International trade in biomass for energy is a very broad topic, and its study involves different countries, different legislative environments and different products, both solid and liquid biofuels, and technical aspects of bioenergy covering the whole chain from raw biomass harvesting to final utilization as a fuel. This thesis addresses only a small part of these issues. The focus of this work was on the main tradable energy biomass forms and main markets for such biomass, with deeper focus on wood pellet markets, particularly the context of the EU, Russia and Finland.

The subject of RE targets in the EU is a much discussed topic in the bioenergy community. However, limited work has been done on comparing the need of countries to engage in international trade of woody biomass to increase the likelihood of achieving their EU targets in 2020, and the possible contribution of woody biomass beyond 2020. Some countries have made commitments and promises to achieve very ambitious targets, the attainment of which seem somewhat unrealistic. It appears that, on the whole, the role of biomass as a part of changes to energy production and consumption has been somewhat overestimated. Drawing attention to the perhaps overly ambitious nature of some biomass energy targets and the extent to which achieved biomass targets have been overestimated in comparison to domestic resources can be considered a meaningful contribution of this thesis (Publication I).

The essential contribution of the research can be found in the updating of international biomass trade estimations earlier done mainly in connection with Task 40 of the International Energy Agency (IEA) Bioenergy Technology Collaboration Programme (Publication VI and Publication VII). Examination and consideration of indirect trade assessment and methodology issues are extended significantly and new emerging biomass trade streams are discussed.

This thesis provides new knowledge about the current and future role of Russian wood pellet industry and wood pellet exports (Publication II and Publication III), which are topics that have not been studied in detail previously. Use of larger than before, scientific literature sources complemented with a large number of Internet sources and reports, partly available only in Russian language, increases the reliability of the information. The wood pellet industry in Finland (Publication IV) and bioenergy as a part of RE development in the EU (Publication I) were studied from a different perspective than previously. Additionally, to the author's knowledge, this thesis includes a first attempt to assess the potential of torrefied biomass on global biomass markets (Publication V).

5.3 Suggestions for future work

International biomass trade is a broad topic that cannot be treated exhaustively within the scope of a single doctoral dissertation. While the findings presented in this work provide much valuable information, many relevant issues remain to be resolved. Numerous factors influence biomass trade streams, such as policy support, historical bioenergy development, biomass resources availability and sustainability concerns. A more detailed study of these factors would be a fruitful area for further work.

Further research is needed to determine trade opportunities for non-mainstream bioenergy products, such as waste and agricultural forest products. Sustainability issues related to biomass trade, including sustainability standards, possible scenarios of biomass trade development, based, for example, on the price of biofuels and changes in fossil fuel prices and availability, and the main sustainability challenges and opportunities in the long term are other attractive areas of investigation. Detailed in-

depth analysis of specific agricultural supply chains from farm gate to final waste utilization and the amount of indirect trade for energy could be a topic of interest for future studies.

In the area of trade in wood pellets, more comprehensive analysis of the wood pellet trade in Asia could be interesting. Moreover, detailed analysis of liquid biofuels trade between the main exporting and importing countries should also be addressed. The results of this thesis can be useful as a basis and pointer for further studies of biomass markets development.

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Publication I

Proskurina, S., Sikkema, R., Heinimö, J., and Vakkilainen, E.
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

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Publication II

Proskurina, S., Heinimö, J., Mikkilä, M., and Vakkilainen, E.
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Publication III

Proskurina, S., Rimppi, H., Heinimö, J., Hansson, J., Orlov, A., Raghu, KC., and Vakkilainen, E.

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Publication V

Proskurina, S., Heinimö, J., Schipfer, F., and Vakkilainen, E.
Biomass for industrial applications:
The role of torrefaction

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Publication VI

Proskurina, S., Junginger, M., Heinimö, J., and Vakkilainen, E.
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Statistical and methodological considerations

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Publication VII

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liquid biofuels, charcoal, industrial roundwood and emerging energy biomass

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