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Evaluation of Renewable Energy Development in Power Generation

System Dynamics Approach for the Nordic Countries

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Julkaisun nimike

Uusiutuvien Energialähteiden Kehittämisen Arviointi Sähköntuotannossa – Pohjoismaita Koskeva Systeemidynamiikan Näkökulma

Tiivistelmä

Vaikka fossiilisten polttoaineiden osuus maailman kaupallisesta sähköntuotannosta on suurin, niiden etulyöntiasema heikkenee fossiilisten polttoaineiden varantojen vähentyessä ja ympäristö- ja taloudellisten näkökulmien painottuessa. Siksi paikallisten luonnonvarojen hyödyntämistä tutkitaan korvaavana sähköntuotantokeinona. Uusiutuvien energiamuotojen hyödyntäminen on kuitenkin vaikeaa niihin liittyvän yritystoiminnan, kehittyvän teknologian, poliittisen päätöksenteon ja markkinoiden epävarmuuden vuoksi.

Tämä tutkimus analysoi uusiutuvien energiamuotojen hyödyntämistä pohjoismaiden sähköntuotannon toimitusvarmuuden lisäämisen näkökulmasta. Työssä selvitetään, mikä rooli on energialähteen monipuolistamisella toimitusvarmuuteen ja riippuvuuteen nykyisistä energialähteistä. Työssä esitellään uusiutuvan energiamuotojen kehittämisen näkökulmia ja kaksi systeemidynamiikan mallia. Mallien avulla arvioidaan, kuinka uusiutuva energiamuotojen kehittäminen vaikuttaa riippuvuuteen energialähteestä ja analysoidaan uusiutuvien energiamuotojen kehittämisen kustannuksia. Systeemidynamiikan mallit osoittavat, että uusiutuvien energialähteiden hyödyntäminen voi vähentää merkittävästi vuosittaisia ulkomaankaupan ostoja riippuen siitä, miten paljon uusiutuvia energiamuotoja kehitetään ja otetaan käyttöön vuosien 2012-2020 aikana.

Asiasanat

Sähköntuotannon toimitusvarmuus, Monipuolistamisen strategia, Uusiutuvat energialähteet, Pohjoismaat, Suomi, Systeemidynamiikka

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Abstract

Although fossil fuels are the main sources of power generation in the world, they are losing their advantages because of their limitations and environmental and economic concerns. In response, utilization of domestic and local natural resources have an important role among the various replacement strategies. However, the diffusion of renewables is difficult because of their entrepreneurial nature and related technological, investment, political, and market uncertainties. This research analyzes the development of renewable energy utilization to increase the security of the energy supply in the Nordic countries. First, the role of resource diversification in the security of energy supply and dependency is reviewed. Then, different dimensions of renewable energy development are presented. Two system dynamics models are presented to evaluate the role of renewables in energy dependency and analyze the costs of renewable energy development. The system dynamics models show that portfolios of renewables will produce noticeable annual savings in imported energy depending the plans and scenarios in Finland during 2012-2020.

Keywords

Security of energy supply, Diversification strategy, Renewable energy resources, Nordic countries, Finland, System dynamics

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Finally, as I had planned many years ago, I finished my doctoral study before I start to be 30 years old. When I wanted to apply for doctoral studies at the University of Vaasa in 2009, I started my motivation letter with a sentence from Isaac Newton. And now, I finish this journey with this sentence:

If I have been able to see further, it was only because I stood on the shoulders of giants

THANK YOU GOD

Vaasa 2014

Alireza Aslani

CONTENTS

ABBREVIATIONS

Paper/Article i ……………………..………………………………..………… [Pi]
Giga joule …………………………..………………………………………..…. GJ
Nordic countries ……………………………………………………….…..... NCs
Operation and maintenance ……………..………..…………………………. O&M
Renewable Energy ……………………………..……………………………..… RE
Renewable Energy Resource ………………………................................... RER
Research Question I ………………………….……………………….……... RQi
Tera joule ……………………………………………..…………………….. TJ
Watt ……………………………………………..………………………….…… W

FIGURES

TABLES

ARTICLES

The dissertation is based on the following appended papers:

[P1] Aslani, A., Antila, E., & Wong, K. (2012). Comparative Analysis of Energy Security in the Nordic Countries: The Role of Renewable Energy Resources in Diversification. Journal of Renewable and Sustainable Energy, 4(6), 062701-11.

[P2] Aslani, A., Helo, P., & Naaranoja, M. (2014). Role of Renewable Energy Policies in Energy Dependency in Finland: System Dynamics Approach. Applied Energy, 113, 758–765.

[P3] Aslani, A., Naaranoja, M., & Wong, K. (2013). Strategic Analysis of Diffusion of Renewable Energy in the Nordic Countries. Renewable and Sustainable Energy Reviews, 22, 497–505.

[P4] Aslani, A., Helo, P., & Naaranoja, M. (2013). Evaluation of Renewable Energy Development in Power Generation in Finland. Journal of Renewable and Sustainable Energy, 5(6), 063132-13.

[P5] Aslani, A., Naaranoja, M., Helo, P., Antila, E., & Hiltunen, E. (2013). Energy Diversification in Finland: Achievements and Potential of Renewable Energy Development. International Journal of Sustainable Energy, 32(5), 504-5014.

[P6] Aslani, A., Helo, P., Feng, B., Antila, E., & Hiltunen, E. (2013). Renewable Energy Supply Chain in Ostrobothnia Region and Vaasa City: Innovative Framework. Renewable and Sustainable Energy Reviews, 23, 405-4011.

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1 INTRODUCTION

Energy demand is growing fast because of the economic and social development of countries. To achieve a secure and safe supply of energy, governments are faced with challenges such as fluctuating fossil fuel prices, increasing world demand for energy, uncertainties in oil and gas supplies arising from geopolitical concerns, and global warming (Lund 2007). In fact, energy security is a translation of those concerns that affect the economy, safety, social welfare, and environment of a country or a region. In response, policy and decision makers have suggested and developed various strategies such as upstream investment of producers, utilizing domestic and local natural resources, long-term contracting at premium prices, diversifying fuels and suppliers, developing dual fuel technologies, decentralized forms of utilization, and efficiency and conservation (USAID 2008; Galarraga et al. 2011). On the other hand, the limitations of nuclear energy illustrate the necessity of utilizing other reliable sources.

To respond to the challenges and achieve a secure level of energy supply, policy makers and researchers have paid special attention to the role of diversification strategies (sources/suppliers) and utilization of renewable energy resources (RER). Because of local availability, the free, clean, eco-friendly aspect and sustainability of RERs, economists and policy makers admit that one of the important ways to reach sustainable development is the maximal consumption of renewables.

Since the renewable energy (RE) industry offers a profitable future, various opportunities exist for investment in this industry. However, the economic utilization of a renewable portfolio, in particular in new technologies such as wind power and solar power, has faced challenges that affect policy-maker and investor decisions.

This research discusses the role of RERs on dependency and security of energy supply in the Nordic countries (NCs), namely Finland, Sweden, Norway, Denmark, and Iceland. The main achievement is the development of two operational system dynamics models of the national RE system. A system dynamics RE simulation model evaluates variety of relevant policies, and estimates the relative impact of policies in a consistent manner.

1.1 Research motivation

The utilization of RERs has a long history in the NCs. The NCs have ambitious RE policy targets to increase their use of domestic energy resources while decreasing CO2 emissions by 70% by 2050 (NETP 2013). According to different scenarios, electricity demand will increase by at least 20% in the NCs by 2050 (NETP 2013). Further, the use of electricity in transportation in the NCs will increase 10 times more than the current situation (mainly railroads) by 2050 (NETP 2013). Although the most pressing RE issues in the NCS have been addressed, the reactions need robust analysis of RE policy options.

There are challenges that the NCs face to achieve a carbon-neutral energy system. First, NCs are among the most sparsely populated countries and have a cold climate. This increases demand for transport, heating and electricity services. Therefore, energy consumption per capita is high in the NCs compared with other European countries in both per capita and per unit of gross domestic product. Second, Nordic economies, in particular Finland and Sweden, are dependent on energy intensive industries such as forestry and paper. While the competitiveness of these industries is dependent on energy prices, decarbonisation policies may increase the energy prices (Alakangas 2002). Third, the local acceptance of some RERs such as wind power presents challenges during the implementation of the policies (Meyer 2007). Fourth, significant growth in the use of electricity in transportation will present new challenges to the electricity supply system. Finally, most of buildings in the NCs are more than 30 years old; therefore the energy efficiency for both heating and electricity is low compared with new and modern buildings (NETP 2013).

Due to the above challenges, two major research motivations are identified to serve as a basis for this dissertation.

1.1.1 Need for an integrated approach for renewable energy policy development

To demonstrate polices and executive plans of RE development and CO2 emission reduction objectives in the NCs, stronger analyses based on strategic thinking and public policy focused research are needed. Given the complexities of different aspects of RE policy, there is need for an integrated approach in the NCs. This means a wide range of economic, social and environmental values should be considered and evaluated in order to make informed policy decisions. On the other hand, the NCs have shown their international leadership in RE utilization. Deep understanding and explaining of different layers of policies and incentive strategies in power generation by REs are beneficial in order to be followed and implemented by other countries and regions.

1.1.2 Need for a dynamics modelling approach to aid an integrated approach to renewable energy policy

As different dynamic elements (e.g. economic, environmental and social) affect energy policy, the impacts and consequences of various policies should be explained and evaluated. Almost all of the RE policy issues in Finland (as a selected country among NCs), have not been addressed using an integrated energy policy model that clearly explains the impacts of various policies on dependency on imported fossil fuels or economic factors such as costs of RE development. This dissertation develops two system dynamics RE simulation models in order to evaluate different elements of RE policy in an integrated fashion. The models help policy-makers to understand the connections between economic, security, and energy policy objectives. Those models are the first such models to be developed, integrating the role and costs of RERs on national's energy dependency.

1.2 Purpose and objectives

As discussed, frequently the analysis of national RE scenarios in order to increase security of the energy supply is carried out in the absence of the broader economic, political, technological, social, and historical influences at play. The main purpose of this dissertation is to develop two system dynamics modelling tools for evaluating future RE policy options in an integrated fashion. Given the purpose, the objectives are to:

- discuss the role of diversification in energy resources in security of the energy supply and dependence on imported fossil fuels.
- identify different dimensions of RE development from the policy and strategic aspects.
- design two system dynamics models to evaluate the role of RE in terms of dependency on imported energy and to analyze the costs of RE development.

- study the achievements and potential of RE utilization from the supply chain viewpoint.

1.3 Research question and scope

1.3.1 Research question

Based on the research motivation and the research purpose, the dissertation answers to following research questions:

RQ1: What are the effective factors of security of energy supply in the Nordic countries?

RQ2: How do “diversification” and “RE utilization” affect energy dependency on imported fossil fuels in a selected NC?

RQ3: What are the dynamics of RE development in the NCs?

RQ4: How can a system dynamics model be implemented to analyze the costs of RE development in a selected NC?

RQ 5: What are the achievements and potentials of RE development in a selected NC and a selected city in the NCs?

The aims of the first question are 1) to define and measure security of the energy supply at the regional level in the case study of Nordic countries, and 2) to analyze systematically the factors of energy security, with special focus on diversification strategy. The role of diversification strategy and RE utilization in dependency on imported energy and energy security are reviewed for a selected NC, Finland, in the second question. The first system dynamics RE simulation model is developed in order to estimate the amount of Finland’s dependency on imported fossil fuels in that question. Different layers of the diffusion of renewables are categorized with an integrated approach from strategic and policy aspects in the third question. The second system dynamics model is developed to analyze the costs of RE development at the country level in question four. Finally, the utilization of RERs is reviewed from the supply chain viewpoint at the country and local levels in question five.

The researcher responds to the above questions in six published articles in journals. Table 1 shows the research objectives, the title of published articles and the researcher's role in each article. Other authors of the articles supervised the research process.

Table 1. Research objectives, the article names in response to each subsidiary question and the researcher's role in each article

Research objective	Article number	Researcher's role
to discuss the role of diversification in security of energy supply and dependency	**[P1]**: Comparative analysis of energy security in the Nordic countries: The role of renewable energy resources in diversification	-First author -Designing the research -Data collection -Data analyzing -Writing the contribution
to design a system dynamics model to evaluate RE policies from a strategic analysis viewpoint	**[P2]**: Role of renewable energy policies in energy dependency in Finland: A system dynamics approach	-First author -Designing the model - Simulating and analyzing the model -Writing the contribution
to identify different dimensions of RE development.	**[P3]**: Strategic analysis of diffusion of renewable energy in the Nordic countries	-First author -Designing the research -Data collection and analyzing -Writing the contribution
to design a system dynamics model to evaluate RE policies from a cost analysis viewpoint.	**[P4]**: Evaluation of renewable energy development in power generation in Finland	- First author -Designing the model -Data collection -Simulating and analyzing the model -Writing the contribution
to study the achievements and potential of RE utilization from the supply chain viewpoint.	**[P5]**: Energy diversification in Finland: achievements and potential of renewable energy development [P6]: Renewable energy supply chain in the Ostrobothnia region and Vaasa city: Innovative framework	-First author -Designing the research -Writing the contribution

1.3.2 Scope

This dissertation studies the above research questions by focusing on the domain, dimensions and levels as described in this section. The domain of this research is security of the energy supply, diversification strategy in energy sources, and RE development. First, the security of the energy supply is defined and the role of diversification in energy resources/suppliers is discussed. As RE utilization is the main strategy of energy diversification, different layers of diffusion and management of renewables are identified and described. The research domain is reviewed from three main dimensions: security analysis, policy schemes, and cost analysis. They show the subjects that the researcher focus on to present the integrated approach and develop the system dynamics RE simulation models.

To provide a rich understanding in the defined domains, the research dimensions are reviewed on three levels, namely regional (Nordic), a selected country to implement designed system dynamics model in the Nordic region (Finland), and a local area in the selected region (Vaasa, Finland). The levels limit the study area to increase the validity and reliability of the system dynamics models.

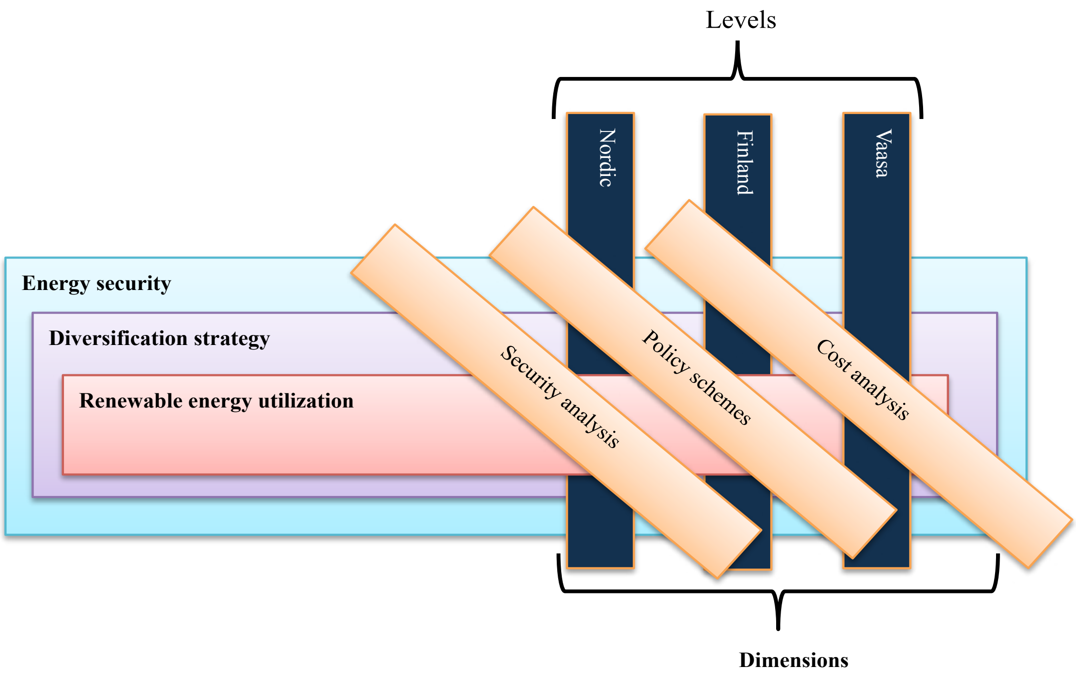

Figure 1. Scope of the dissertation

1.4 Research methodology and design

This section describes the research methodology of the dissertation. To help the construction of an applicable research methodology, the research onion model presented by Saunders et al. (2009) is used. According to this model, each research consists of six layers, including philosophies, approaches, strategies, choices, time horizons, techniques, and procedures. Figure 2 shows the research onion model and the selected method for this dissertation in each layer.

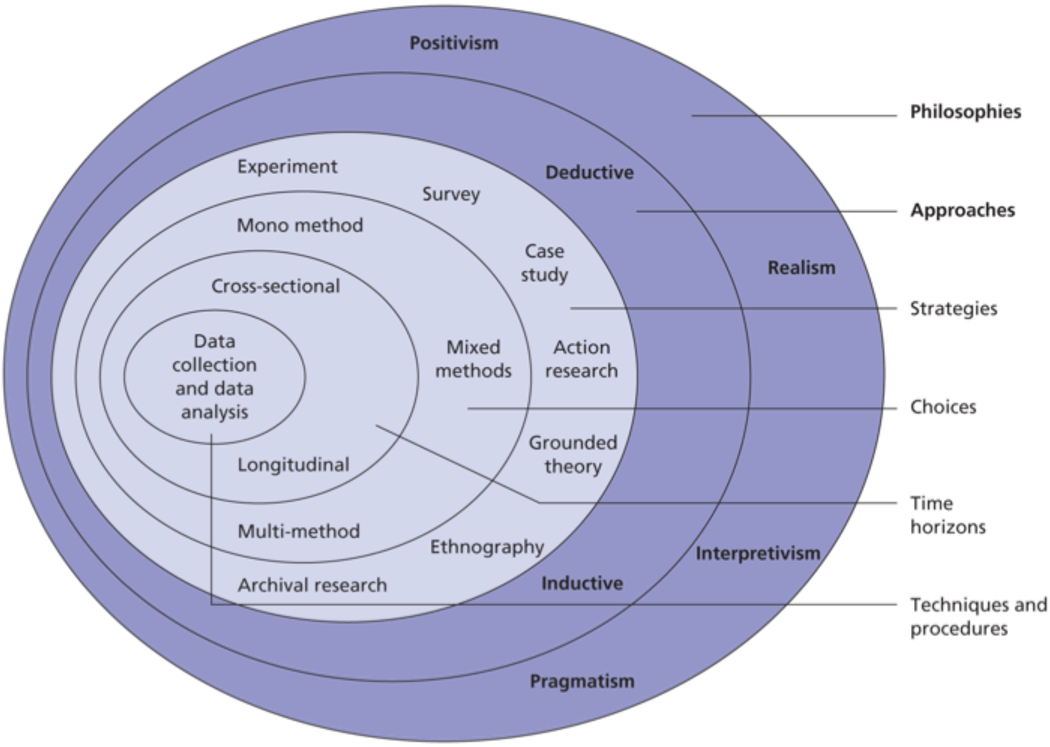

Figure 2. Research model presented by Saunders et al. (2009)

1.4.1 Research philosophy

This dissertation is to study the security of energy supply and development of RE technologies by focusing on strategic system thinking and policy studies in the case NCs. Since the aim is to give bona fide analysis not only for scientific evaluation but also for decision makers in RE, the research philosophy is pragmatism. According to pragmatism in the management research, ideas and practices are assessed in terms of their usefulness, workability, and practicality (Saunders 2009). Therefore, the contribution of this research are evaluated based on how true, right and valuable the policies and models are related to diffusion of innovation (Reason 2003).

1.4.2 Research approach and research strategy

The approach to this study is inductive that gives a flexible structure for researcher to alter the intended path based on new findings. An inductive approach develops a theory or a way of thinking as a result of data analysis (Saunders 2009). A close understanding of security of the energy supply and RE utilization in the NCs is gained by using systems thinking and dynamics models, since both focus on the important hidden structures of the research phenomena. Due to the nature of the inductive research and the research philosophy (pragmatism), the researcher cannot develop hypothesis in the dissertation (Sarmad 2009). In other words, an inductive approach along with pragmatism philosophy usually use research questions to narrow the scope of the study.

To create a deeper understanding of security of the energy supply, RE development, and modeling of related polices, the research strategy of the dissertation is grounded theory. The results of the grounded theory phase are used in the content analysis of the literature. The case study approach is used to find answers to the other research questions, for example to build and test the system dynamic models.

1.4.3 Research choices and time horizon

This research uses multiple research methods. Both qualitative and quantitative methods by using system dynamics approach are implemented in the current work. Multi-methods enable the use of different data collection methods within one study to ensure the validity and reliability of the data.

The time horizon of this study is longitudinal by studying the statistics of energy and RE utilization from 1970 until 2011. The predicting period of system dynamics models is until 2020.

1.4.4 Techniques and procedures

Five main sources of the data and information for this research are observation, judgment of the researcher, analysis of statistical reports, scientific references, and interviews with professionals in the field of RE and energy security. Figure 3 shows the body of data collection.

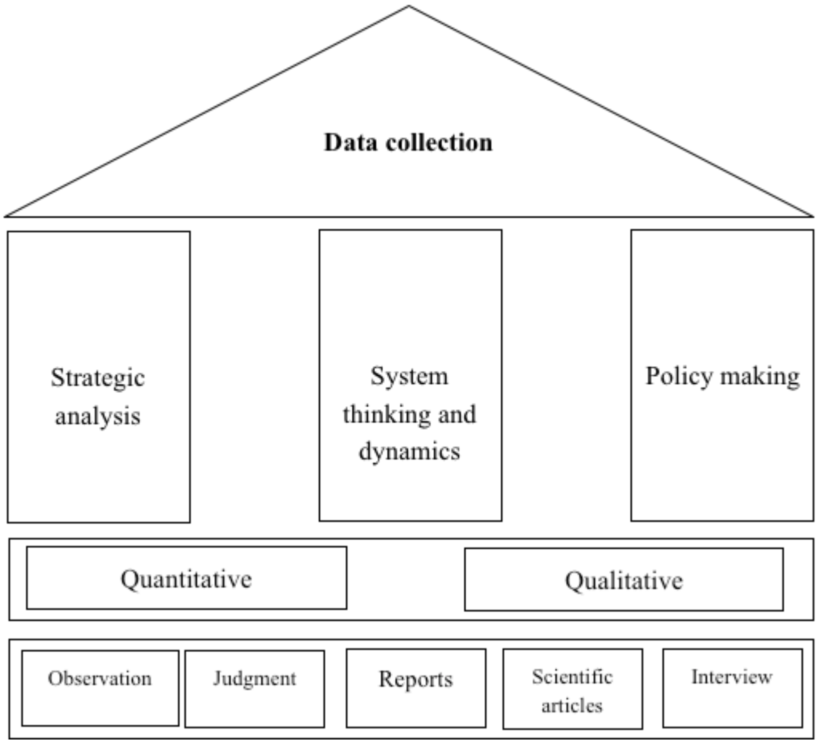

Figure 3. Body of data collection

Observation of the energy policies to use on increasing security of the energy supply and RE development comprises an important part of this research. Further, observation of the behavior of policy makers and professionals in the energy sector is important to capture the beliefs and assumptions of the participants in RE development. The main body of system thinking in current research is based on observation. In particular, behavior analysis of consumers and policy makers located in different levels of the study, Nordic countries and Finland as the case for system dynamics model, are at the core of the observation. Enough time was considered for learning to increase understanding and discovery of the relationships of the problem structure and variables during system thinking.

To extract policy schemes and system dynamics variables, more than 20 interviews with academic professionals and policy makers from different countries (e.g. Finland, the U.S., Sweden, Norway and Italy) were carried out by the researcher. Open ended interviews helped the researcher to make a reliable causal loop diagram, system dynamics, and strategic analysis.

Approximately 900 academic articles, and documents, including statistics, annual reports, detailed government reports, project reports, and published investigations published by international agencies such as the International Energy Agency (IEA), Energy Information Administration of the U.S. Department of Energy (EIA), International Atomic Energy Agency (IAEA), and European Commission of Energy were reviewed for the current dissertation. The researcher tried to use the most valid and updated English references in case there were more than one reference for a subject, particularly for statistics/data. However, the researcher's lack of native language knowledge of the NCs (e.g. Finnish and Swedish), as well as writing the articles in different times during 2011-2013 are limitations in the research process.

The publishers of the used academic articles are Elsevier, Taylor and Francis, SAGA, Wiley, IEEE in the fields of energy security, diversification, renewables, innovation management, technology management, system dynamics, and research methods.

1.4.5 Research design

Figure 4 shows the research focus and sub-areas of the theoretical foundation that lead to contribution of the dissertation (six articles). The structure of the thesis is as follows:

Chapter two reviews the theoretical foundation of the dissertation. It also involves the history of RE development and policy in the NCs with special focus on the selected country, Finland. Chapter three provides the research contributions to response to each research question in the frame of six academic articles. Chapter four summarizes the dissertation discussion, and lays out the key findings. The chapter will also discuss research limitations and validation, and the future work required for the advancement or improvement of the system dynamics models.

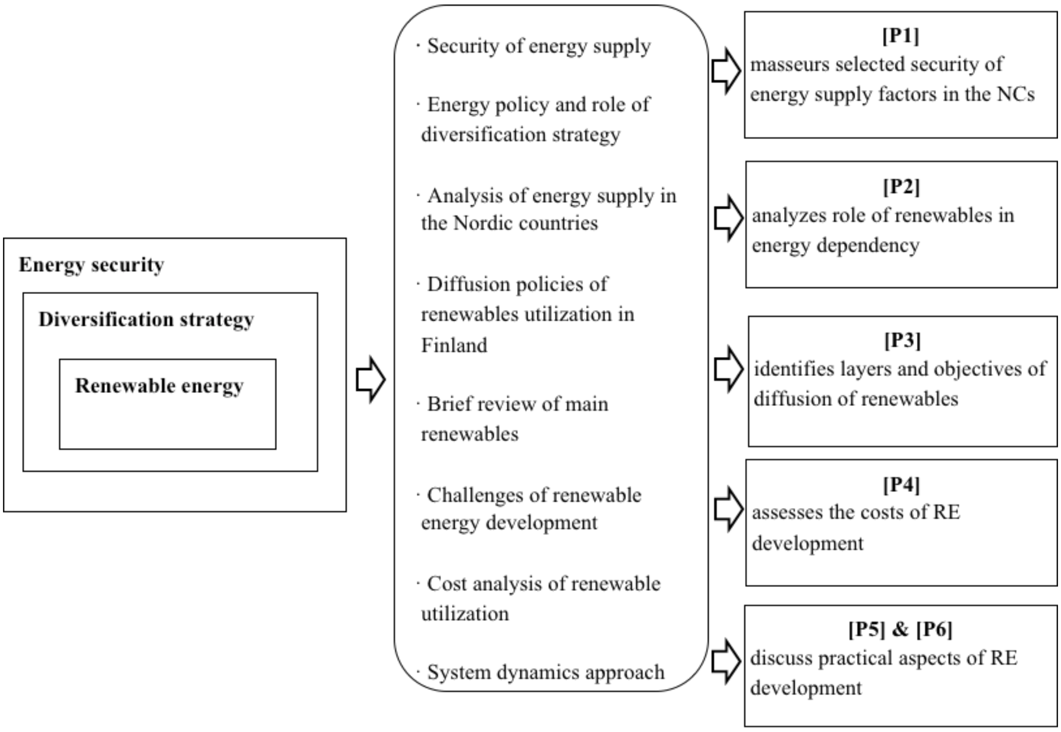

Figure 4. Research design of the dissertation

2 THEORETICAL FOUNDATION

This chapter reviews the theoretical foundation of the dissertation. It also involves the history of RE development and policy in the NCs with special focus on the selected country, Finland. The chapter is divided into eight sub-areas, namely security of energy supply, energy policy and role of diversification strategy, analysis of energy supply in the NCs, diffusion policies of renewables utilization in Finland, brief review of main RERs, challenges of RE development, cost analysis of renewables utilization, and system dynamics approach.

2.1 Security of energy supply

Access to adequate, affordable, reliable, and clean energy is the requirement of modern economies. Energy security is the translation of this concern and affects economy, safety, social welfare, and the environment. The European Commission defines energy security as the "uninterrupted physical availability of energy products on the market with price that is affordable for all categories of consumers." Energy security traditionally focuses on securing access to supplies of oil and other fossil fuels. However, the influence of other energy resources and other aspects of energy supply chains are also studied in one of the main subjects of energy security (Ulmann 2011; Jenny 2007).

According to Brown et al. (2003), energy security consists in three levels: internal security, energy consumption, and external security. Internal security is for national production, transmission, and distribution of the energy supply to the end-user. The volume and quality of consumption based on the amount of supply and prices are studied in energy consumption. External security shows imported energy products meet the needs of the consumers in time and quantity (Brown et al. 2003).

According to Chevalier (2006), the elements of security of energy supply are categorized in four main elements: reliability of energy supply (diversification of primary energy sources and suppliers), reliability of supply transportation of supply (energy networks), reliability of distribution and delivery of supply to end-users, and reasonable price.

To measure and evaluate the level of energy security, policy makers and researchers define different indicators and factors. These indicators help policy makers to observe the achievement of their policy objectives and warn about undesirable trends in energy systems. The potential of natural resources, government interventions to set energy prices against market forces, and long/short term planning are three important factors to evaluate the level of energy security in a country (IAEA 2005; IEA 2004; Hippel et al. 2011; APERC 2007; Jansen and Seebregts 2010; Kruyt 2009; Looschel et al. 2010).

To show and compare the level of security of energy supply in the NCs, two of the most important security of energy supply indicators are reviewed in this dissertation, namely "diversification of energy supply sources", and "net import dependency". The basic idea for diversification indicators is based on the portfolio theory in finance. According to this theory, the overall risk of energy supply is smaller if there is a diversified portfolio of suppliers (Dybvig & Ross 2004). The "diversification of energy supply sources" indicator considers both the significance of diversification in terms of abundance and equitability of sources. The "net import dependency" indicator reflects the impact of both diversification and imports on energy supply security (USAID 2008).

2.2 Energy policy and role of diversification strategy

Energy policy is a subject addressing the issues of energy utilization including production, distribution, consumption, and energy development. The attributes of energy policy may include policy implications of energy supply and use from their economic, social, planning and environmental aspects, incentives to investment and other public policy techniques (Andrews & Jelley 2013). While the policies related to energy can cover a variety of sources such as renewables, nuclear and fossil fuels, the subject can be studied in different levels, namely regional, national, state, industry, business, and corporate.

The limitations of fossil fuels as the main supply source of energy consumption have motivated policy makers, scientists, politicians, and economists to think about ensconced alternatives with lower potential risk. For instance, fossil fuels are not harvestable in all countries nor are they sustainable in the producer countries. Further, continuous fluctuations in prices as well as increase in other costs (e.g. transportation) make fossil fuels more unreliable. On the other hand, the environmental, technological, and political dangers of nuclear energy illustrate the utilization necessity from other reliable resources.

Diversification is one of the important aspects in energy security studies. According to Ganova (2007), diversification has three levels: diversification of energy resources, diversification of suppliers, and diversification of transport routes. Diversification of suppliers and energy resources are very important to assess the level of security of energy supply and dependency in a country. Over reliance on a few numbers of suppliers and energy sources brings security risks for countries dependent on imported energy. Factors such as political instability, economic risk, and violence provide supplier risk. Further, dependency on one energy source (e.g. fossil fuels) not only increases the supply risk, but also brings extra economic and environmental risks.

Diversification of the energy supply means a portfolio of domestic natural energy sources (domestic or imported) that should be implemented in a country or region to reduce the security risks of energy supply and dependency on energy imports. According to Yergin (2006), diversification in energy sources reduces the impact of disruption in supply or generation. It also provides a stable energy market, as well as serving the interests of consumers and producers.

2.3 Analysis of energy supply in the Nordic countries

The Nordic countries (NCs) are the northernmost countries in Europe. This region includes independent countries (Finland, Sweden, Norway, Denmark, and Iceland) plus three autonomous regions (Aland, Faroe Islands, and Greenland). The population of the NCs was 25,830,631 (0.37% of world population) in April 2012 (Vaestorekisterikeskus 2012; SCB 2012; SSB 2012; Energistyrelsen 2012; Iceland in Figures 2012). The region comprises among the top developed countries from economic and social welfare indicators.

The NCs are energy intensive countries because of the cold climate, energy intensive industries, wide sparsely populated areas with long distances, and high standard of living. For instance, Finland’s per capita energy consumption is the highest within the European Union (IEA 2000). Norway and Sweden are also among the top countries in this indicator. Figure 5 illustrates the total primary energy supply in the NCs by sources in 2011.

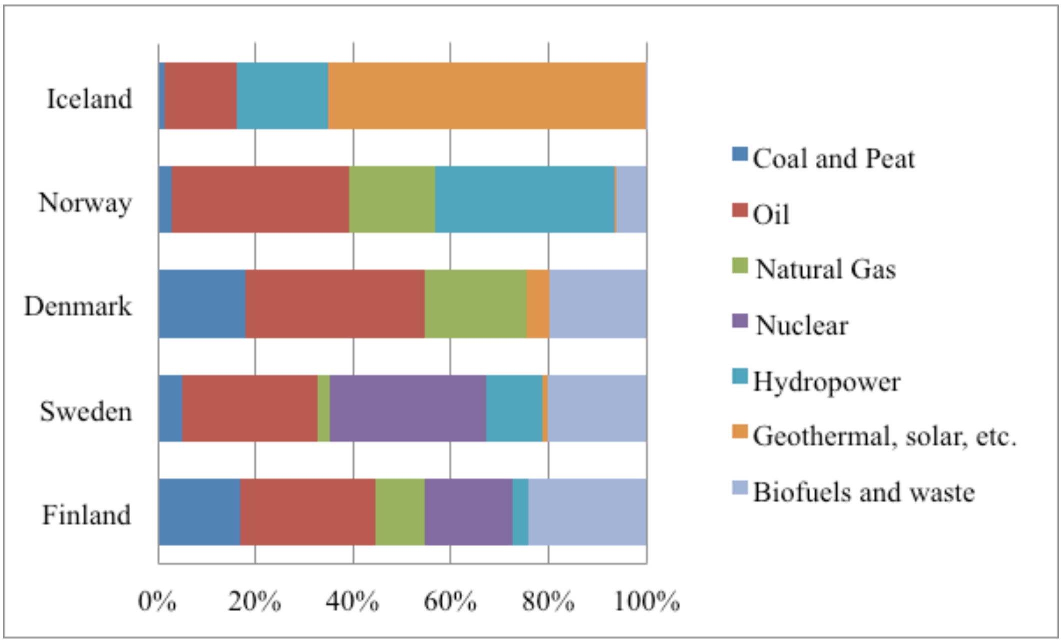

Figure 5. Total primary energy supply in the Nordic countries in 2011 (IEA 2011)

According to the figure, Finland and Sweden have the largest diversity in their energy supply compared to other NCs. While Finland, Sweden, and Iceland have to import a substantial part of their fossil fuels, the annual production of energy in Norway is approximately 10 times that of the domestic use (KanEnergi 2009). Figure 6 shows the breakdown of final consumption by source in the NCs' industry sectors before the first economic recession (1973) and in 2001 and 2011.

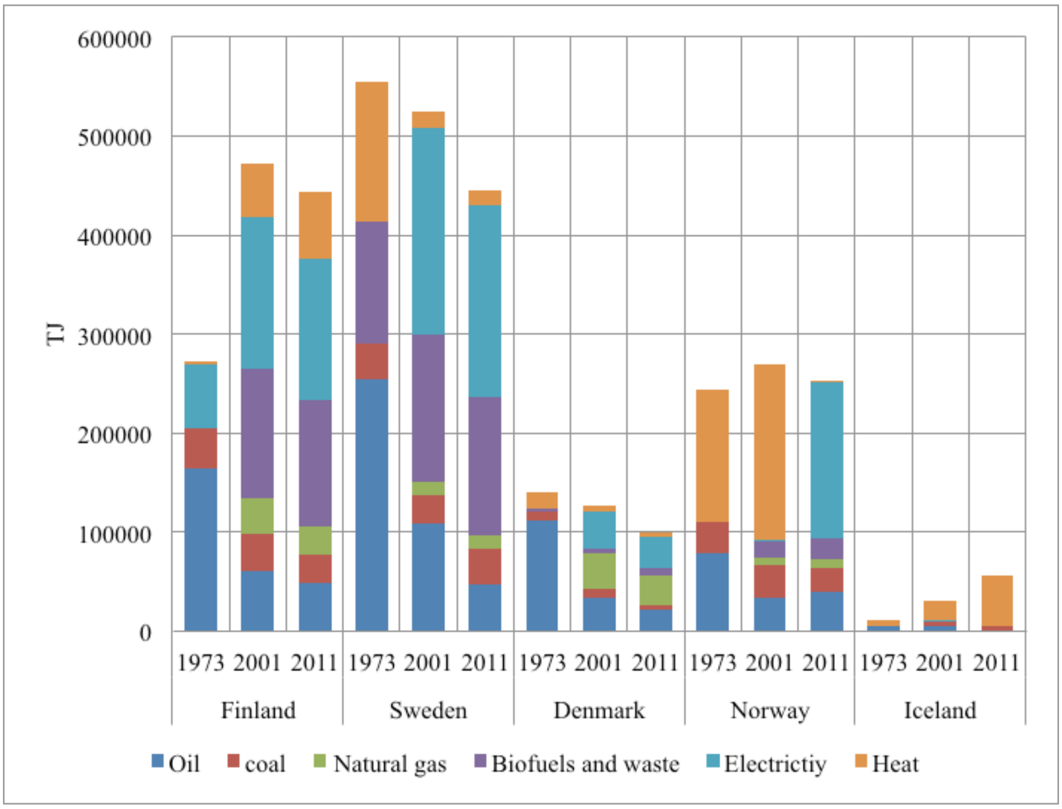

Figure 6. Breakdown of sectorial final consumption by source in industry sector (IEA 2011)

According to the figure, the shares of oil and coal in the energy supply have been substantially reduced in the last three decades in the NCs, especially in Finland, Sweden, and Denmark (red and violet colors). In Finland, it dropped from 64% in 1973 to 28.7% in 2009. While electricity and district heating system consume the most part of the energy supply, RERs are their main supply sources. Figure 7 shows the energy consumption mix for electricity plants, combined heat and power plants (CHP), and heat plants in the NCs. Due to the geographic situation of the NCs, solar energy is not a utilization priority on an economic scale.

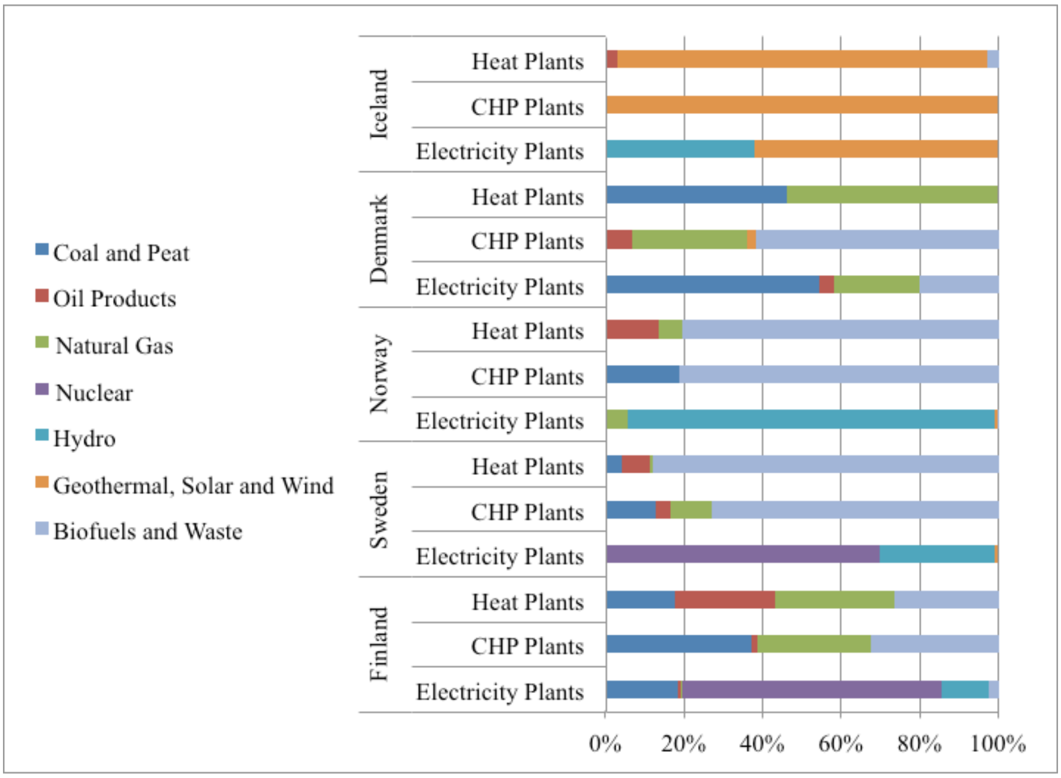

Figure 7. Energy consumption mix for electricity and heat plants in 2009 (KanEnergi 2009; IEA 2011)

Iceland derived 84% of its primary energy from indigenous RERs in 2011 (65% geothermal and 19% hydropower). They covered 100% of electricity generation with the amount of about 45000 TJ for hydropower and about 17000 TJ for geothermal in 2011 (IEA 2011). Hydropower is also utilized for more than 95% of electricity generation in Norway (about 440000 TJ in 2011; IEA 2011). On the other hand, Finland and Sweden are two of the leading countries using bioenergy and waste, with about 41000 TJ and about 47000 TJ electricity generation in the world in 2011 (IEA 2011). The national target for Finland is to increase electricity production from biomass, of which the major part originates from the forest industry (EREC 2009). In recent years, the pellet market is one of the rapidly developing industries in Sweden and makes Sweden one of the world's leading producers and users of pellets in the energy supply (Energy Policies of IEA Countries: Sweden 2008). Finally, Denmark has a leading role in wind power and the expansion of wind power is an important goal in Danish energy policy and supply (Energy Statistics 2011). Therefore, the main energy policy of the Nordic go vernments is to diffuse RE utilization by providing different policies and mechanisms. The NCs have long-term strategies for CO2 emission reduction to be achieved by 2050 (NETP 2013). Table 2 reviews some targets categorized based on country.

Table 2. Climate and energy related targets for Nordic countries (NETP 2013)

Country	**Greenhouse gas reduction targets (CO2 equivalents)**			**Renewable energy targets, gross final energy consumption**		**Climate-and energy related constraints or targets (examples)**
	2012 (Kyoto)	2020	2050	2005	2020	
Finland	0%	-16% (non ETS)	-80% (domestic)	28.5%	38%	• Regulations on the use of water resources (*e.g.* hydro power) by the Water Act • Decisions on licenses for new nuclear plants to be adopted by Parliament
Sweden	+4%	-40% (non ETS)	-100% (net)	39.8%	49%	• Law to protect some rivers from hydro power • Limitation on new nuclear plants : *e.g.* maximum 10 reactors, no effect limit
Norway	+1%	-30% (net)	-100% (net)	58.2%	67.5%	• Protection Plan for watercourses, protection of water resources from hydro power • 2/3 of emission reductions in 2030 will be domestic (the rest through flexible mechanisms)

Den-mark	-21%	-20% (non-ETS) -40% ETS and non-ETS)	100% rene-ne-wab-le ener-gy supp-ly	17%	30%	• 100% RE system (all sectors) in 2050 • All use of coal phased out by 2030 • 100% renewable electricity and heating in 2035 • Phase out of oil for heating in buildings by 2030 • Wind power covers 50% of power production in 2020
Iceland	+10%	-15%	-50%-70% (net)	55%	64%	-

2.4 Policies of renewables utilization in Finland

Finland is the fifth largest and the most sparsely populated country after Iceland and Norway in Europe. Finland's economy is highly dependent on industrial products. The industrial sector consumes more than half of the primary energy supply. While the population of Finland increased by 12% during 1981-2011, energy consumption increased by more than 90% from about 730000 TJ to about 1390000 TJ (Statistics Finland 2013). The country is highly dependent on external fossil fuels and uranium (for nuclear power). The net energy import in Finland was 57.4% of energy production in 2011 and 90% dependency on imported fossil fuels (IEA Sankey 2011). Concerns such as fluctuating fossil fuel prices, increasing world demand for energy, and uncertain oil and gas supplies have caused Finnish policy makers to realize the need to have a secure and safe energy supply. In response, different strategies such as utilizing domestic and local natural resources, diversifying fuels and suppliers, and decentralized forms of utilization have been reviewed to keep a safe level of energy security. As table 3 shows, the share of fossil fuels and peat in final consumption decreased during 1981-2011 from 62% to 50% (Statistics Finland 2013).

Table 3. Share of energy sources in primary energy consumption in Finland (Statistics Finland 2013)

Year	Fossil Fuels and Peat	Nuclear energy	Renewables	Others
1981	62%	21%	16%	2%
1991	61%	18%	18%	3%
2001	56%	23%	17%	3%
2011	50%	28%	18%	4%

Figure 8 compares the change of each energy source in primary energy consumption during 1981-2011. While the quantity of fossil fuels and peats increased from about 560000 TJ to about 610000 TJ (19.6% growth), RERs increased from about 194000 TJ to about 394000 TJ (202.90% growth). However, the share of renewables did not change noticeably (Statistics Finland 2013).

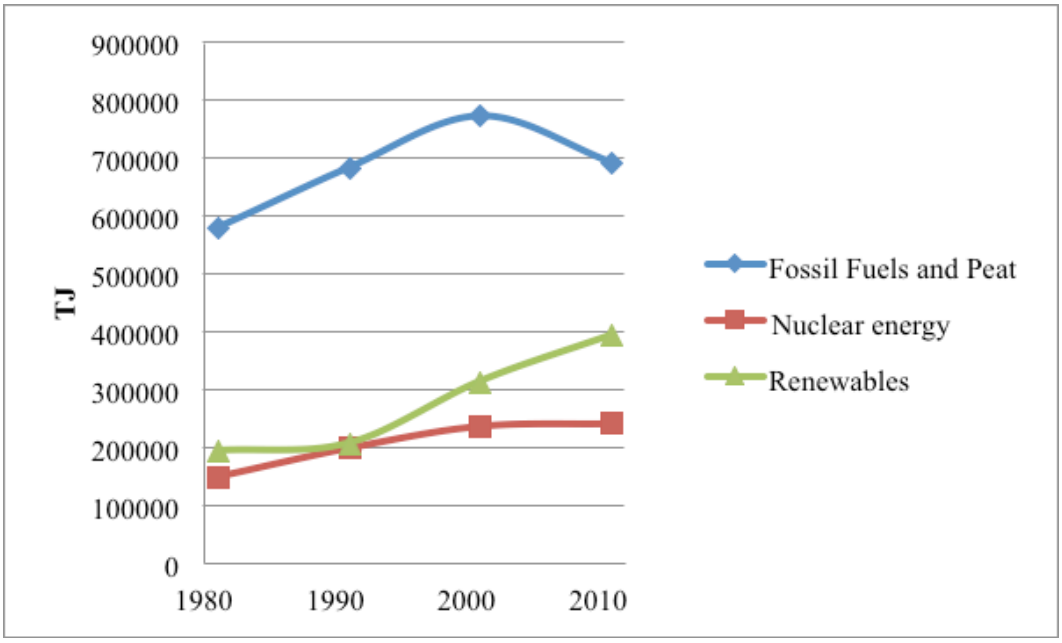

Figure 8. Primary energy consumption in Finland by three main sources

Finland has high-energy consumption per capita compared to other European countries because of its cold climate, the structure of Finnish industries, long distances, as well as a high standard of living. While forest and paper, metal and chemical, and engineering represent 80% of Finnish industrial products and services, the forest and paper industry alone consumes more than 60% of industrial energy (World Bank report 2013). Therefore, electricity has a key role in energy production and supply in Finnish energy policies. The increase in electricity consumption was from about 150000 TJ to about 300000 TJ during 1981-2011 (Statistics Finland 2013). In 2011, the consumption of energy sources for electricity generation by mode of production was about 80000 TJ for nuclear power, about 44000 TJ for hydropower, about 51000 TJ for coal and peat, about 33000 TJ for natural gas, 3600 TJ for oil and other fossil fuels, about 36000 TJ for wood fuels, 1800 TJ for wind power, and about 1400 TJ for other sources (Statistics Finland 2013). Those resources provided about 250000 TJ of production that with about 50000 TJ of imported electricity corresponded to about 300000 TJ electricity demand in Finland. The share of RERs for electricity generation in Finland fluctuated between 25% and 28% during the last 30 years.

In general, RE alternatives have an important role in the Finnish energy and climate strategies. Figure 9 shows the main sources of energy consumption/electricity generation in Finland in 2012. The principal RE source in Finland is biomass and forest (solid biomass) that covers nearly 86% of Finland's land. Recently, other sources, particularly wind power, have increased their contribution to Finland's national action plans. It is expected that about 38% of the gross final consumption will be from RERs by 2020 in Finland (Finland's National Action Plan for Promoting Energy 2010). It is worth noting that the word "dependency" in the dissertation and attached articles refers to dependency on energy imports, mainly fossil fuel imports.

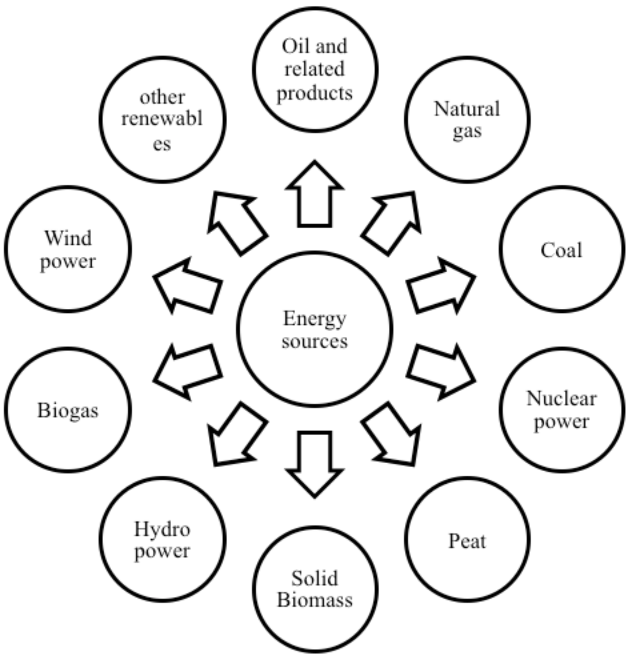

Figure 9. Energy sources for energy consumption and electricity generation in Finland in 2012

2.5 Brief review of main renewable energy resources

This section provides a brief review of the main sources of renewables in electricity/heat generation.

2.5.1 Biomass

Biomass refers to energy from plants or plant-derived materials (World Energy Council 2004). However, there are other categories of biomass including crops, agricultural residues, co-products from manufacturing and industrial processes, and food and industrial wastes. As a RER, bioenergy can be used to produce electricity and heat, or can be used as gaseous, liquid, or solid fuels (IPCC 2011). Approximately 62% of RE utilization is for biomass mainly used for heating. Biomass combustion is used for heat and power generation from wood, organic waste products, etc. Biomass is changed to biofuel by different methods such as chemical, thermal, and biochemical methods. According to the IEA energy statistics, biomass and wastes comprised 10% of total primary energy supply in 2011 (IEA 2011).

2.5.2 Hydropower

Hydropower refers to using water for electricity generation. Falling water behind a dam flows and turns a generator to produce electricity through a turbine. Generated electricity by hydropower can meet sudden fluctuations in demand and compensate for the loss of other supply options. According to the IEA energy statistics, the total amount of hydropower utilization in primary energy supply was about 12840000 TJ worldwide with a share of 2.3% in 2011 (IEA 2011). Large-scale hydropower provides 21% of electricity generation by RERs. The main sources of electricity generated by hydropower are large dams. However, some hydropower plants use canals to channel water through a turbine in rivers (National atlas 2013). Small or micro hydroelectric power systems can generate electricity for private use in homes or farms.

2.5.3 Wind power

Wind power is one of the fastest growing technologies for electricity generation. From an engineering viewpoint, wind power is dependent on the cube of wind speed within the operating range (IRENA 2012). The survival speed of commercial wind turbines is in the range of 40 m/s to 72 m/s. Therefore, turbines are not available at times of low or very high wind speeds. Turbines with two or three blades are mounted on tall towers to capture more energy. The output of a wind turbine depends on the location and capacity factor and is variable in time-scales from minutes to hours or seasonal. The total amount of wind power utilization in primary energy supply was about 1560000 TJ (less than 1%) worldwide in 2011 (IEA 2011).

2.5.4 Solar power

Solar power technologies provide heat, light, hot water, electricity, and even cooling for different sectors. Solar energy is utilized in two main frames: solar photovoltaic (PV) and solar thermal. Photovoltaic (PV) is for technology to electricity generation by converting solar radiation into direct current electricity using semiconductors and solar panels (Kemp 2009). Solar PV is not dispatchable, which is the main weakness of this technology. In other words, the output of solar PV cannot be controlled or scheduled to respond to variable demands. Solar thermal is a technology of solar energy utilization for thermal energy (heat). According to the US Energy Information Administration (EIA), solar thermal collectors are classified in three levels: low-temperature collectors (LTC), medium-temperature collectors (MTC), and high-temperature collectors (HTC). The total amount of the world's solar power utilization was about 230000 TJ for electricity generation and 165 TJ for heat production in 2011 (IEA 2011).

2.5.5 Geothermal

Geothermal is thermal energy, utilizing the accessible thermal energy from the Earth's interior (IPCC 2011). It ranges from shallow ground to hot water and hot rock found a few miles under the Earth's surface and deeper to the extremely high temperatures of molten rocks (Renewable Energy World 2013). Geothermal power is utilized by different technologies such as direct-use system, the use of deep reservoirs to generate electricity, and geothermal heat pumps. Heat pumps are the main technology for geothermal energy. The total amount of geothermal power utilization was about 250000 TJ for electricity generation and about 12000 TJ for heat production worldwide in 2011 (IEA 2011).

2.6 Challenges of renewable energy development

Most economists and policy makers admit that one of the ways to reach sustainable development is the maximal consumption of RERs. RERs are attractive because of their free and local availability; they are clean, eco-friendly, and sustainable. RERs enhance energy security by electricity generation, heat supply, and transportation.

As RERs are widely distributed, utilization of RERs can minimize transmission losses and costs when they are located close to demand loads. In addition to electricity generation, deploying renewable heating and cooling technologies can reduce dependency on fossil fuels. Finally, the production of liquid transport fuels from a range of biomass resources is a part of the solution presented by policy makers to reduce dependency on imported oil and achieve the environmental targets (NETP 2013).

The share of renewables in the energy sector is growing considerably. In Europe, this growth is largely driven by policies adopted in different levels from the European Union to national and regional targets. According to the European Union's RERs directive, the share of RERs in all EU countries should rise to 20% of the final consumption by 2020 (35% of electricity production). The advantages of this policy are considered in three main layers: energy security, economic development, and environmental aspects.

Despite successful efforts, there are remarkable policy gaps between achievements and plans. In fact, the diffusion of RERs still faces structural and technological challenges such as competitiveness in terms of technological price, high complex policy environment, and public acceptability and reliability.

Since the RE industry offers a profitable future, there is sufficient possibility and potential for private sector investments. From a private investor's viewpoint, the RE industry is an entrepreneurial industry along with technological and political uncertainties that make traditional evaluation of investment difficult (Zuluaga & Dyner 2007; Fadai & Esfandabadi 2011; Aslani et al. 2012a; Aslani et al. 2012b).

2.7 Cost analysis of renewables utilization

Financial factors that indicate the required investment and other costs of RE utilization (e.g. maintenance and operation), as well as efficiency of energy sources (performance), are two key criteria for RE promotion. For instance, wind energy has been cost-effective in many cases (IPCC 2011). While the efficiency and reliability of wind turbines have increased, the capital costs have been halved over the last 30 years (OECD 2012). On the other hand, the cost of solar PV technologies is decreasing as demand is rising (IPCC 2011).

2.7.1 Energy conversion efficiency of energy sources

Efficiency has various definitions in different sciences. One of the definitions of energy efficiency is related to energy conversion efficiency (η), which means using less energy to provide the same or improved desirable output. Two main fossil sources for electricity generation in Finland are coal/peat, and natural gas. While the share of coal/peat in electricity generation by fossil fuels was 61% (about 57000 TJ), natural gas had a share of 37% (about 34000 TJ) in 2011 (IEA 2011). However, natural gas has many advantages compared to coal. For instance, natural gas burns more cleanly than coal and other fossil fuels. It is also more efficient compared to coal/peat.

According to EIA 2013, the capital cost of natural gas power plants is almost a quarter of the capital cost of coal/peat power plants. Natural gas can be easily transported via pipelines. Although natural gas is cleaner than oil and coal, it still produces a large amount of carbon. From the supply viewpoint, Finland has 100% dependency on imports of this source (IEA Sankey 2011).

The costs of RE utilization and development (first scenario) in this dissertation are compared with natural gas as a replacement fossil fuel (second scenario). The reason is because of the role of greenhouse gas reduction in Finland's national action plans. In other words, to launch the system dynamics model of RE cost analysis, the researcher assumed that the new capacities of fossil source for electricity/heat generation are natural gas power plants.

As discussed in Chapter 1, the main objective is to present and implement a system dynamics model for cost analysis of RE development. Therefore, natural gas is a scenario for system dynamics model and the presented model can be updated with new scenarios such as nuclear power plants.

The main biomass source in Finland is wood used in combined heat and power (CHP) plants. Wood residual chips (forest chips) are the cheapest available wood fuel and used as a mixture with milled peat. As the costs of generated electricity by wood are clearly higher than other sources, there are no power plants only for electricity generation by wood in Finland. If the CHP plants are used for electricity/heat generation, the investment cost of a merely electricity producing power plant are around 3000 €/kW with efficiency of around 35%.

Statistics show that the average peak load utilization time of wind power plants is about 1800 hours per year in Finland (Holttinen 2007). In this study, a peak load utilization time of 2000 hours per year with 40% energy conversion efficiency is estimated for wind power plants. A lifetime of 25 years is also used for wind turbines. Finally, the typical energy conversion efficiency of 60% for hydropower, 20% for solar PV and thermal, and 20% for heat pumps are estimated for electricity/heat generation (Electropaedia 2013).

2.7.2 Costs of renewables utilization

The costs of producing energy for electricity/heat generation from RERs depend highly on location and the resources involved. Figure 10 reviews different segments of the energy technologies costs extracted from IEA-RETD (2012).

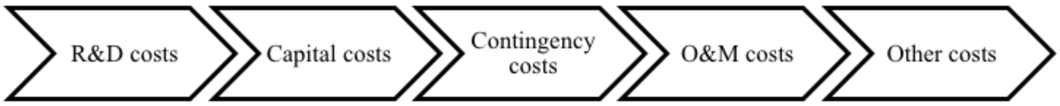

Figure 10. Different segments of the energy system costs

- *Research and development (R&D) costs:* R&D expenditures have two main sources: public/government and private. While private firms include their R&D costs in the sale price of their product or service, R&D grants or funding by public institutions and governments are impossible to track for specific cost components of specific plants (IEA-RETD 2012).

- *Capital costs:* These costs include all expenses needed to bring an energy plant to commercially operating status such as the costs of land acquisition, buildings, construction, financing costs and equipment for electricity/heat generation. According to an IEA-RETD report (2012), four main types of capital costs include: 1) engineering, procurement and construction (EPC) costs (or Base plant costs); 2) owner's costs; 3) interest during construction (IDC); 4) integration costs (transmission or grid).

- *Contingency costs:* this group of costs comprises all the unplanned costs during the construction or operating phases.

- *Operating and management (O&M) costs:* They include the expenses during the energy system operating. Two types of O&M costs include fixed O&M costs and variable O&M costs. Fixed O&M costs mean fixed maintenance costs plus maintenance and operation staff costs. Variable O&M costs depend on the source of different items that may be included. Fuel costs can be a part of O&M costs (operating costs). Emissions costs (greenhouse gases costs) that is usually for fossil fuel sources, can be also bring in fuel costs.

- *Other costs:* such as selling price, taxes, and subsidies

Given that one of the steps of the current research is to build a system dynamics model for cost analysis of RE development, we need different parameters of the costs. The costs are summarized in four items, including initial investment (cost of capital), operations and maintenance costs (O&M), cost of fuel, and costs of greenhouse gases (e.g. carbon emissions). Other costs including selling price, taxes, and subsidies are not included. In recent years, beyond the effects of technology development on prices decreasing in RE technologies, the overall price level of RE systems has risen remarkably (e.g. construction prices such as metals and other materials used in the power plant components and fuel prices). To increase the validity of the research and provide a comprehensive and similar scale implementable for other countries or cases, the cost levels calculated and published by the US Department of Energy are used in this study (except fuel cost and emission costs). This reference is the most valid and reliable source of energy cost analysis (IEA 2012). However, any other references can be implemented for use in system dynamics models.

While the investment costs are based on estimations until 2017, value added costs such as taxes are not included. To calculate the costs, the "Levelized Cost of Energy" (LCOE) is used in this dissertation. LCOE shows the cost of an investment assuming the certainty of production costs and the stability of electricity prices based on the following formula (IEA-NEA 2010):

$$LCOE = Elec_{price} = \frac{\sum_t \left((I_t + O\&M_t + Fuel_t + C_t + D_t) * (1 + r)^{-t} \right)}{\sum_t (Elec_t * (1 + r)^{-t})}$$

$Elec_{price}$ = The constant price of electricity

$(1 + r)^{-t}$ = The discount factor for year t

I_t = Investment costs in year t

$O\&M_t$ = Operations and Maintenance costs in year t

$Fuel_t$ = Fuel costs in year t

C_t = Carbon costs in year t

D_t = Decommissioning costs in year t

$Elec_t$ = Electricity produced in year t

The LCOE factor allows a comparison between energy technologies with very different generation characteristics and plant sizes. It is a most typical variable used by many scientific articles and reports on the energy sector. However, according to the IEA-RETD report (2012), LCOE factor drawbacks are such as:

– variables are included that make it difficult to trace the cause,
– it is just a “partial” figure for policy makers or investors,
– It does not reflect total costs, being just a ratio.

The researcher assumes that if the policy makers plan to develop electricity generation via fossil fuels, new combined cycle gas turbine plants can be located near the existing natural gas network in Finland. Therefore, the connection fee does not contribute to the investment cost. The investment cost of the combined cycle gas turbine plant is estimated at 7.4 €/GJ. The O&M costs is also proposed as 0.86 €/GJ (EIA 2011). As the prices of fossil fuels have recently risen, the natural gas prices are assumed as 11.25 €/GJ (EIA 2011). According to EU regulations, an additional cost for fossil fuels should be also added as a greenhouse gas emission price. The emission price is estimated at 60 €/tonCO2 during 2013-2020 (Tarjanne & Kivistö 2008).

For RERs, the investment cost of a wood power plant is assumed to be 12.14 €/GJ (EIA 2011). The fuel prices are also estimated for peat at 2.47 €/GJ and for wood chips at 3.7 €/GJ. The O&M cost is estimated at 2.9 €/GJ (EIA 2011). The level of investment in wind power plants (on-shore) is estimated at around 17.8 €/GJ. However, the investment cost level depends on the market, regional conditions, competition, and project size (Tarjanne & Kivistö 2008). According to the operation experience of existing wind power plants, the O&M cost of wind power plants is estimated at 2.08 €/GJ, that is bigger unit size decreases the O&M cost (Tarjanne & Kivistö 2008).

In 2009, the average cost of installed solar panels systems was 5.8 €/W installed capacity in Germany, $3.5 €/W in Japan, and ranging from 3.8-8 €/W in the United States (NREL 2009; Branker et al. 2011). Therefore, a 2KW capacity solar panel system would cost between 7100 € and 15000 € installed depending on the location. About 20% additional costs such as using batteries for power saving should be added to the named costs (Branker et al. 2011). The prices of solar technologies dropped by 50% in 2011 due to adoption of new technologies in related industries (Branker et al. 2011). The cost of installing a heat pump using ground-heat is about twice the price of installing systems based on electricity. However, the running costs of ground-heat systems are much lower (Kukkonen 2000). The investment and O&M costs of this technology are estimated at 16.36 €/GJ and 2 €/GJ respectively (EIA 2011). Finally, the investment and O&M cost of electricity generated by hydropower are approximately estimated at 16.4 €/GJ and 0.86 €/GJ (EIA 2011).

2.8 System dynamics approach

System thinking is a mechanism of deeper understanding with consideration to different aspects and consequences for a problem or phenomena. This understanding is beyond the events, trends, and patterns that we see as everyday behavior (Senge 1990). System dynamics is a modeling approach for problem detection, system description, qualitative modeling, and analysis of changes in complex systems (Sterman 2000; Sterman 2001). Due to the complexity of policy and behavioral patterns of a system in the real world, the system dynamics approach is very useful for analysis. System dynamics modeling is a valuable and powerful tool for related policy analysis of energy security and RE development.

As a tool for energy systems conceptualizing, system dynamics has been used for more than 30 years (Finland's National Action Plan for Promoting Energy 2010). Some researchers have utilized system dynamics to evaluate physical structure of energy systems and build different scenarios (Naill 1972; Naill 1977; Chi et al. 2009; Connolly et al. 2010). They also evaluate the consumption of energy to find the relationship between economic factors such as GDP with energy indicators to predict the scenarios of energy market and prices (Naill 1977). The second group of researchers has implemented system dynamics models to assess environmental and effects of CO2 emission in energy systems (Anand et al. 2005; Han & Hayashi 2008; Jin & Young 2009; Trappey et al. 2012). They have developed different dynamic platforms to support policies related to subjects such as urban sustainability improvement, cost analysis of CO2 emissions. Energy policy in terms of security of energy supply is the third group of research of system dynamics and thinking approach (Chi et al. 2009; Wu et al. 2011; Shin et al. 2013). These models help experts to identify key energy components to implement in a particular country in the frame of indicators or policies. A few works also focus on dynamic modeling of RE polices (Krutilla & Reuveny 2006; Bennett 2012;

Hsu 2012; Mediavilla et al. 2013). These research analyze the replacement of RERs with oil and non-renewable fuels.

Despite different system dynamics works done on energy research, the number of research worked on the effects of RE on dependency and energy security is not more than ten fingers of two hands. The purpose of current dissertation is to cover a part of this research gap to help experts and policy makers to review their RE promotion plans to achieve a desirable level of dependency and security of energy supply. The simulation software used for this research is Vesnsim made by Ventana Systems Inc. Vensim can simulate the dynamic behavior of complex systems influenced by several factors, such as feedback, delay, etc.

3 RESEARCH RESULTS

This chapter provides the answers of each research questions in the frame of six academic articles.

3.1 Research question 1- article 1 results

*** Research question:**	**What are the effective factors of security of energy supply in the Nordic countries?**
*** Research objectives:**	To discuss the role of diversification in security of energy supply and dependency.
*** Article name:**	Comparative Analysis of Energy Security in the Nordic Countries: The Role of Renewable Energy Resources in Diversification
*** Published in:**	Journal of Renewable and Sustainable Energy

This article shows that the Nordic countries have a high level of energy security in comparison with other developed countries and their neighbors. In particular, countries like Finland and Sweden with few domestic resources are able to sustain reasonable economic growth, a high level of social welfare, and a high GDP. Investigations show that a set of strategies and policies provides the circumstances for this success. Figure 11 illustrates the inter-relations of the influencing factors in the frame of system thinking loops.

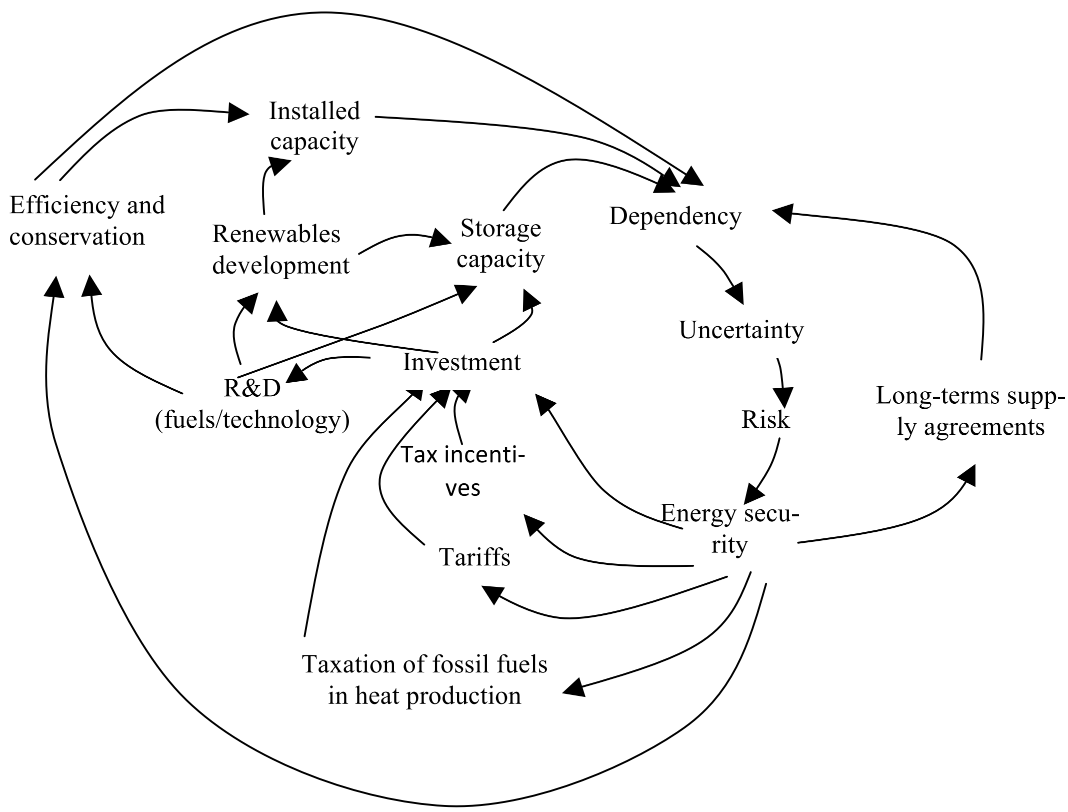

Figure 11. Feedback structure of support schemes and policies for energy security in the Nordic countries

Examining the right hand side of the diagram, if the "dependency" is decreased, "uncertainty" and thus "risk" decrease. Thereby, risk reduction will increase "energy security." The simplest loop to increase energy security in Figure 11 is related to "long-term supply agreements." These agreements prevent the fluctuations of energy supply, price, and dependency especially in crisis conditions.

More than 15 loops are identified to describe the relevance of each influencing strategy and policy. For example, "investments" affect the "storage capacity," "RE development," and "R&D" schemes of the Nordic countries. Causal links from both "storage capacity" and "installed capacity" to "dependency" are negative. This means that the development of RE utilization decreases the dependence on imported energy.

Investments in RE development take place in two areas: "storage capacity" for utilized energy from RER, and diffusion of RE utilization ("installed capacity"). Generally, investments (public or private) provide the following development loops:

1. Development of storage capacity for different fuels and their products (e.g. strategic reserves).
2. Diffusion of utilization from renewable alternatives (new capacities).
3. Development of storage capacity for renewable alternatives.
4. R&D support for improving the renewable technologies and storage capacity.
5. R&D support to improve the efficiency and conservation of current systems and new capacities.

On the other hand, "tax incentives," "tariffs," and "taxation of fossil fuels" affect investment. The most important schemes for the diffusion of RE in the Nordic countries are subsidies and tax incentives. Taxation aims to curb the growth of energy consumption (efficiency and conservation) and steer the production and use of energy towards alternatives with less emissions.

3.2 Research question 2- article 2 results

*** Research question:**	**How do "diversification" and "RE utilization" affect energy dependency on imported fossil fuels in a selected NC?**
*** Research objectives:**	To design a system dynamics model to evaluate RE policies from the strategic analysis viewpoint
*** Article name:**	Role of Renewable Energy Policies in Energy Dependency in Finland: System Dynamics Approach
*** Published in:**	Applied Energy Journal

This article provides an evaluation method to analyze the effectiveness of RE policies for electricity/heat generation on dependency and security of energy supply polices in the country and at local levels. Due to the number of factors affecting energy dependency and security, as well as the complexity of such systems a system dynamics approach is used to review the consequences of policies and scenarios.

Figure 12 shows the system dynamics model for RE policy in Finland to analyze the level of dependency based on each RE scenario. There are six stocks in the system dynamics model for RE policy in Finland, including electricity/heat demand, capacity of biomass electricity/heat, capacity of hydropower electricity, capacity of solar electricity/heat, capacity of wind power electricity, and capacity of geothermal electricity/heat. The total amount of electricity/heat generated by RERs is the sum of capacity of each RER. As Figure 12 illustrates, the capacity of each RER is influenced by the sum of electricity/heat generated with the increased number because of policies and action plans, and decreased number of RER systems which affects delay (minus). This research assumes that the depreciation periods of RER systems are 20 years for solar, 25 for wind, 25 years for geothermal, 30 years for biomass plants, and 15 years for small hydropower. The number of increased RER systems (rates in the system dynamics model) is directly affected by plans and government policies.

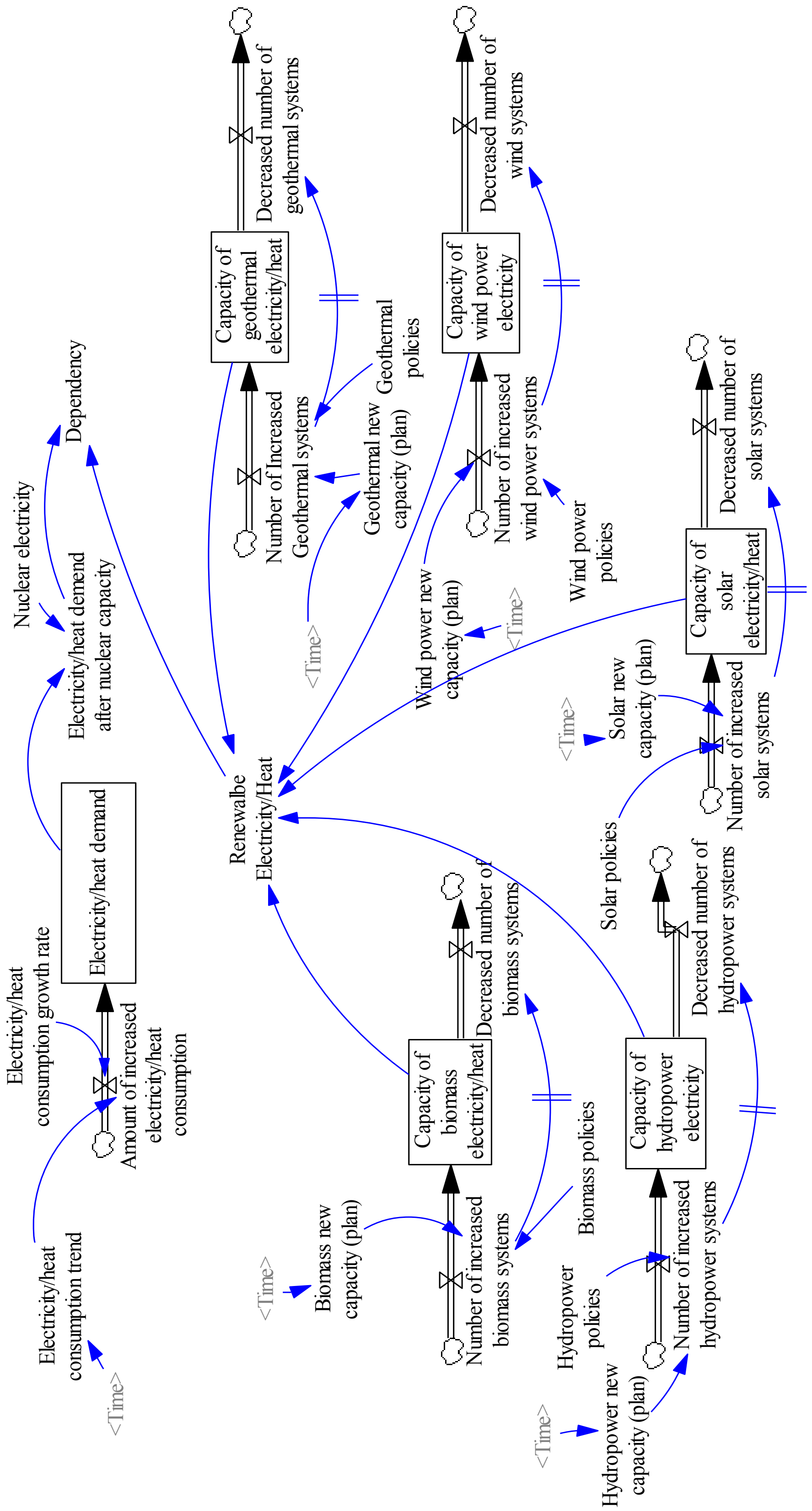

Figure 12. System dynamics model of renewable application policies in Finland

Therefore, dependency on imported sources (to respond to heat/electricity demand) is the difference between electricity/heat generated by nuclear and renewable and electricity/heat demand. As a result, three different policy scenarios are designed for the period 2012-2020:

1. Before promoting renewable policies and implementing the action plan,
2. After 100% implementation of the RE action plan,
3. After implementation of the 90%biomass, 50% hydropower, 80% wind, 100% geothermal, and 50% solar action plans.

The first scenario is a basis for comparing with other scenarios. According to the first scenario, the amount of electricity/heat generated by RE will be fixed during 2012-2020. Therefore, energy dependency will increase by 2013.

The second scenario is based on the action plan defined by the Finnish government. According to this scenario, dependency decreases to around 619000 TJ in 2013 and 539000 TJ in 2020. This means that despite energy consumption growth (around 3% per year), Finland's dependency will decrease by 1% in 2013 and 7% compared to the first scenario by 2020. Further, while the electricity/heat demand increases by around 9% during the period 2011-2020, the amount of dependency will decrease by around 11%.

The third scenario (conservative scenario) is designed based on experts' opinions and the trend of RE projects in the last ten years in Finland. Therefore, the amount of energy dependency in Finland in 2013 and 2020 will be around 620000 TJ and 550000 TJ (0.4% and 5% decrease compared to the first scenario).

3.3 Research question 3- article 3 results

*** Research question:**	**What are the dynamics of RE development in the NCs?**
*** Research objectives:**	To identify different dimensions of RE development.
*** Article name:**	Strategic analysis of diffusion of renewable energy in the Nordic countries
*** Published in:**	Renewable and Sustainable Energy Reviews-2013

The aim is to understand the strategic aspects of RE development. Different layers of RE development were identified that act as barriers or encouragement factors. While some of them have a cultural or a political nature, others have an economic or an environmental structure. Four main layers based on the strategic thinking were defined to categorize each factor: dimensions, characters, objectives, and key schemes. Figure 13 illustrates the framework of the analysis. In this section, a short description of each layer and the names of subsets are discussed. Each factor has been widely described in the article three.

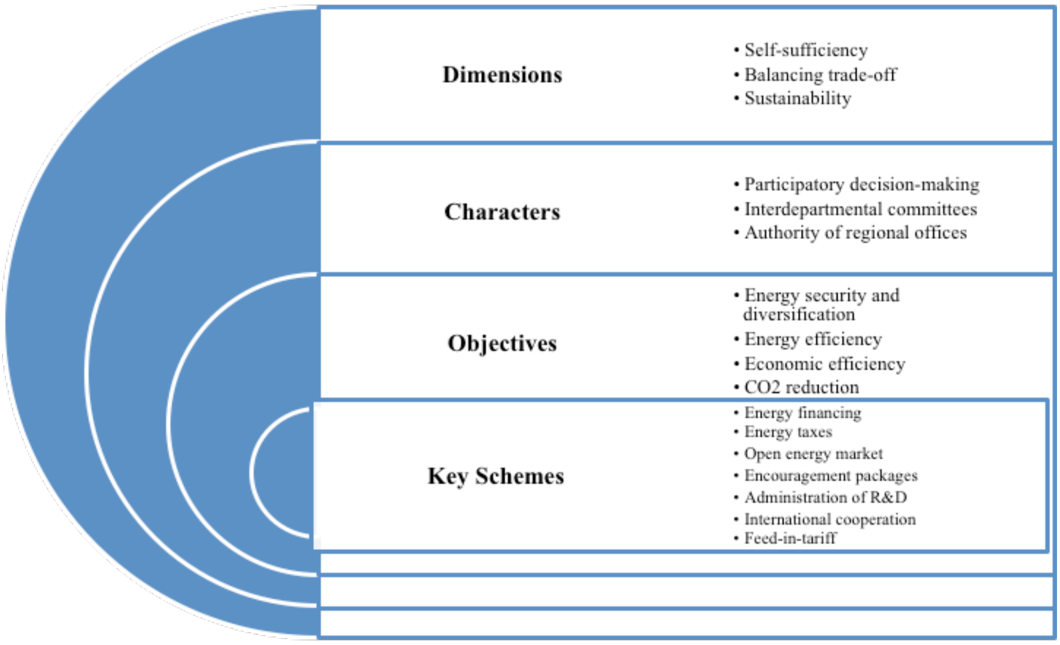

Figure 13. Layers of renewable development

Dimensions of policy making for RE development in the Nordic region can be summarized in three main purposes: self-sufficiency, balancing trade-off, and sustainability. The first and important aspect of RE development in the NCs is to reduce the consumption of fossil fuels and increase the dependency of indigenous resources (self-sufficiency). Second, as RE is available locally, it helps in economic and technologic growth of the region that brings new job opportunities and social welfare development (balancing trade-off). Finally, the reduction in the consumption of carbon-based fuels reduces the pollution and environmental impacts (Environmental sustainability).

Different groups of stakeholders affect public policies and the process of decision-making. Three main characters influence on promotion plans of RE development in the NCs, namely participatory decision-making, the role of inter-departmental committees, and the role and authority of regional offices, universities, and companies.

The objectives of diffusion of RE in the NCs show different perspectives of diffusion of RE including engineering, social, and management viewpoint. They can be broken down into four specific elements: energy security and diversification, energy efficiency, economic efficiency, and CO2 reduction.

Finally, to promote the RE utilization, governmental support schemes are essential. These schemes are different and depend on the government policies, resources etc. However, there are common diffusion schemes in the NCs:

– Energy financing
– Energy taxes
– Open energy market
– Encouragement packages and green certificates
– Administration of research and innovation and policy instruments
– International cooperation
– Feed-in-tariff (FIT)

3.4 Research question 4- article 4 results

*** Research question:**	**How can a system dynamics model be implemented to analyze the costs of RE development in a selected NC?**
*** Research objectives:**	To design a system dynamics model to evaluate RE policies from the cost analysis viewpoint for a selected country in the Nordic region.
*** Article name:**	Evaluation of renewable energy development in power generation in Finland
*** Published in:**	Journal of Renewable and Sustainable Energy

The total costs of RE utilization, including investment costs, operation and management costs, and fuel costs were compared with fossil fuel utilization costs during 2011-2020. The simulation results show that the total costs of new capacities of RE systems and other operation and maintenance costs of the current systems produce a 7% saving (minimum) compared to the total costs of new natural gas power plants during 2011-2020 in Finland.

Figure 14 shows the inter-relations of the influencing factors in the frame of a causal loop diagram. Among a number of variables within the subsystems of RE development, only the main variables related to our model are included in the figure.

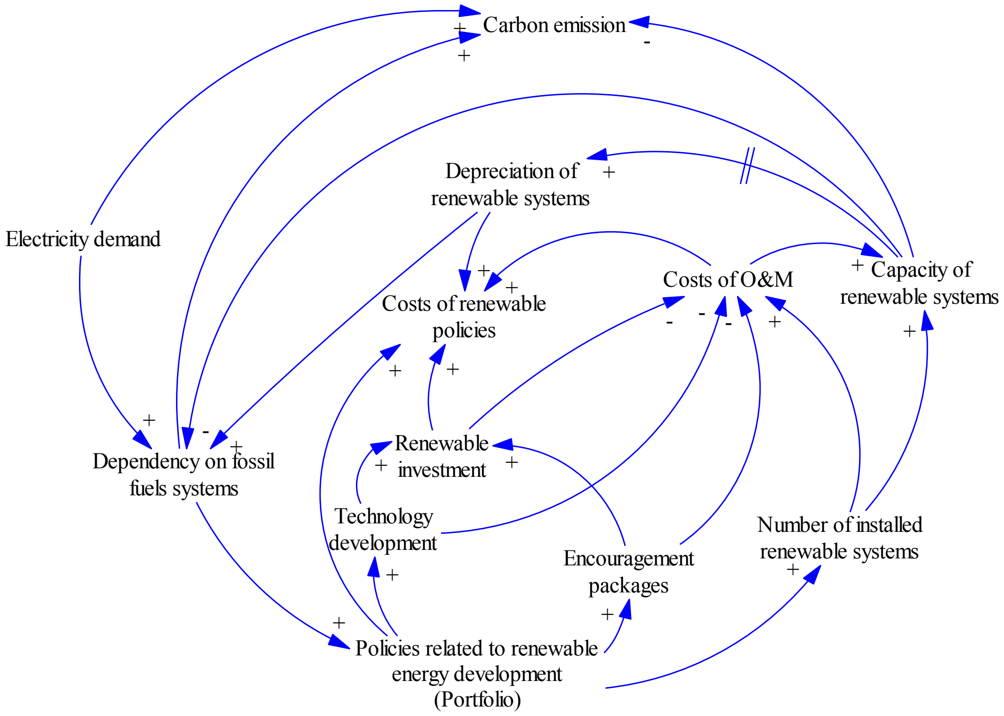

Figure 14. Causal loop diagram of RE development

Based on the above causal loop variables, a system dynamics model is constructed to evaluate and compare the effect of RERs on Finnish energy dependency during 2011 - 2020.

There are five stocks in the proposed system dynamics model, including capacity of biomass electricity/heat, capacity of hydropower electricity, capacity of solar electricity/heat, capacity of wind power electricity, and capacity of geothermal electricity/heat. The total amount of electricity/heat generated by RERs is the sum of the capacity of each RER. Figure 15 shows the system dynamics model of RE development in Finland. As the figure illustrates, the capacity of each RER is influenced by current systems plus new installations (based on the policies and plans) and decreased number of RER systems affected by time delay (depreciation). We assume that the depreciation periods of RER systems are 20 years for solar, 25 years for wind, 25 years for geothermal, 30 years for biomass plants, and

15 years for small hydropower. The number of increased RER systems (rates in the system dynamics model) are directly affected by plans, and government policies. As discussed, the costs data (investment and O&M costs) are based on the data published by the US Department of Energy (EIA 2012). Figure 16 shows the total costs of electricity/heat generated by RERs during 2011-2020. These costs include current RE systems (O&M costs) and new installations during 2011-2020.

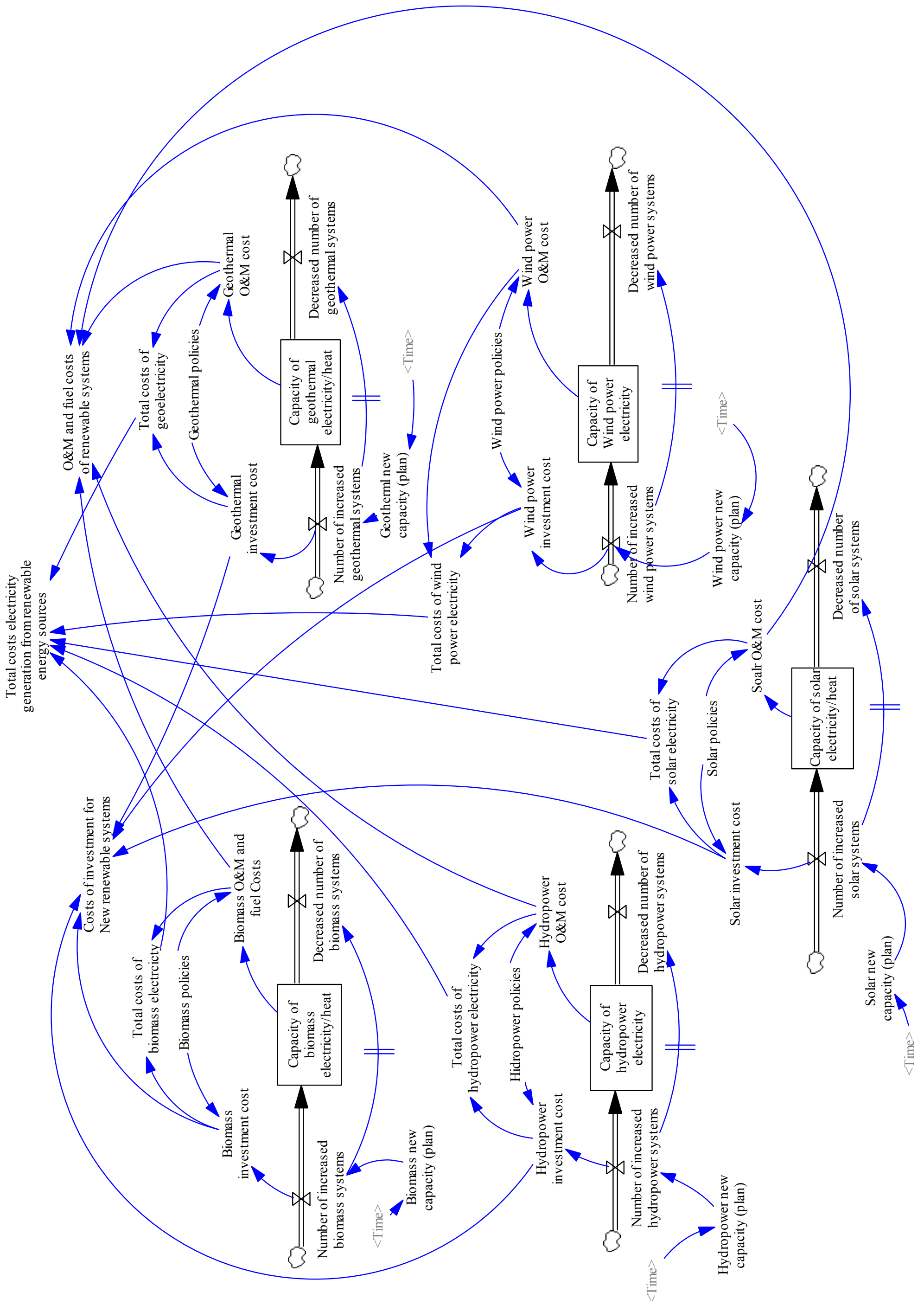

Figure 15. Stock and flow diagram of RE development

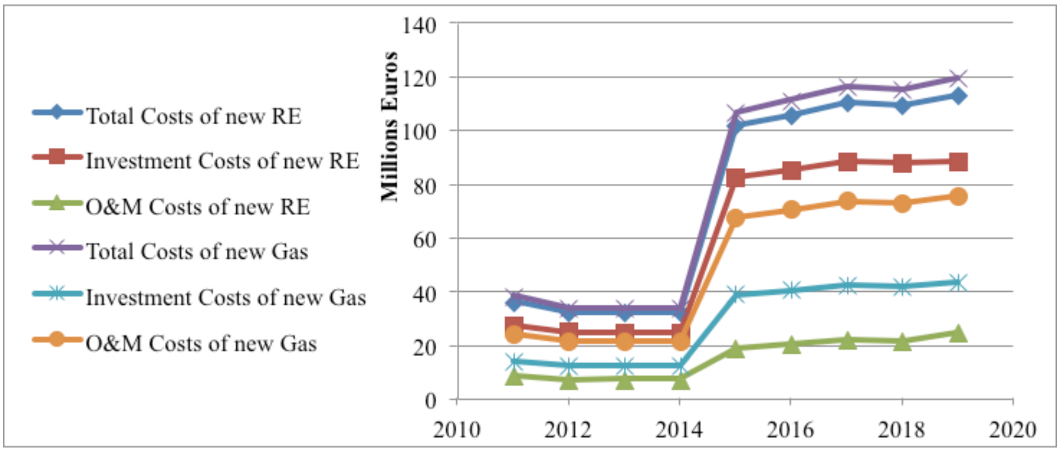

Figure 16. Costs of new RE capacities compared to new natural gas power plants

3.5 Research question 5- article 5 and 6 results

*** Research question:**	**What are the achievements and potential of RE development in a selected NC and a selected city in the NCs?**
*** Research objectives:**	To study the achievements and potential of RE utilization from the supply chain viewpoint.
*** Article name:**	Energy diversification in Finland: achievements and potential of renewable energy development
*** Published in:**	International Journal of Sustainable Energy-2013
*** Article name:**	Renewable energy supply chain in Ostrobothnia region and Vaasa city: Innovative framework
*** Published in:**	Renewable and Sustainable Energy Reviews-2013

As development of RE utilization depends on geographical potentials, policies and strategic investigations on RE promotion should focus more on regionals and locations level. In other words, regions with good potential of human and technological resources are in priority for RE development and investment. This is important especially in the countries with high authority of municipalities like Finland. Due to the focus of Finnish government to new RERs including wind, solar, and geothermal, investigations show that Ostrobothnia and its capital Vaasa are among the high potential regions for RE portfolio utilization.

The articles four and five respond to RE development and requirements at the national and local levels: Finland, and Ostrobothnia. They overview the latest actions, strengths, and weaknesses from the viewpoints of supply chain and policy schemes.

The east cost of Bothnia gulf (Ostrobothnia) is one of the high potential locations for wind power generation in Finland. Vaasa is also one of the sunniest cities in Finland and the Nordic countries. On the other hand, largest Finnish energy technology companies that are also among the world's leaders are located in Vaasa (e.g. WARTSILA, ABB, SWITCH, and VACON). As technological development is a key diffusion driver of RE utilization, companies located in this region help to speed RE adoption plans and research. Ostrobothnia and Vaasa have a large amount of university students compared to population (in the fields of energy technology and business) and the research facilities focus on increasing efficiency of the entire energy chain as well as promotion of RE utilization in the regional level. As research scholars create the first stage of a robust regional Redevelopment, the number of research institutes related to this technology is an important factor for RE promotion.

Above issues show that successful investigations on diffusion of RE utilization in the regional level should concentrate on the supply chains of RE development. In other words, beyond the strategic issues, the development and performance of renewables are highly dependent on the successful implementation of RE supply chain at the regional level (Figure 17).

According to the figure, the practical issues of successful RE programs (RE supply chain) are characterized from two sides: domains and approaches. The domains cover the process of RE chain from resources to end-users for each source. They create opportunities for business activities and are introduced in five main domains, namely RE supply, RE generation, RE transmission, RE distribution, and RE demand.

The approaches of the RE supply chain show different aspects of the RE supply chain process from engineering, social, and management science. They cover all the necessary elements of supply chain management. The first approach, policies and strategies, takes into account the role of municipalities and government on diffusion of RE in the region. Creating a development road map for each domain of RE chain and introducing supportive schemes (e.g. subsidies and taxes) are two subjects that are discussed in this approach.

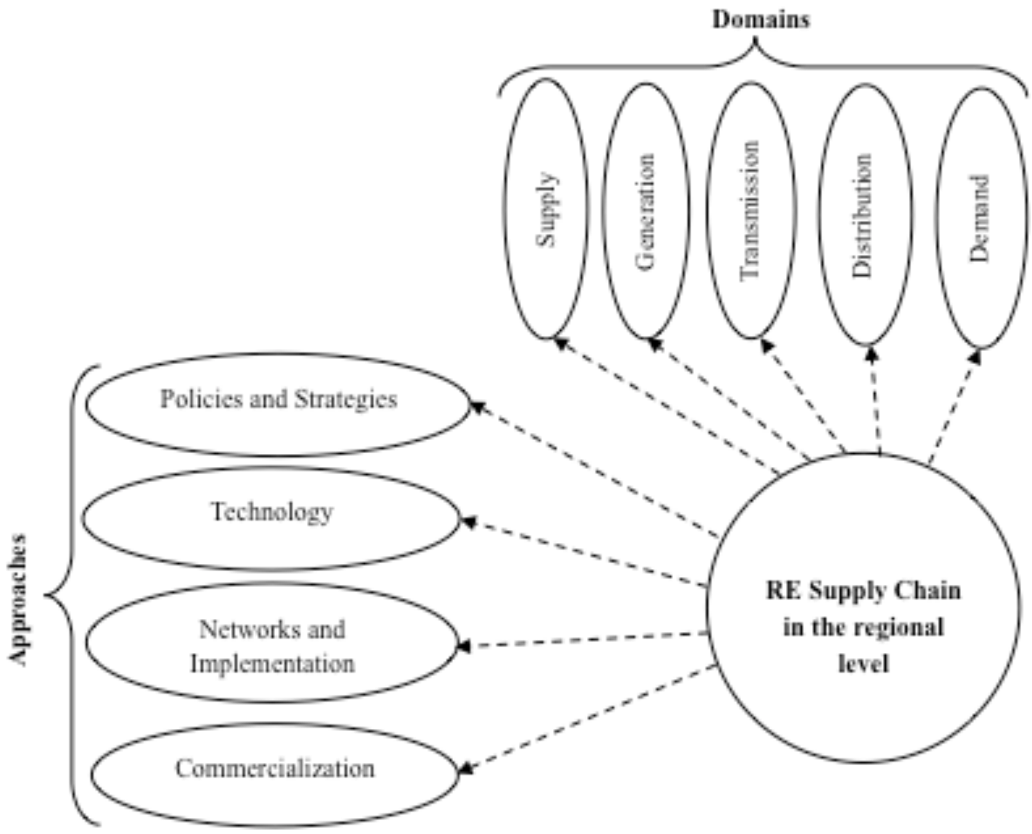

Figure 17. Framework of RE supply chain

The approach “Technology” examines the ways to provide a successful use of RERs in the region. Evaluation and analysis of region’s potentials in each domain from technological and infrastructure viewpoints are the focuses of this approach. “Networks and implementation” presents, analyzes, and designs high efficient performance of RE domains. Creating better value for customers and shareholders in each RE domains, quality of RE services, joint investments, and knowledge sharing with other regions are examples of this approach. Finally, “commercialization” includes the economic and investment issues of RE development in the region. Studies show that RE market is complex. In other words, while free market is encouraged in Finland, the government intervention or incentives should support new technologies and businesses in this market. To keep the research integration and due to the pages limitation, the approaches of RE supply chain are considered into each domain.

4 DISCUSSION AND CONTRIBUTION TO KNOWLEDGE

This dissertation tried to answer to one of the important questions of policy makers and researchers, namely ”How can we develop RE utilization in power generation to achieve security of the energy supply?” The following chapter lays out the key findings, research limitations and validation, and future of the discussed subjects.

4.1 Theoretical and practical implications

This dissertation is one of the first public policy focused-research that examines the policies of RE development to achieve security of the energy supply from the strategic and systematic viewpoints at three different levels in the NCs at the regional, national, and local. Taken together, the research provides a basis for understanding the challenges and potential of RE development, through an extended case study of the NCs. Therefore, the implications of the research can be discussed from both the quantitative (e.g. system dynamics analysis) and qualitative (e.g. energy policy analysis) aspects. Figure 18 summarizes the share of qualitative/quantitative research in each article.

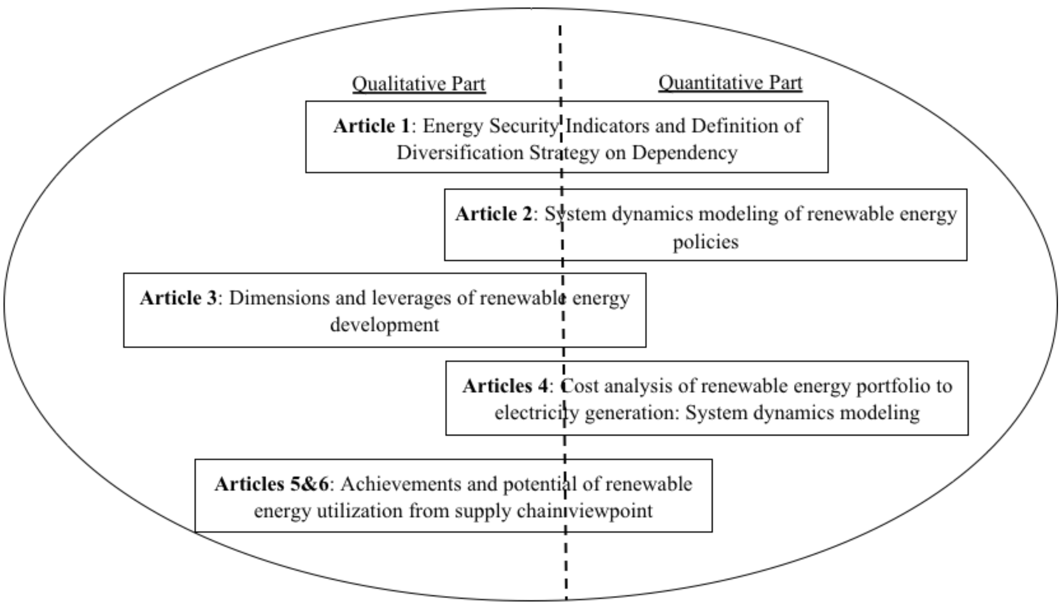

Figure 18. Share of qualitative/quantitative research in each article

By combining data and information with policy objectives of the RE development in the selected case country, the system dynamics models evaluated different scenarios of RE policies and describe the relationship between dynamic factors such as economic costs, RE encouragement packages, dependency, and energy demand. First, the inter-relations of the influencing factors on dependency and energy security were analyzed in the frame of causal loop diagram. The models evaluated the effectiveness of RE policies for electricity/heat generation on dependency and security of energy supply policies in the country level. For quantitative analysis, a causal loop diagram was transformed to system dynamics models (stock and flow diagrams). The system dynamics model showed that the amount of Finnish dependency on imported energy fluctuates between 7.6-9.3 billion Euros, depending on different scenarios during 2012-2020 (including all energy sectors such as transport, with a 45% share). Thereby, diffusion portfolios of renewables produce a saving of between 38-540 million euros in imported energy (for heat/electricity generation) in each year, depending on the plans and scenarios during 2012-2020. Due to the high dependency of Finland on imported fossil fuels, as well as the long life cycle of RE technologies, the implementation of RE action plans is highly recommended for Finland.

The second model was a developed version of the first model by adding cost variables. The model helps policy makers to analyze different parameters of RE costs compared to any other sources (e.g. fossil fuels or nuclear). According to Finland's national action plan for promoting RE, Finland should have around 277000 TJ electricity/heat utilized by RERs by 2020. To achieve this, and because of the electricity consumption growth in Finland, the analysis showed that investment in RE plans produces 7% saving compared to the total costs of new natural gas power plants (to respond to the electricity demand) during 2012-2020 both from capital and O&M costs. This analysis is based on the data published by the U.S. Department of Energy. It shows the economic benefits of RE development in Finland. As the main contribution of the quantitative part and due to the high validly and reliability of both system dynamic models, they can also be implemented for other case studies at the regional, country and local levels.

The qualitative part of the dissertation analyses different aspects of the diffusion of renewables in electricity/heat generation by considering different analytical perspectives in the NCs. The findings show that instabilities in fossil fuel markets are the reason that policy makers consider diversification strategy in resources/suppliers. Although the NCs have robust economic and business environments, fluctuations of fossil fuel prices and the level of energy dependency in countries such as Finland, Sweden, and Iceland have a direct effect on their economic growth. In addition to market instability, technical problems in the supply systems and physical actions are other risks to energy security for these countries. Therefore, generated power (heat/electricity) by RE and energy efficiency are the core subjects of transformed energy systems toward a decarbonized society. As future energy systems in the NCs will be more supplied by renewables, this requires action across all sectors. Although improvements in RE utilization in the industries and home/commercial sectors have been implemented, a large potential for improvement remains, in particular in the home/commercial sector by means of introducing more supportive regional polices. However, policies to support RE development must ensure the global competitiveness of Nordic industries. This is also important for resource-efficient policies and the global competitiveness of NCs industries. On the other hand, a flexible electricity system is essential for the NCs in order to reach a resource-efficient energy system. Therefore, an efficient infrastructure and agile regional grid are two bases for the fast development of RE power generation. An expansion of the electricity-transmission grid facilitates an effective use of the power system.

As discussed before, since the NCs are sparsely populated, transport is one of the main consumers of fossil fuels. For instance, 40% of total primary energy was used for transport in Sweden in 2010 (NETP 2013). Therefore, the role of transport in the NCs should not be forgotten in the development plans of RE utilization. Due to the potential and technological development, transport can be shifted from fossil fuels to biofuels or electric vehicles.

Due to the high market share of district heating in the NCs, it is important to improve its competitiveness with the core role of RERs. Identifying new markets such as absorption heating and household appliances are examples of improving the share of RE district heating. Finally, although the NCs have energy pricing mechanisms, energy prices should reflect the true cost of energy in the region. For instance, the price level for carbon emission can be evaluated and revised to reach the different RE utilization and climate objectives. Harmonizing the energy and carbon prices in different sectors among the NCs is the main policy in this respect.

4.2 Reliability, validity, and research limitation

The reliability and validity of this research are described for both two quantitative (system dynamics) and qualitative (policy and strategic analysis) methods.

4.2.1 Validation and testing of the model

Testing and validation of the models are very important in system dynamics research. The first aim of model validation is to provide accurate statistical information as decisions would be made based on the model contributions. As Kelton and Law (1991) highlight, if a model is not a "valid" illustration of a system, the model results provide little useful information about the real system. Further, the suitability of a model needs to be tested to show the robustness and defendability of the model in order to achieve the purposes of the model creating. To test and validate system dynamics models two approaches can be implemented: model structure validation, and model behavior validation (Muliadiredja 2005).

4.2.1.1 Model structure validation

There are three methods to test the structure of system dynamics model: structure validation, boundary adequacy, and extreme conditions and dimensional consistency.

According to “structure validation”, the structure of a system dynamics model is suitable if it is internally consistent with its assumptions and the causal structures contains the key feedback loops for describing the model and real system. The models implemented in the current dissertation respond to these factors from two viewpoints. First, both system dynamics models describe the behavior of the system based on the identified variables and causal loops extracted by the researcher’s observation and expert opinions. Second, the policy scenarios of the first model, as well as the cost analysis of the second model, were designed based on real data, trends and the opinions of professionals in the energy sector. In particular, the researcher tried to involve stakeholders and decision makers of the policy options from the beginning of the model building. Therefore, changes in the simulation forecast closely follow changes in the real world systems.

According to “boundary adequacy,” the system dynamics model boundary is described as adequate if the model builder is convinced that all key interactions through feedback loops essentially replicate the behavior of the real world system. As the structure of the both models was checked by energy and system dynamics experts, the models cover this factor.

Finally, “extreme conditions and dimensional consistency” includes judging the implications of putting imaginary minimum and maximum values of each state variable or combination of state variables that influence a rate equation. If produces results that are closely consistent to the real world system, then the model can be judged as reliable. In addition, it is essential that the dimensions of the state variables and parameters are correctly specified and consistent in the model. Failure to confirm this basic and important test may cause serious uncertainties in the structure of the model (Mofatt 1992). As all the used data in the frames of the statistics, equations, and lookups are based on real data and plans extracted from reliable organizations, the models meet this aspect of structure validation.

4.2.1.2 Model behavior validation

The validation of model behavior can be reached by three main methods: parameter verification and sensitivity, behavior reproduction and forecasting, and changed behavior forecasts (Mofatt 1992). In this dissertation three types of parameters were verified for "parameter the verification and sensitivity," namely initial values (reliable and accurate data), other constants (accurate coefficient), and table functions (best-fit curves).

"Behavior reproduction and forecasting" tries to reproduce the behavior of a specific system. When the historical path of the variables is simulated with a reasonable level of accuracy, an unconditional forecast is made.

Finally, "changed behavior forecasts" determine the response of the real system to policy actions. The new policy options may change the path of the conditional forecasts in different ways. According to Mofatt (1992), the best alternative policy to influence a desired change can be selected by means of simulating various alternative scenarios.

From the behavior validation viewpoint, the models were checked by two methods: 1) reviewing the process of the modeling and results and comparing with historical patterns and 2) testing the results of the scenarios and comparing them with the plans defined by the EU or Finnish government (e.g. share of the RE in electricity generation according to EU or national plans).

4.2.2 Validity of qualitative part

Qualitative research is any kind of research that produces findings that are not based on statistical procedures or other means of quantification (Strauss & Corbin 1990). While quantitative research tries to find causal determination, prediction, and the generalization of findings, qualitative research seeks to understand and extrapolate similar situations (Hoepfl 1997). The validity and reliability along with designing a study, analyzing results and judging the quality of the study are the important issues in qualitative research (Patton 2001). Thereby, reliability and validity in qualitative research should show the trustworthiness, rigor and quality of the research (Golafshani 2002). To validate a qualitative research, the triangulation method is used by most of the researcher. Data triangulation is the most popular validity method in qualitative research (Guion et al. 2011). Data triangulation uses different sources of data and information to increase the validity of a study. Engaging multiple methods, including observation and judgment, statistics and reports published by valid sources (e.g. IEA, EIA, and EU), interviews with experts and professionals, and scientific references are the methods used in this dissertation to provide valid qualitative research.

In addition to data triangulation, the use of multiple qualitative and quantitative methods in this dissertation improves the validity of the research from the methodological triangulation viewpoint (Morse et al. 2002).

4.2.3 Research limitations

Despite the various contributions of this research, there are limitations both in qualitative and quantitative approaches. The limitations are categorized in three groups: theoretical (e.g. unexpected future changes for modeling), practical (e.g. complexity of the system) and data limitations (e.g. lack of sufficient data for cost analysis for Finland during 2012-2020, instruments, and resources). In particular, some limitations still exist for model testing and validation that are mostly because of the complex nature of the problem and data. For instance, different parameters of the costs of electricity by source have drawbacks such as (IEA-RETD report 2012):

– they include many variables that make it difficult to trace cause,
– they are just a “partial” figure for policy makers or investors,
– they do not reflect total costs, just a ratio,

In other words, it is difficult to provide the necessary data for models with a broad range of details or policies. However, this increases the complexity of the model and harms its validity.

On the other hand, although the researcher has tried to use the most valid and updated data and references (where more than one reference exists), lack of native language knowledge of the researcher (e.g. Swedish and Finnish) as well as writing the articles during 2011-2013 may provide differences in the data or statistics (even in two articles), which can be presented as one of the research limitations.

4.3 Conclusion

Studies of security of the energy supply and RE development at the regional, national, and local levels with reference to Nordic countries are very limited and have not accommodated a system thinking and dynamics approach. As the strategic and policy analysis of energy problems are becoming more complex and difficult to manage, a qualitative method along with system dynamics modeling approach offer an important contribution to the future energy policy formulations and planning. This approach helps researchers and policy makers to understand the complexity and dynamics of energy security and energy diversification systems and identify different layers and behavioral patterns that are changing over time.

An important contribution of this dissertation is to provide an integrative strategic analysis of the broader security, political, technological, economic, and social influences on diffusion of RE policies in different levels.

The level of security of energy supply and role of diversification strategy on security targets were evaluated in the first question. The role of RERs in the energy portfolio targets and security of energy supply policies at the national level are assessed in Research Question 2. Therefore, a causal feedback diagram and a system dynamics model were constructed to reveal the relationships between the dynamic factors of energy security and dependency, and the effects of RE promotion policies. Different layers and process of policy making to RE promotion were reviewed in Question 3. This analysis is very important in particular to identify the barriers and challenges of diffusion of RE technologies. These layers need to be carefully considered in policy analysis to make robust and optimal RE policy options.

The main achievement of Research Question 4 is to develop an applied system dynamics model to assess the costs of RE development at the national level. In fact, the model is one of the first system dynamics models that evaluate the costs of RE portfolios in Finland. Both system dynamics models help policy makers to create new knowledge about future dependency and energy scenarios for Finland or other cases. However, the inputs of the models (e.g. cost data) can be updated any time, depending on different scenarios.

The practical aspects of RE development at the national and local levels are the contributions of the fifth question. The analysis was based on the supply chain approach that provide a new way of thinking for engineering and business analysis of the diffusion of RE. Future and emerging energy policy objectives were also discussed in the context of Finnish institutional and political frameworks.

4.4 Recommendations for further research

This dissertation is one of the first attempts to construct a systematic and strategic analysis of RE development that integrates both security and development factors in the Nordic region. By combining system dynamics models with policy analysis, this research provides numerous opportunities for future researchers to use the models and analysis to further advance both the understanding of energy policies and the application on energy analysis to improved renewable energy system management. Both qualitative (strategic policy analysis) and quantitative (system dynamics modeling) approaches can be further improved by additional research. Following the potential of future research is reviewed in each area.

4.4.1 Security of energy supply and diversification analysis

The contribution of the dissertation and published articles can help policy makers to promote a constructive dialogue among researchers, politicians, and authorities about the role of diversification strategy on energy self-sufficiency. In particular, comparative studies and energy supply evaluation can be used from the uncertainty and risk analysis viewpoints. At the regional level, while energy security is the main impetus for promoting RE, local economic benefits tend to be overlooked. This is an important subject for future research. From the diversification viewpoint, while diversification in supply sources does not need to be limited to current RERs (biomass, hydropower, wind, solar, and geothermal), investments in research and policy issues on the development of new ideas (e.g. hydrogen) and improving current technologies (e.g. clean coal technology) are encouraged. Further, analysis of the possibility of a source to offset other variable power production systems is a new subject for future research. Storing biomass (e.g. straw bales or wood chips) as a back-up to a solar thermal power plant is one example. The co-firing of biomass with coal can also partly reduce the risk of supply.

4.4.2 RE development and promotion

A wide range of social and economic opportunities is created by the diffusion of renewables in different levels, in particular in rural areas. For future research, analysis of the embedding of energy strategies in local economic development is recommended to assess and reflect local potential and needs in the NCs. Further, the role of RE within larger supply chains in rural and local economies such as agriculture, public acceptance, manufacturing and tourism are interesting subjects for future research.

On the other hand, the role of feed in tariffs and subsidies should be more discussed. As the mission of subsidies is to encourage RE projects, they should be limited, in particular in duration. If subsidies are high, they bring high energy system cost. That system is viable as long as the subsidies are sustained. However, subsidies may have negative effects on land use and displace other activities such tourism and agriculture. An accurate analysis of the amount and period of subsidies in different countries, as well as different resources, should be analyzed in professional research. Further, assessing the potential of investment which is not the basis of long-term subsides is a topic for future work. The policy and practical debates related to rise to these challenges would be interesting research area for future research.

Finally, although renewable portfolio standards have made an important contribution to the growth of renewable electricity generation in some countries such as the U.S., the concept is still new for many countries both in developed (e.g. Finland) and developing countries. According to a part of renewable portfolio standards, electricity providers have to generate a minimum amount of electricity from RERs by a specified date. Identifying effective factors for standards, policies, and localization of them is important for future research.

4.4.3 System dynamics model

The system dynamics models of the current research can be extended to provide extra information on both RE supply and demand, and cost analysis options. The model may need to be more detailed in order to explore particular policy issues. For example, the level of structural detail in RE supply policies or costs may be insufficient for some policy makers, and this may need to be improved if the model is to be used for a detailed analysis of energy supply options. Further, the models can be used for different and new scenarios (e.g. comparing cost analysis of RE with nuclear, etc.).

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Comparative analysis of energy security in the Nordic countries: The role of renewable energy resources in diversification

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Comparative analysis of energy security in the Nordic countries: The role of renewable energy resources in diversification

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Security of energy supply has been one of the important debates among citizens and governments of the Nordic countries after the first energy crisis. In response, diversification was defined as the heart strategy to reach a certain level of energy supply. This article discusses about the level of energy security in the Nordic countries with comparison to other developed countries and their neighbors. Then, the support schemes and policies to achieve the energy security and diversification are reviewed based on the system thinking approach with especial focus on the renewable energy resources. This approach provides a unique and powerful tool to explain the complexity and the relationships among the elements of the support schemes in the energy security analysis. © *2012 American Institute of Physics*. [http://dx.doi.org/10.1063/1.4765695]

I. INTRODUCTION

Increasing world demand for energy, fluctuating carbon based fuel prices, uncertain oil and gas supplies arising from geopolitical concerns, and global warming are the challenges that the Nordic citizens and governments (Finland, Sweden, Norway, Denmark, and Iceland) realized to have the secure and safe supply of energy. From the economic recession in 1970s and early 1980s, most energy importers have developed various strategies to enhance energy security such as upstream investment in producing countries, utilizing domestic and local natural resources, long-term contracting at premium prices, diversifying fuels and suppliers, developing dual fuel technologies, decentralized forms of utilization, efficiency and conservation, building strategic reserves, etc.[1,14] However today, more than in the past, environmental considerations impact on energy security calculations. Therefore, policies like development of renewable alternatives and non-carbon generation technologies have been encouraged to contribute diversification and security of energy supply. Furthermore, local availability of alternative resources is also one of the main drivers for governments to attend diversification in their energy security strategies.

The studies show that the Nordic countries including Finland, Sweden, Norway, Denmark, and Iceland are good examples of this utilization. They have made considerable and successful efforts in the utilization of renewable energy resources (RER). For instance, while this region had only 0.37% (less than 1%) of the world's population and 1.35% of GDP share (PPP) in the world in 2011 (Table I), the average utilization of RER for electricity generation was 62.82% (Table II). In 2010, Norway and Iceland are among top 10 renewable electricity producers with 96.6% and 100% of their electricity generation from RER in the world.[12]

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TABLE I. Basic statistics overview of the Nordic countries.[2–9]

	Area (m^2)[a]	Population[b]	GDP (PPP) ($million)[c]	GDP (PPP) per capita ($)[d]
World	148 940 000	7 022 000 000	78 897 426	
Finland	303 815	5 411 500	195 723	36 236
Sweden	410 335	9 495 113	381 719	40 394
Norway	304 282	5 019 200	265 911	53 471
Denmark	42 434	5 584 758	206 586	37 152
Iceland	100 250	320 060	12 409	38 061
Nordic	1 161 116	25 830 631	1 062 348	11 489
Nordic's share compare to the world (%)	0.78	0.37	1.35	...

[a]United Nations statistics.
[b]Official websites of the government-April 2012.
[c]International Monetary Fund-2011.
[d]International Monetary Fund-2011.

Table III and Figure 1 compare the situation of the Nordic countries among top 33 richest countries (T33) in terms of share of RER as one of the important diversification strategies in electricity generation in 2009. While the share of RER in the electricity generation in the T33 is 23.58%, it is 62.82% for the Nordic countries (2.66 times more than the T33 (A/B)). Indeed, the T33 produce 23.58% of their electricity from RER (B), while the share of the Nordic countries in this generation is 43% (B/C). As some of these 33 rich countries like Qatar, Kuwait, United Arab Emirates, Singapore, and Oman do not use RER in the economic level, the share of the Nordic countries in the electricity generation from RER is about 31% without those five countries (D/E).

Therefore, while the Nordic countries are among successful countries in the diffusion of RER, a few researchers have discussed about drivers of energy diversification in this region as a package including all the five countries. Therefore, the study of this region in terms of diversification policies and RE promotion and thereby energy security is one of the best case studies to be followed by other countries and regions. For instance, Finland and Sweden are two of the leading bioenergy-using countries in the world. Norway also with hydro power development, Denmark with high growth in wind power utilization, and Iceland with geothermal are the successful examples of the utilization of RER. On the other hand, since the Nordic countries have their own specific and distinguished approaches in political, economic, and social welfare (Nordic model), the study of energy security in this region, as one of the main drivers of sustainable development, is beneficial and noticeable. As an example, while Iceland was one of the Europe's poorest countries during the 20th century with dependence upon peat and imported coal for its energy, it has developed to a country with a high standard of living in which roughly 86.3% of primary energy is derived from indigenous RER.

The aim of this research is to provide an overview to study the role of diversification and RE in the national energy security objectives of the Nordic countries. The research discusses about the level of energy security in the Nordic countries with comparison to other developed

TABLE II. Share of RER in the total electricity generation (%) in the Nordic in 2009.[10,11]

	Total electricity generation from RER (%)
Finland	31.56
Sweden	58.52
Norway	96.63
Denmark	27.4
Iceland	100
Average	62.82

TABLE III. Average share of RER in the electricity generation among the Nordic and top 33 richest countries based on GDP (PPP) per capita.[10,12]

	Share of RER in electricity generation-average (2009) (%)
A[a]	62.82
B[b]	23.58
C[c]	16.51
D[d]	30
E[e]	23

[a]Nordic countries.
[b]Top 33 richest countries based on GDP (PPP) per capita.
[c]B without Nordic countries.
[d]B without countries which do not utilize RER for electricity generation such as Qatar, Kuwait, and United Arab Emirates.
[e]D without Nordic countries.

countries and their neighbors. Then, it points out drivers that have been most effective in the diffusion of RE in this region from energy security viewpoint. To achieve a better understanding of the high level of energy security, different support schemes and strategies are reviewed based on system thinking theory by using feedback structure loop.

II. OVERVIEW OF ENERGY SECURITY INDICATORS IN THE NORDIC COUNTRIES

Generally, the Nordic countries are energy intensive countries because of cold climate, the wide sparsely populated areas with long distances (especially Finland, Sweden, and Norway), the high standard of living, and energy intensive industry. For instance, Finland's per capita energy consumption is the highest in Europe.

A. Energy consumption, imports, and exports in the Nordic countries

Figure 2 illustrates the primary energy consumption in the Nordic countries in 2009.

The share of oil in energy supply has been substantially reduced in the last three decades in the Nordic countries, especially in Finland and Sweden. For example, Finland dropped the share of oil products from 64% in 1973 to 28.7% in 2009. This reduction is important because at the same time the Finland's population increased 18% as the penetration factor of personal automobile has been multiplied too. Meanwhile, the use of oil and oil products dropped off over 43% in Sweden since 1970.

The energy consumption mix for electricity plants, combined heat and power plants (CHP), and heat plants is depicted in Fig. 3. Due to the geographic situation of the Nordic countries,

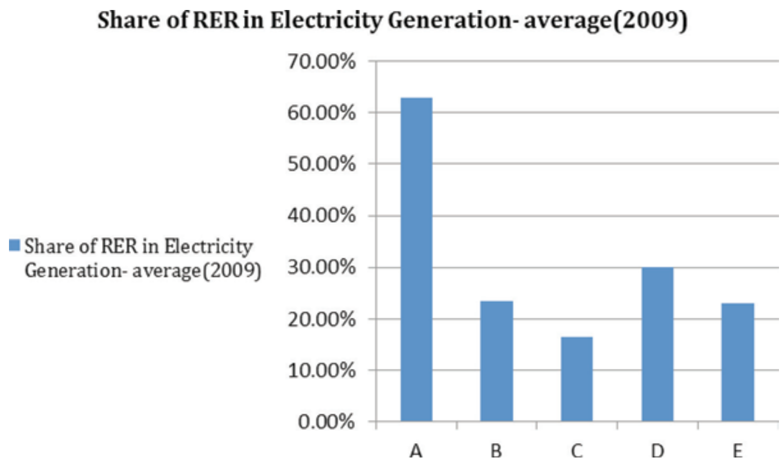

FIG. 1. Average share of RER in electricity generation among the Nordic and top 33 rich countries.

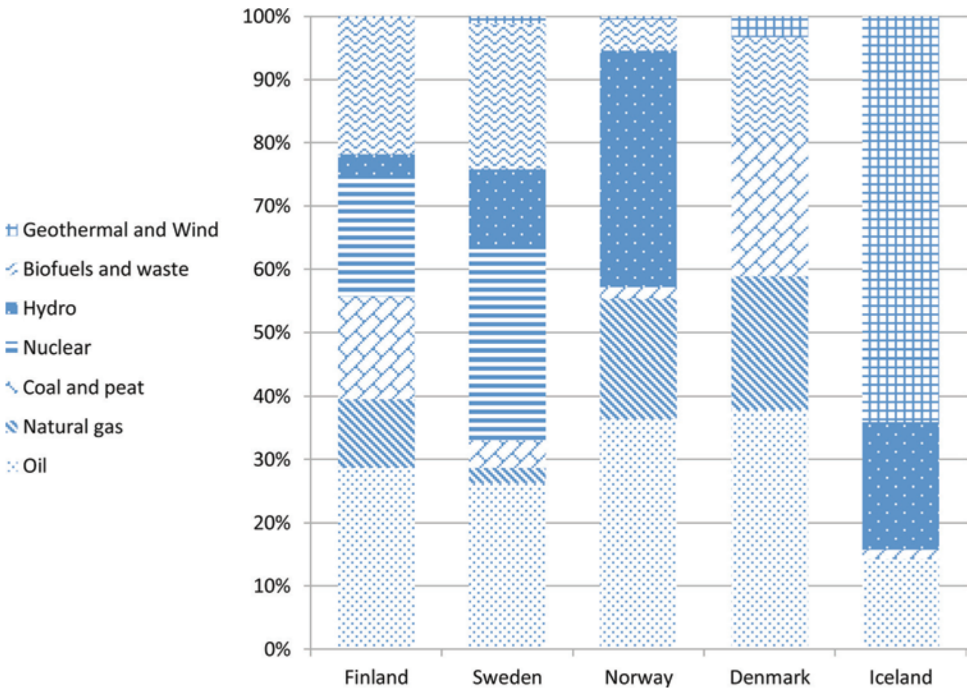

FIG. 2. Primary energy consumption in the Nordic Countries (Mtoe: million tons of oil equivalent), 2009.[10]

the solar energy is not in the priority of their economic utilization. As an example, the country's geological characteristics have endowed Iceland with an abundant supply of geothermal resources and hydro power. This country derived 84.3% of its primary energy from indigenous RER (64.1% geothermal and 20.2% hydropower) (Figs. 2 and 3). It is noteworthy that current and dominate utilization of geothermal energy in Iceland is for heating (Fig. 3).

The national target for Finland is to increase the electricity production from biomass with major part derives from the forest industry.[21] Pellets market also is one of the rapidly developed

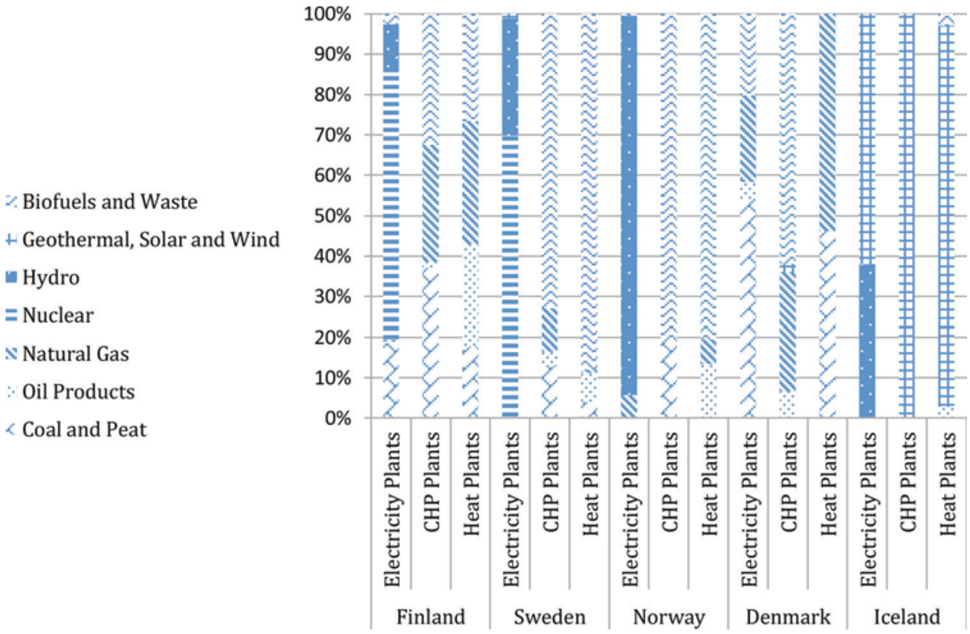

FIG. 3. Energy consumption mix for electricity and heat plants (2009).[10]

TABLE IV. Total primary energy supply-fossil fuels, imports, and exports (TPES) (ktoe), 2009.[10]

Total primary energy supply (ktoe)		Coal and peat	Crude oil	Oil product	Natural gas
Finland	Imports	3803	11764	5076	3483
	Exports	−13	−117	−6622	0
Sweden	Imports	1541	19594	7369	1101
	Exports	−188	−378	−11684	0
Norway	Imports	474	1000	4757	0
	Exports	−1609	−88144	−16163	−85170
Denmark	Imports	3967	3611	5365	0
	Exports	−38	−9081	−4504	−3578
Iceland	Imports	80	0	926	0
	Exports	0	0	−50	0

industries in Sweden in recent years and makes Sweden as one of the world's leading producers and users of pellets in the energy supply. On the other hand, Denmark has a leading role in the field of wind power. The expansion of wind power has been an important goal in the Danish energy policy and supply.

Table IV shows the amount of fossil fuels imports and exports in the Nordic region. For example, Finland imported about 38303 Ktoe Coal and peat from Russia, Poland, and North America. Sweden also imported about 1101 ktoe from Denmark in 2009.

As Fig. 4 illustrates, Denmark and Norway export crude oil and natural gas. In 1970s, energy supply was largely based on oil in Denmark (89% of TPES) which was severely affected by oil crisis. To reduce the oil demand and TPES as a whole, the Danish government introduced energy efficiency measures and developed combined heat and power production and RE.[11]

B. Energy security indicators for Nordic countries

The data analysis of energy consumption, imports, and exports highlights the important role of energy security and its subsets such as diversification of energy sources and import dependency on policy and decision makers. Several researches have been developed to measure and implement the level of energy security in different countries. A joint work by the United

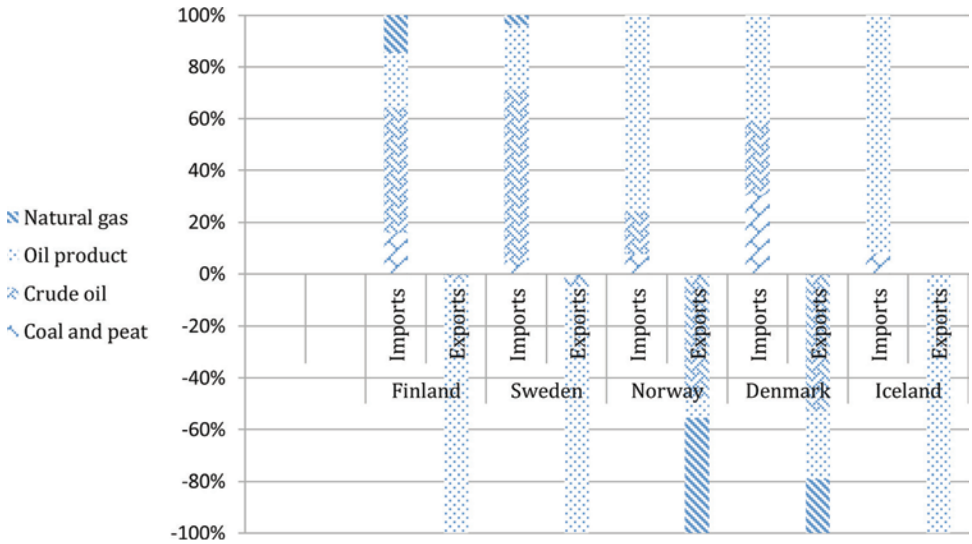

FIG. 4. Share of fossil resources in Nordic countries (imports +, exports −), 2009.[10]

Nations Department of Economic and Social Affairs, International Energy Agency (IEA), International Atomic Energy Agency, Eurostat and European Environment Agency has identified 4 social, 16 economic, and 10 environmental indicators for energy security.[13–18] Recently, a set of indicators has been introduced to evaluate the energy security from the diversity of energy supply viewpoint.[14] The basic idea for diversification indicators was borrowed from portfolio theory in finance. According to this theory, the overall risk of energy supply is smaller if there is a diversified portfolio of suppliers.[19] Diversification in supply sources can reduce vulnerability of supply disruptions from a particular source. Furthermore, diversification decreases the market power of any one supplier and the risks of higher prices.[20] Following two main and valid indicators are implemented for the Nordic countries and six selected countries. The countries were selected based on three factors of GDP similarity with the Nordic countries, close political and economic relations with the Nordic countries, and leading in the diversification strategy in their countries.

1. *Diversification of energy supply sources (DESS)*

This indicator considers both the significance of diversification in terms of abundance and equitability of sources.[22]

$$\mathrm{DESS} = -\left(\frac{\sum_{i=1}^{n} ai * \mathrm{Ln}(ai)}{\mathrm{Ln}(n)}\right). \tag{1}$$

In this equation ai is the share of each primary energy sources in total energy supply (or, other defined supply factor). n is also the number of sources based on IEA categorization (coal and peat, oil, natural gas, nuclear, hydro, geothermal and solar and wind, and biofuel and waste). In this research the DESS has been calculated from IEA data for 2009 in two different levels: total energy supply (Fig. 5), and total energy supply of electricity and heat plants generation (Fig. 6). Generally, higher DESS score for a country means high energy security and low risk.

To calculate the DESS index, the overall consumption including different sectors such as transport was used. According to Figure 5, Finland and Sweden have the top diversified energy portfolios among other countries with the scores of 0.86 and 0.82. As they are two countries without significant domestic resources, the level of diversification in those countries is noteworthy. The average score of the eleven selected countries is 0.71 in which Canada and Germany have the scores of 0.81 and 0.80. The scores of Denmark, Norway and Iceland are 0.74, 0.66, and 0.49. So, Finland, Sweden, and Denmark have the scores more than the average scores among the Nordic countries. However, the low scores of Norway and Iceland are not necessarily a handicap. It can be debated from the second indicator viewpoint (NID) and the level of their dependency on their domestic resources in the electricity generation (Fig. 3).

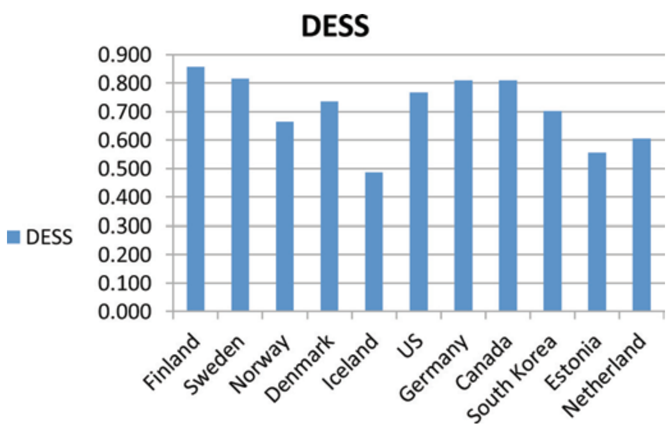

FIG. 5. DESS in the level of total energy supply (2009).

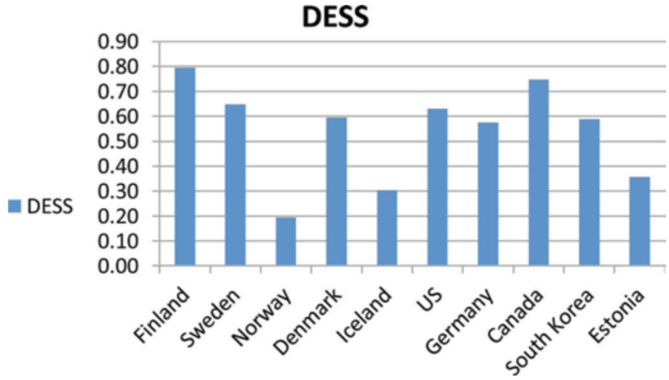

FIG. 6. DESS in the level of total energy supply for electricity and heat plants generation.

Next, the DESS index was calculated based on the consumption of electricity and heat sector (Fig. 6). Due to the geographical situation of the Nordic countries (located in the cold belt), this index directly effect on the political decisions related to energy security.

Figure 6 along with Figure 3 can analyze and compare the scores of each Nordic country in the security of energy supply in their electricity sectors. For example, while the overall DESS index for Norway is 36.6% more than Iceland (Fig. 5), the DESS for electricity and heat plants sectors is 64% of Iceland (Fig. 6). This is because of high dependency in Norway to hydropower resources and high weight of electricity plants compared with CHP plants and heat plants (Fig. 3).

2. Net import dependency

NID reflects the impact of both diversification and imports on energy supply security.[23]

$$\mathrm{NID} = 1 - \frac{\frac{\sum_{i=1}^{n}((1-\mathrm{mi})*\mathrm{ai}*\mathrm{Ln}(\mathrm{ai}))}{\mathrm{Ln}(n)}}{\mathrm{DESS}}, \tag{2}$$

mi is the import share for energy source i. Obviously, less NID score for a country means lower level of dependency on imported resources, higher energy security, and lower risk (Fig. 7).

Based on the Figure 7, The NID average of the Nordic countries is 0.33. Since Norway is one of the exporters of crude oil and natural gas, the NID index for the Nordic countries without Norway is 0.394 (39.4%) which is less than average of selected countries: 0.463 (0.467 without Norway). This means that although the Nordic countries (without Norway and in some

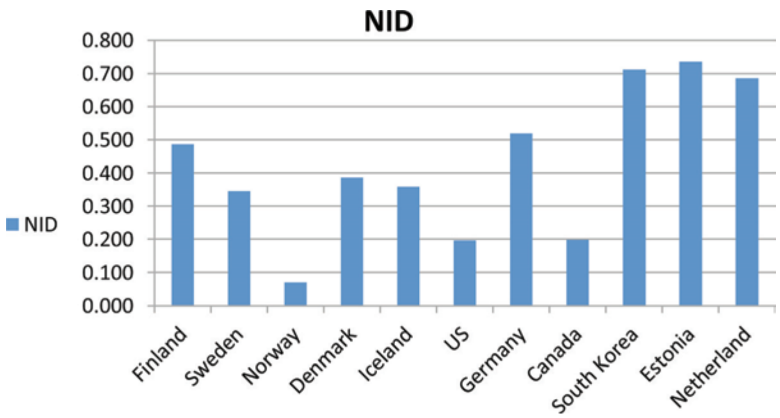

FIG. 7. Net import dependency.

cases Denmark) have a high level of dependency on fossil fuels, they could implement other resources such as renewable and nuclear (just for Finland and Sweden) in their energy policies to manage a healthy economy.

III. STRATEGIES FOR ENHANCING ENERGY SECURITY IN THE NORDIC COUNTRIES

Discussed indicators and the literature of this article show that the Nordic countries have a high level of energy security in comparison with other developed countries and their neighbors. In particular, countries like Finland and Sweden with little domestic resources are able to sustain a reasonable economic growth, a high level of social welfare, and a high GDP. The investigations and observations of the authors indicate that a set of strategies and policies have provided the circumstances of these successes. Most common schemes and strategies are the following:

(1) Investment supports (in the levels of government and private sector).
(2) Developing storage capacity for fuels (e.g., strategic reserves).
(3) Diffusion of renewable energy alternatives.[24]
(4) R&D supports.
(5) Increasing energy efficiency and conservation.
(6) Tax incentives including tax rebates, direct production support, environmental bonus, etc.
(7) Taxation of fossil fuels in heat production.
(8) Engaging in long-term supply agreements with suppliers.
(9) Feed-in-tariffs (fixed price or premium).[29]

Table V shows a short description of each policy and scheme.

Figure 8 illustrates the inter-relations of the influencing factors (Table V) in the frame of system thinking loops. Among a number of variables within the sub-systems of energy security, only main variables were included in this model. The main advantage of this kind of analysis is to understand the feedback structure of each scheme and policy related to the energy security.[25,26] Therefore, using

TABLE V. Short description or example of policies and support schemes.

Support scheme	Description
Investment supports	Including governmental investments, investment aids for private sector participation, Tax reduction for private investment on especial source (e.g., tax reduction for Biomass development in Sweden and Finland)
Developing storage capacity	In order to decrease the fluctuation of fossil fuels prices and emergency conditions in different locations, etc.
Diffusion of renewable energy alternatives in advanced levels	Via direct and indirect investment and R&D supports, tax refund, funding, etc.E.g., a project is developing to improve the smart energy systems in the Ostrobothnia region (Finland)
R&D supports	Funds for technology development and commercialization of RE technologies, energy efficiency and conservation, and energy use of waste, green certificates (for example, Tekes, Fortum, and VTT in Finland, ERP and DPRE in Denmark, Norwegian Research Council, Gassnova, and Innovation Norway in Norway, etc.)
Increasing energy efficiency and conservation	E.g., encouragement of fuel efficiency, mandatory technical examination of vehicles
Tax incentives	E.g., tax refund for electricity produced from RE
Taxation of fossil fuels	Tax paid (basic and surtax) for fossil fuels used for heat production improves the price competitiveness of bioenergy. Also, since electricity from bio energy is mainly produced in CHP power plants, fossil fuel taxation indirectly enhances electricity production from RER
Long-term supply agreements	E.g., Nordel contracts among the Nordic countries, EKO-energy agreement in Sweden, Finland, and Russia energy contracts, etc.
Feed-in-tariffs	I.e., an obligation for retailers of electricity to buy whatever quantity of green electricity is supplied at a price determined by the regulator

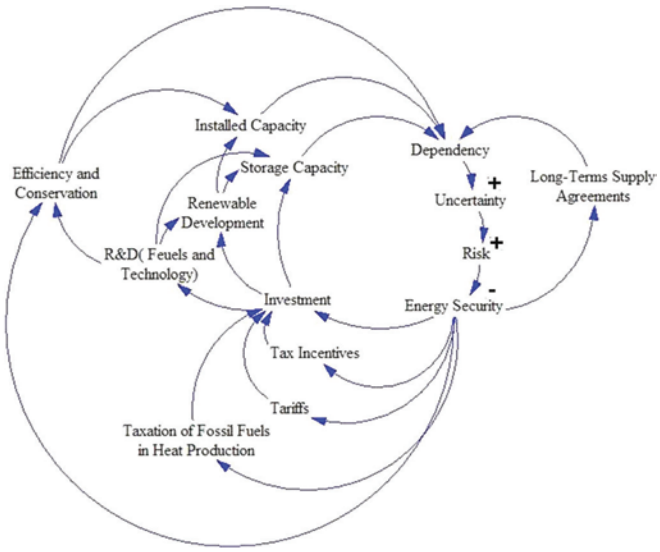

FIG. 8. Feedback structure of support schemes and policies for energy security in the Nordic countries.

the feedback structure of the Nordic support schemes can help researchers to understand, communicate, share, change, measure, simulate, and learn more about the different aspects of energy security in the Nordic countries.

In the Figure 8, the short descriptive phrases represent the support schemes and policies, and the arrows represent the causal influences between these schemes and policies with energy security. Examining the right hand side of the diagram, if the "dependency" is decreased, the "uncertainty" and thus "risk" decrease. So, the risk reduction will increase the "energy security." The simplest loop to increase the energy security in the Figure 8 is related to the "long-term supply agreements." These agreements prevent the fluctuations of energy supply, price, and dependency especially in the crisis conditions.

More than 15 loops are identified to describe the relevance of each influencing strategy and policy. For example, the "investments" affect the "storage capacity," "RE development," and "R&D" schemes of the Nordic countries. Causal links from both "storage capacity" and "installed capacity" to "dependency" are negative. This means that the development of RE utilization decreases the dependence on imported energy.

The investments on RE development take place in the two scopes: "storage capacity" for utilized energy from RER, and diffusion of RE utilization ("installed capacity"). Generally, the investments (public or private) provide the following development loops:

(1) Development of storage capacity for different fuels and their products (e.g., strategic reserves).
(2) Diffusion of utilization from renewable alternatives (new capacities).
(3) Development of storage capacity for renewable alternatives.
(4) R&D supports for improving the renewable technologies and storage capacity.
(5) R&D supports to improve the efficiency and conservation of current systems and new capacities.

On the other hand, "tax incentives," "tariffs," and "taxation of fossil fuels" also affect the investment too. Our studies show that the most important schemes to the diffusion of RE in the Nordic countries are subsidies and tax incentives. Taxation aims to curb the growth of energy consumption ("efficiency and conservation") and steer the production and use of energy towards alternatives with less emissions.

IV. CONCLUSION

This article discussed how diversification strategies and policies of RE development are effective to achieve a high level of energy security in the Nordic countries. Our studies show that the diversification and the diffusion of RE have created incentives for various actors to make new investments and business especially in rural areas of the Nordic countries. Generally, each Nordic country has a special attention and focus on one or two RER in its policies and decision making. While Finland has chosen a policy for diffusion of biomass, Iceland has focused on the geothermal resources. Norway also has special attention to its geographical situation and utilization of electricity from hydro power. On the other hand, Denmark has selected the promotion of wind power as the main element of its new energy security policy. Finally, Sweden focuses on biomass and pellets implementation, biofuels for transport, and developing the heat pump market. This caused one-third of all heat pumps installed in Europe to be located in Sweden at this date.

On the other hand, to have the economic utilization of any energy alternative, further than sufficient resources and technology that should be available; producers should be able to have the capital and access to utilize the resources. In contrast, the consumers should also be able to afford the end product. Therefore, achieving the desired level of diversification faces challenges.[27,28] Our research shows that despite all the success, the strategies of the Nordic countries for energy security and diversification development might be challenging in some cases. For example, energy security and diversification can cost more in the long-run if, for example, the market prices falls or fields turn out to be less productive or more costly. Simultaneously, building and maintaining of strategic reserves can be expensive in terms of the capital cost of building, maintaining storage facilities, the cost of transferring, and the cost of fuels purchased to fill them. As an example of the challenges of RE utilization, large scale hydro power can be controversial due to their negative impact on communities and ecologies that will be disturbed by the formation of large reservoirs.[22] Therefore, these issues and other dimensions of diversification especially acceptability and affordability should be considered in the energy security studies and related future research.

In conclusion, this research helps to promote a constructive dialogue for future research among researchers, politicians, authorities and actors of the energy market especially from EU countries (e.g., Baltic region, Eastern Europe), countries out of EU but in the same natural or economic situations (e.g., Chile or Peru), and even the Nordic countries in order to comparative analysis of their weaknesses and strengths in the policies and decisions.

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Role of renewable energy policies in energy dependency in Finland: System dynamics approach

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HIGHLIGHTS

- A system dynamics model for evaluating renewable energy policies on dependency is proposed.
- The model considers the role of diversification on dependency and security of energy supply in Finland.
- Dependency on imported sources will decrease depends on the defined scenarios in Finland.

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ABSTRACT

Objective: We discuss the role of diversification on dependency and security of energy supply. A system dynamics model with especial focus on the role of renewable energy resources (as a portfolio) on Finland's energy dependency is developed. The purpose is also to cover a part of research gap exists in the system dynamics modeling of energy security investigations.
Methods: A causal loops diagram and a system dynamics model evaluate Finnish scenarios of renewable energy policies. The analysis describes the relationship between dynamic factors such as RE encouragement packages, dependency, and energy demand.
Results: A causal loops diagram and a system dynamics model evaluate three different Finnish scenarios of renewable energy policies by 2020.
Conclusion: Analysis shows that despite 7% electricity/heat consumption growth by 2020 in Finland, dependency on imported sources will decrease between 1% and 7% depend on the defined scenarios.
Practice Implications: The proposed model not only helps decision makers to test their scenarios related to renewable energy polices, it can be implemented by other countries.

1. Introduction

One of the effective factors of the governments' policies is security of energy supply. Energy security refers to a resilient energy system that is capable withstanding threats with focus on critical infrastructures [1]. It includes direct security measures (e.g., surveillance and guards) and indirect measures (e.g., redundancy, duplication of critical equipment and diversity in resources).

Energy security directly affects the level of economy, safety, and social welfare of a country [2]. Therefore, concerns such as growing energy demands, limitations of fossil fuels, threats of carbon dioxide (CO_2) emission and consequently global warming have caused policy makers and governments to debate role of diversification and utilization of renewable energy resources (RER) in their energy policies. A diversified portfolio of resources and suppliers for electricity/heat generation in a country decreases the overall risk of energy supply [3]. Diversification in supply resources not only reduce vulnerability of supply disruptions from a source, but also it decreases the power of suppliers and risks of higher prices in the market [4,5]. To succeed diffusion programs of RE development, different strategies such as technological improvements, increased economies of scale, and strong policy support should be contributed in both developed and developing countries [6,7].

After economic recession in the 1970s and early 1980s, as well as high dependency of Finland to imported fossil fuels, renewable energy (RE) alternatives have had an important role in the Finnish energy and climate strategies [8]. However, development of RE particularly in areas such as wind power has lagged that of other European countries in recent years in Finland [9].

This article discusses the role of diversification on dependency and security of energy supply in Finland. Our study develops an energy dependency analysis with especial focus on the role of renewable energy resources (RER) via both qualitative and quantitative

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factors. A causal loops diagram and a system dynamics model evaluate Finnish scenarios of RE policies. The analysis describes the relationship between dynamic factors such as RE encouragement packages, dependency, and energy demand.

The work is organized based on the following sections. Section 2 reviews related research literature in four parts including energy structure and dependency in Finland, effects of RERs in the Finnish policies, overview on system dynamics approach, and fast review on research worked on system dynamics modeling of energy policies. Section 3 describes the causal loops diagram of energy dependency with special focus on the role of RERs. Finally, Section 4 proposes the system dynamics of RE and dependency in Finland and analyzes the system behavior based on the defined scenarios.

2. Literature review

2.1. Energy supply and dependency in Finland

Finland is a developed country located in Northern Europe. It is the fifth largest and the most sparsely populated country after Iceland and Norway in Europe (16 people/km^2 in 2012). As Finland's economy is highly dependent on industrial products, industrial sector consumes more than half of the primary energy supply. Despite the population of Finland increased 12% during 1981–2011, energy consumption increased more than 90% from 202,712 GWh to 385,554.7 GWh [10]. The country is highly dependent on external fossil fuels and imported uranium for nuclear power plants. A World Bank report shows that the net of energy import in Finland was 51.83% of energy use in 2010 (50.1% in 2009, and 57.37 in 2004) [11]. Therefore, concerns such as fluctuating carbon based fuel prices, increasing world demand for energy, and uncertain oil and gas supplies have caused Finnish policy makers to have a secure and safe energy supply. In response, different strategies such as upstream investment in producing countries, utilizing domestic and local natural resources, long-term contracting at premium prices, diversifying fuels and suppliers, and decentralized forms of utilization have been reviewed to keep the safe level of energy security. As Table 1 shows, the share of fossil fuels and peat in final energy consumption decreased during 1981–2011 from 62% to 50% [10].

Fig. 1 compares the change of each energy source in primary energy consumption during 1981–2011. While the quantity of fossil fuels and peats increased from 155,773 GWh to 168,948 GWh (8.5% growth), RERs increased from 53,974 GWh to 109,514 GWh (202.90% growth). However, the share of renewables did not change noticeable.

Finland has also high-energy consumption per capita compared to other European countries because of cold climate, structure of Finnish industries, long distances, as well as high standards of living. While forest and paper, metal and chemical, and engineering represent 80% of Finnish industrial products and services, the forest and paper industry alone consumes more than 60% of industrial energy [12]. Therefore, electricity has a key role in energy production and supply in the Finnish energy policies. The increase in electricity consumption was from 41,359 GWh to 84,241 GWh during 1981–2011[10].

Table 1
Share of energy sources in primary energy consumption in Finland [10].

	Fossil fuels and peat (%)	Nuclear energy (%)	Renewables (%)	Others (%)
1981	62	21	16	2
1991	61	18	18	3
2001	56	23	17	3
2011	50	28	18	4

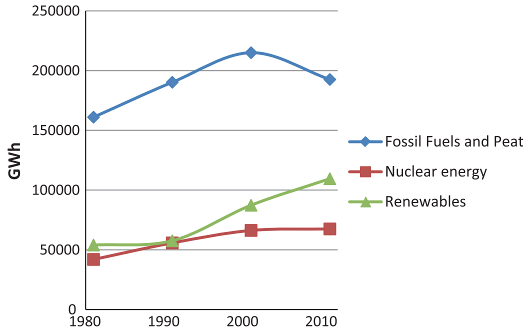


Fig. 1. Primary energy consumption in Finland by three main sources.

Fig. 2 shows the main sources of energy consumption or electricity generation in Finland in 2012. In 2011, the consumption of energy sources for electricity generation by mode of production was 22,300 GWh nuclear power, 12,300 GWh hydropower, 14,200 GWh coal and peat, 9200 GWh natural gas, 1000 GWh oil and other fossil fuels, 10,100 GWh wood fuels, 500 GWh Wind power, and 400 GWh other renewable sources [10]. They provided 70,400 GWh of production that with 13,900 GWh imported electricity responded to 84,200 GWh electricity demand in Finland. The share of renewable resources for electricity generation in Finland was fluctuating between 25% and 28% during last 30 years.

2.2. Effects of renewable energy resources on Finnish policies

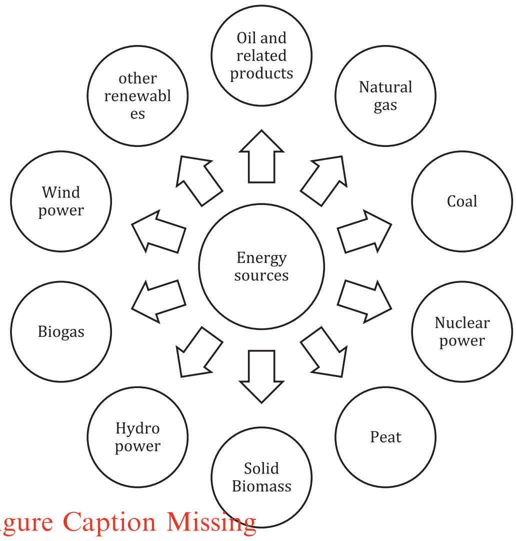
The principal RE source in Finland is biomass and forest (solid biomass) covers nearly 86% of the Finland's land. Recently, other sources particularly wind power have increased their contribution in the Finnish energy security roadmap. While the share of wind power was less than 1% in the total primary energy supply in 2009, it should increase to 15% in 2020 [12]. According to the plans, about 38% of the gross final consumption should be from RERs by 2020 [12,13].

The process of RE development in Finland is described in different layers [14]. The layers have strategic, policy, and practical natures that cover a portfolio of political, technological, managerial, social, and cultural issues (Fig. 3). Table 2 summarizes each layer and their related schemes.

2.3. Overview of the system dynamics approach

System thinking is a process for understanding how things as parts of a set influence each other. It is an approach for problem solving by viewing "problems" as parts of an overall system rather than reacting to specific part [15]. System dynamics is a methodology based on system thinking to understand and model the behavior and activities of the complex systems over time [16]. System dynamics utilizes various control factors such as feedback loops and time delays to observe how the system reacts and behaves to trends. It can assist policy and decision makers when behaviors of a system are complex and dynamic.

Fig. 4 shows the methodology of system dynamics and its related stages. As all stages try to have feedbacks for system understanding, the main concentration of system dynamic is "system understanding" [17]. Problem identification and definition is the first stage in the system dynamics research. Determining where the problem stands and objectives are two issues that should be clearly described in this stage. The materials of this stage are data and information, experiences, and judgments. The system



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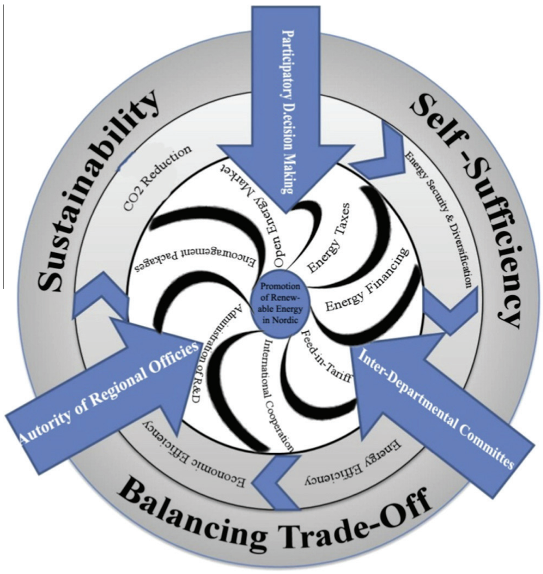

Fig. 3. Layers of RE development in Finland [14].

conceptualization is the second stage and includes determination of boundaries, identification of causal relations, and policy framework (qualitative analysis). Three different diagrams are introduced and analyzed in the system conceptualization namely, subsystem diagram, policy structure diagram, and causal loop diagram. Diagrams help researchers and experts to communicate an overview of the research subject, making clear what is included and what is excluded from the study. A causal loop diagram is a causal chart that shows how interrelated variables affect each other. The diagram consists of nodes (variables) and their relationships (arrows). Relationship of two variables can be positive (+) or negative (−).If a variable affect another variable with delay it is also shown in the diagram (II). This diagram and stock-flow diagram (system dynamics model) play central role in system dynamics modeling [18]. A stock-flow diagram includes stocks (levels), flows (rates), connectors, and auxiliaries.

Finding the mathematical equations and simulation is the third stage of system dynamics methodology. The analyst also needs to test the model's reliability and validity in this stage. Policy/decision analysis is the next stage used to evaluate the system simulation outcome and plan appropriate policies. Finally, a policy/decision will be implemented in the real word.

2.4. Fast review of the system dynamics research of energy policies

As a tool for energy systems conceptualizing, system dynamics has been used for more than 30 years [40]. Some researchers have utilized system dynamics to evaluate physical structure of energy systems and build different scenarios [19–22]. They also evaluate the consumption of energy to find the relationship between economic factors such as GDP with energy indicators to predict the scenarios of energy market and prices [20]. The second group of researchers has implemented system dynamics models to assess environmental and effects of CO_2 emission in energy systems [23–27]. They have developed different dynamic platforms to support policies related to subjects such as urban sustainability improvement, and cost analysis of CO_2 emissions. Energy policy in terms of security of energy supply is the third group of research of system dynamics and thinking approach [28,29,19]. These models help experts to identify key energy components to implement in a particular country in the frame of indicators or policies. A few works also focus on dynamic modeling of RE polices [8,30–33]. These researches analyze the replacement of RERs with oil and non-renewable fuels. Fig. 5 shows an example of causal loop diagram used to show the exhaustion patterns of world fossil and their possible replacement by RERs [31].

As noted above, despite different system dynamics works done on energy research, the number of research worked on the effects of RE on dependency and energy security is not more than ten fingers of two hands. The purpose of current research is to cover a part of this research gap to help experts and policy makers to review their RE promotion plans to achieve a desirable level of dependency and security of energy supply.

3. Conceptualizing of renewable energy development in Finland

Our study provides an evaluation method for analyzing the effectiveness of RE policies for electricity/heat generation on dependency and security of energy supply polices in the country and regional levels. Due to the number of factors effect on energy dependency and security, as well as the complexity of such systems, system dynamics approach is used to review the consequences of policies and scenarios. Fig. 6 shows the inter-relations of the influencing factors in the frame of causal feedback loops (causal loop diagram).

Among a number of variables within the subsystems of energy security, only main variables that are related to our model are included in this diagram (Fig. 6). The main advantage of this kind of analysis is to understand the feedback structure of each variable or policy related to the energy security [8].

According to Fig. 6, the population and economic growth positively affect GDP [35]. When GDP of a country is increased, the electricity consumption and thereby energy demand will be increased (+) [36]. Growth in electricity demand increases the Finland's dependency to energy imports. While this brings uncertainties and risks for policy makers, government tries to overcome to dependency by introducing several strategies such

Table 2
Different layers of diffusion of renewable energy in Finland and Nordic countries [14].

Layer	Description	Scheme	Aim
Dimensions	To show the purposes of diffusion of RE utilization	Self-sufficiency	To reduce consumption of fossil fuels and increase the dependency of indigenous resources
		Balancing trade-off	To help to economic and technologic growth of the regions
		Sustainability	To reduce pollution and environmental impacts
Characters	To identify main stakeholders affect public policies and process of decision-making	Participatory decision-making	To have the supports of the community organizations and citizens
		Inter-departmental committees	To have a comprehensive and coordinative decision making
		Authority of regional offices	To increase the role of regionals (municipalities) in decision-making
Objectives	To show different perspectives of diffusion of RE	Energy security and diversification	To reduce the dependency to the external resources (energy imports)
		Energy efficiency	To produce specific amount of services using less energy
		Economic efficiency	– Technical efficiency – Allocative efficiency
		CO_2 reduction	To minimize CO_2 emissions from fossil fuel burning caused by human activities
Key schemes	To describe different policies or regulations related to diffusion of RERs utilization	Energy financing	To direct government investment on the RE technologies and efficiency solutions
		Energy taxes	To curb the growth of energy consumption
		Open energy market	To make RE utilization competitive
		Encouragement packages and green certificates	To improve the knowledge and awareness of the citizens about RERs
		Administration of research	To manage research and R&D funds
		International cooperation	To share and crate the knowledge
		Feed-in-tariff	To accelerate investment in RE utilization

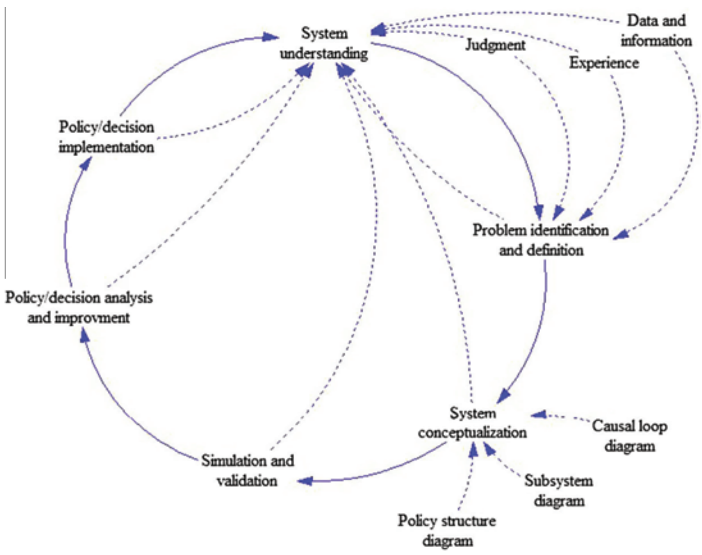

Fig. 4. System dynamics methodology.

as development of RE utilization, energy conservation policies, and other schemes [10]. These polices consist different packages including direct investments, tax/tariffs packages, and other encouragement policies. For instance, government investments or encouraging private sector to participate in RE development programs helps to speed RE diffusion programs [37,38]. Therefore, diffusion programs positively influence on number of installed renewable systems and capacity of renewable systems. This not only decreases the energy dependency on external sources, it brings new opportunities for creating new businesses and employment that provide economic growth and social welfare. On the other hand, the depreciation period of a renewable system has negative effect on dependency after a period (−) (e.g., 20 years for wind power plants). It also affects negatively on capacity of RE systems.

4. Dynamic analysis of renewable energy utilization plans in energy dependency of Finland

Due to the above causal feedback loop, a system dynamics model is constructed to evaluate the effect of RERs on Finnish energy dependency during 2011–2020. According to the Finland's national action plan for promoting RE (document number: 2009/28/EC),

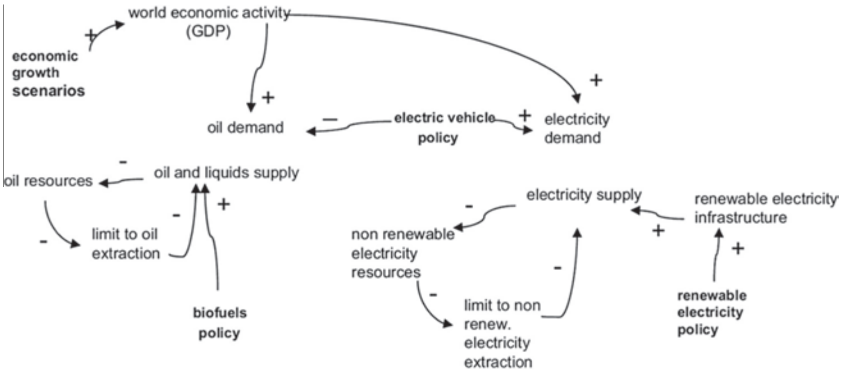

Fig. 5. Example of causal loop diagram defined in a research to assess the situation of renewable resources [31].

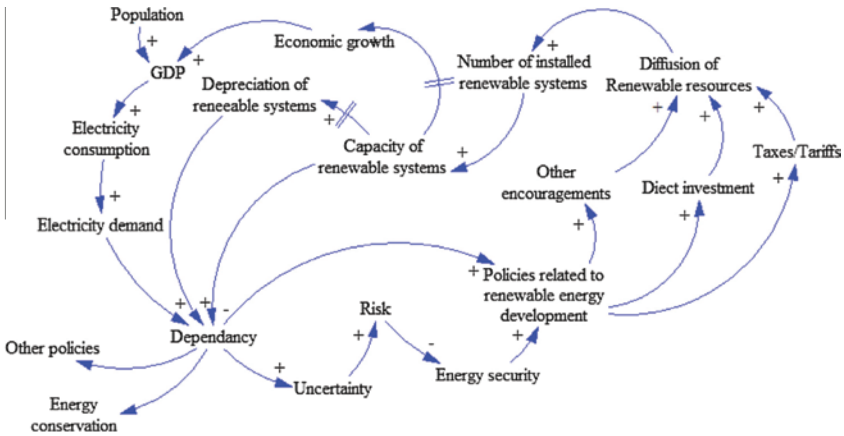

Fig. 6. Feedback structure of role of renewable energy in energy dependency and security in Finland.

Table 3
Overview important targets and policies to promote RE utilization in Finland by 2020 [10,39,40].

Renewable resource	Target in 2020	Some policy schemes
Biomass-wood	– Increasing the use of wood chips in CHP production and separate heat production to 25,000 GWh per year by 2020 (equivalent to 13.5 million cubic metres of wood chips)	– Support package comprises energy support for small-sized wood – Feed-in tariff to compensate for the difference in costs between wood chips and alternative fuels – Feed-in tariff for small CHP plants
Biomass-small-scale use of wood	– Maintaining the small-scale use of wood for heating purposes at its present level of 12,000 GWh	– Electricity tariffs which vary hour by hour (incentives to use wood as a source of extra heating)
Biomass-biogas	– Use of biogas should be increased to 700 GWh by 2020	– Market-based feed-in tariff scheme
Pellets	– Target for use of pellets is 2000 GWh in 2020	– Investments related to the use of pellets in renovated buildings will be subsidized with investment grants
Hydropower	– Increasing around 500 GWh per year of average water flow to 14,000 GWh in 2020	– Small hydropower is promoted by means of the existing investment support scheme
Wind power	– Wind power production will rise to 6000 GWh by 2020	– Market-based feed-in tariff scheme funded from the state budget
Heat pumps	– Increasing to 8000 GWh by 2020	– Heat pumps in renovated buildings will be subsidized with investment grants
Solar	– Increase to 10 MW by 2020	– For one-family houses, solar heating systems are promoted through the tax system by granting an offset for the household

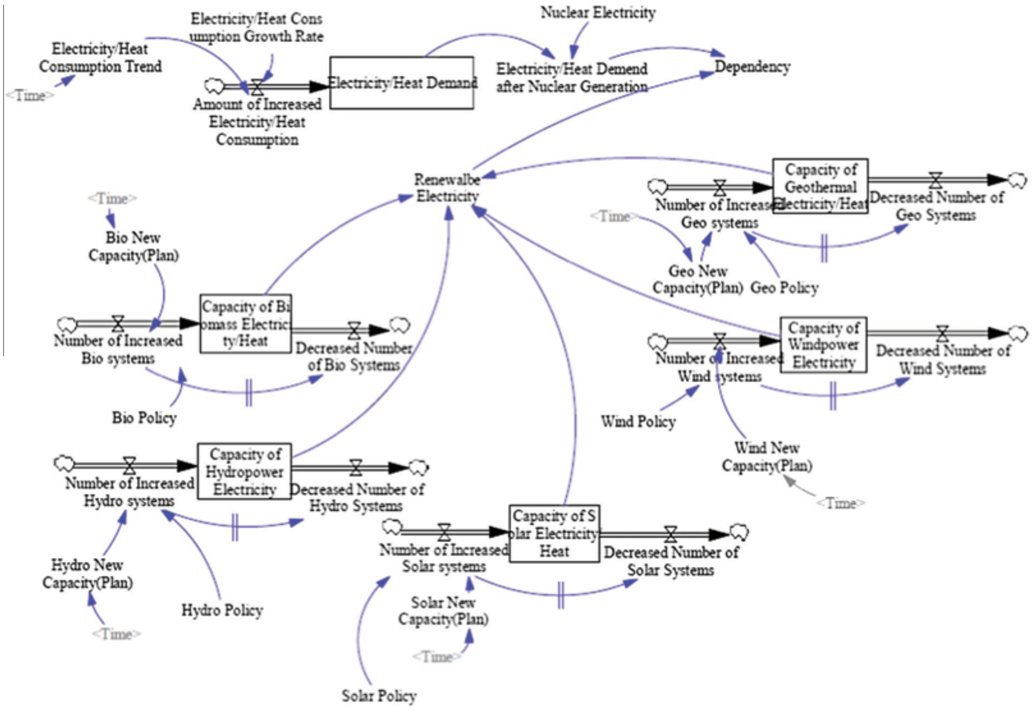

Fig. 7. The system dynamics model of renewable application policies in Finland.

Finland should have 77,000 GWh electricity/heat utilized by RERs by 2020 [39]. For instance, electricity generated by wind power should be raised to 6000 GWh by 2020. As noted in Table 3, to achieve this target, feed-in tariff and other promotional schemes have been introduced. For instance, feed-in tariffs are equivalent to the difference between the guaranteed price provided for by law and the actual market price of electricity. The target price by feed-in tariff is EUR83.50 per MWh, but until the end of 2015 the target price for electricity generated by wind power should be EUR105.30 MWh (feed-in tariff is paid for maximum of 3 years) [10]. Table 3 reviews some of the important policies and targets for RE development by 2020 in Finland.

Fig. 7 shows the system dynamics model for RE policy in Finland to analyze the level of dependency (GWh). There are six stocks in the proposed system dynamics model for RE policy in Finland including electricity/heat demand, capacity of Biomass electricity/heat, capacity of hydropower electricity, capacity of solar electricity/heat, capacity of wind power electricity, and capacity of geothermal electricity/heat. Total amount of electricity/heat generated by RERs is the sum of capacity of each RER. As figure illustrates, the capacity of each RER influenced by current operating electricity/heat generated by renewables and new installations (based on the policies and plans), as well as decreased number of RER systems affected by delay time (depreciation). This research assumes that the depreciation periods of RER systems are 20 years for solar, 25 for wind, 25 years for geothermal, 30 years for biomass plants, and 15 years for small hydropower. The number of increased RER systems (rates in the system dynamics model) are directly affected by plans and government policies discussed in Section 2 and Table 3.

Therefore, dependency on external energy resources (imports) in order to response to the heat/electricity demands, is the difference between electricity/heat generated by nuclear and renewable and electricity/heat demand.

4.1. Simulation results

Fig. 8 illustrates the electricity/heat demand (prediction) in Finland during 2011–2020. The prediction is based on the Finland's action plans multiplied by especial factor for electricity/head demand growth (affected by criteria such as weather conditions and economic growth). As Fig. 8 shows, the electricity/heat consumption will arise from 265,959 GWh in 2012 to 285,177 GWh in 2020 (7.2% growth).

Next, the amount of dependency in each year is calculated based on the three different policy scenarios as following:

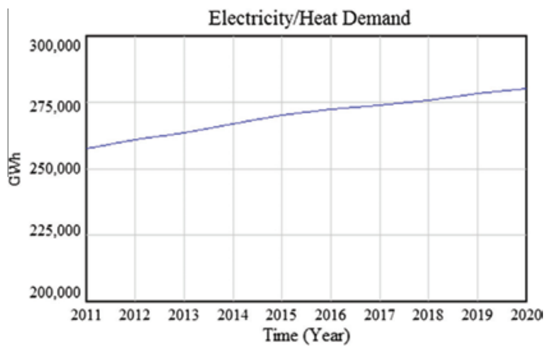

Fig. 8. Electricity/heat consumption demand in Finland.

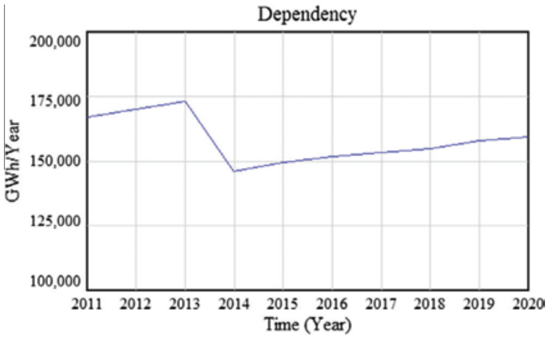

Fig. 9. Dependency based on the first scenario.

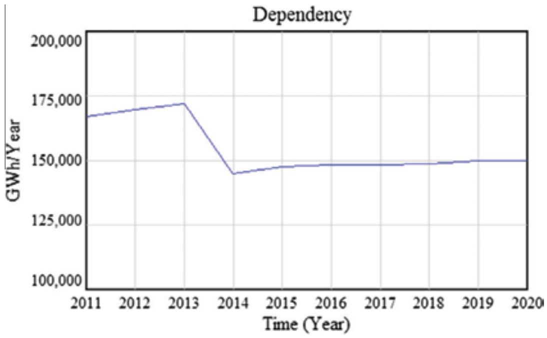

Fig. 10. Dependency based on the second scenario.

1. Before promoting renewable policies and implementing action plan (current operating systems without installations in the future).
2. After 100% implementation of RE action plan.
3. After implementation of 90% biomass, 50% hydropower, 80% wind, 100% geothermal, and 50% solar action plans (designed based on the experts' opinions).

Figs. 9–11 show the simulation results of dependency based on each scenario.

The first scenario is a criteria to compare with other scenarios. This scenario helps to analyze the effects of each energy policy on dependency with an appropriate validity. According to the first scenario, the amount of electricity/heat generated by RE will be fixed during 2012–2020 (total: 23,710 GWh). Therefore, the energy dependency will increase by 2013 (172,945 GWh). Since a new nuclear power plant with 1550 MW capacity starts to work in 2013, the dependency will decrease in 2014, but again it will increase to 159,315 GWh in 2020.

The second scenario is based on the action plan defined by Finnish government (Fig. 10). According to this scenario, dependency decreases to 171,965 GWh in 2013 and 149,693 GWh in 2020. This means, despite energy consumption growth (around 3% per year) Finland's dependency will decrease 1% in 2013, and 7% compared to first scenario by 2020. Indeed, while the electricity/heat demand increases around 9% during the period of 2011–2020, the amount of dependency will decrease around 11%.

The third scenario (conservative scenario) is designed based on the expert's opinions and trend of RE projects in the last 10 years in Finland. Several factors such as investments, economic crisis, bank interests, and estimation errors affect the action plan of RE development in Finland. Therefore, the achievements in 2020 would decrease based on 90% biomass, 50% hydropower, 80% wind, 100% geothermal, and 50% solar. As Fig. 10 illustrates, the amount of energy dependency in Finland in 2013 and 2020 will be 172,161 GWh and 151,678 GWh (0.4% and 5% decrease compared to the first scenario).

Table 4 shows the amount of energy dependency ($) and saving in each scenario in 2 years of 2013, and 2020. Since the most dependency of Finnish fossil fuels power plant is natural gas, the costs of dependency is compared based on the average natural

Table 4
Amount of dependency and saving by renewable energy action plan in Finland ($).

		Scenario		
		1	2	3
Dependency ($)	2011	11,448,928,400	11,448,928,400	11,448,928,400
	2013	11,864,027,000	11,796,799,000	11,810,244,600
	2020	10,929,009,000	10,268,939,800	10,405,110,800
Saving ($) compared to first scenario	2011	–	–	–
	2013	–	67,228,000	53,782,400
	2020	–	660,069,200	523,898,200

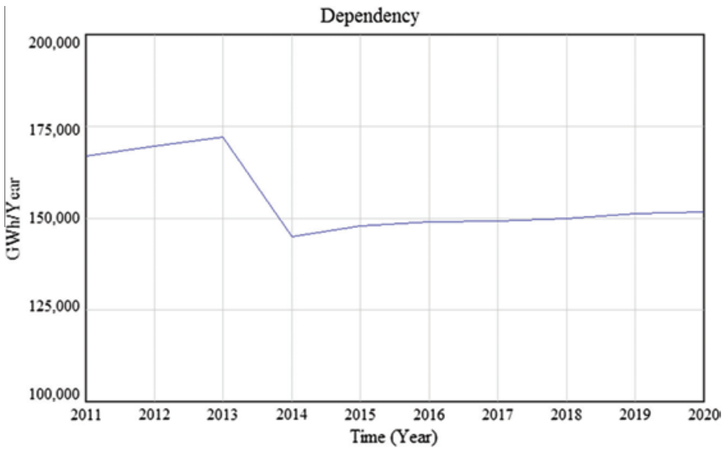

Fig. 11. Dependency based on the third scenario.

gas price estimated by US department of energy for advanced combustion turbine power plans in 2018 (68.2$/MWh) [34]. This is not included other costs including capital costs, transmission costs, operation and maintenance costs (fixed costs), and emission prices costs.

5. Conclusion

Many countries in particular import-dependent countries have made efforts to be effective in management of energy supply. Due to the various effective factors, security of energy supply is characterized as a complex system. This study provided a systematic research to evaluate the role of renewable energy resources (as a portfolio) for electricity/heat generation in Finland. Therefore, a causal feedback diagram and a system dynamics model were constructed to reveal the relationships between the dynamic factors of energy security and dependency, and the effects of renewable energy promotion policies. Therefore, three scenarios were introduced to assess role of renewable energy plans on dependency. Results showed that implementation of energy actions plans to install new renewables capacities brings more than 4billion dollar saving for natural gas imports (from 67.2 million dollar in 2013 to 660 million dollar in 2020).

For future research, the created system dynamics model can be implemented in other countries and the results can be compared with current work. Further, the total costs of renewable energy development in Finland can be compared with other sources along with risk analysis to indicate the strength and weaknesses of the renewables. Finally, accurate analysis of each of the parameters of renewable energy utilization, strategies for cost reduction via issues such as combination of markets, tax, and regulatory incentives are subjects that are suggested by authors.

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Strategic analysis of diffusion of renewable energy in the Nordic countries

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ABSTRACT

Today, there are concerns related to security of energy supply, growing energy demands, limitations of fossil fuels, and threats of disruptive climate changes. To overcome the challenges, diversification and utilization of renewable energy resources are defined as the main strategies. However, successful diffusion of renewable energy requires consideration to many factors including social, economic, and technical ones. Nordic countries are among the leading countries on successful development of renewable energy and energy efficiency. This research, in the frame of a strategic conceptual analysis, studies the policies and achievements of the Nordic region in their development of renewable energy. The framework consists of four layers including dimensions, characters, objectives, and key schemes.

Contents

1. Introduction

Although carbon-based fuels are dominant resources of power generation for residential and industrial needs, they do not offer

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long term and sustainable perspectives. According to the IEA reports, approximately 81% of the world's energy demand was supplied by fossil fuels in 2009 [1]. Since they are not located equally in the world, European countries depend largely on fossil fuels imports from other regions such as Middle East and Russia. Thereby, concerns and challenges (e.g., fluctuating carbon based fuel prices and uncertain oil and gas supplies) exist to have a secure energy supply in Europe. In response, various strategies are suggested and developed by governments and related authorities (e.g., European Union) such as upstream investment in producing countries, utilizing domestic and local natural resources, long-term contracting at premium prices, diversifying fuels and suppliers, decentralized forms of utilization etc. [2]. However today, environmental considerations influence energy security calculations. Therefore, policies like development of renewable alternatives are encouraged to contribute diversification and security of energy supply.

Studies show that the Nordic countries (NCs) including Finland, Sweden, Norway, Denmark, and Iceland are good examples to enhance the level of their energy security indicators [3]. For example, while Sweden, Finland, and Iceland are highly dependent to the fossil fuels, they are among top secure countries from energy supply viewpoint [3]. Further, although Norway is one of the main oil and gas exporters, it has the lowest level of dependency to the fossil fuels on its energy systems. In other words, the NCs have made considerable and successful efforts to improve the diversification strategy of their energy supply with core focus on utilization of renewable energy resources (RER). In 2010, Norway and Iceland are among top 10 renewable electricity producers with 96.6% and 100% of their electricity generation from RERs in the world [4]. Denmark has also one of the highest and fastest growth levels of wind power utilization in the world. Therefore, while NCs have only 0.37% (less than 1%) of the world's population, they stand among the countries with highest contribution to primary energy supply from RERs. Table 1 shows the total electricity generation from RER in the Nordic countries and some selected countries and regions in 2009 [3].

The Nordic region is also playing a leading role in diffusion of renewable energy technologies such as Finland and Sweden in biomass technologies, Norway in hydropower development, Denmark with wind power, and Iceland with geothermal utilization. Therefore, not only investigation on strategic and policy perspectives of renewable energy development in the Nordic region is beneficial, it is also one of the best case studies to be followed by other countries and regions.

This article studies the policies and achievements related to renewable energy utilization in the Nordic region. The aim is to develop a strategic framework to evaluate energy policies and decisions, and provides a structure to analyze the adoption of renewable energy. The article starts with a brief review of energy structure in the NCs. Some important and related statistics are reviewed in that section. Then, an innovative conceptual framework is presented and discussed to show the layers of renewable energy development policies. The layers include dimensions, characters, objectives, and key schemes.

Table 1
Share of RER in the total electricity generation (%) in the Nordic region and some selected cases in 2009 [3,6].

Country or region	Total electricity generation from RER (%)
Finland	31.56
Sweden	58.52
Norway	96.63
Denmark	27.4
Iceland	100
USA	10.5
Germany	20.1
UK	6.18
France	13.34
Belgium	6.53
Nordic average	62.82
Top 33 richest countries based on GDP	23.58
Top 33 richest countries based on GDP (without Nordic countries)	16.51

2. Analytical framework of energy supply in the Nordic countries

The Nordic countries (NCs) are the northernmost countries in Europe. This region includes independent countries (Finland, Sweden, Norway, Denmark, and Iceland) plus three autonomous regions (Aland, Faroe Islands, and Greenland). The population of the NCs was 25,830,631 (0.37% of World) on April 2012 [3]. The region is among top developed countries from economic and social welfare indicators.

The NCs are energy intensive countries because of cold climate, their energy intensive industries, wide sparsely populated areas with long distances, and their high standard of living. For instance, Finland's per capita energy consumption is the highest within European Union [5]. Norway and Sweden are also among top countries in this indicator. Fig. 1 illustrates the primary energy consumption in the NCs by sources in 2009.

According to Fig. 1, Finland and Sweden have the largest diversity in their energy supply compared to other NCs. While Finland, Sweden, and Iceland have to import a substantial part of their fossil fuels, the annual production of energy in Norway is approximately 10 times of the domestic use [7]. Fig. 2 shows and compares the breakdown of final consumption by source in industry sector of the NCs before first economic recession (1970s) and 2009.

Fig. 2 illustrates that the shares of oil and coal in energy supply have been substantially reduced in the last three decades in the NCs, especially in Finland, Sweden, and Denmark (red and violet colors). In Finland, it dropped from 64% in 1973 to 28.7% in 2009. While electricity and district heating system consume the most part of energy supply, RERs are their main supply resources. Fig. 3 illustrates the energy consumption mix for electricity plants, combined heat and power plants (CHP), and heat plants.

Due to geographic situation of the NCs, solar energy is not a priority for economic utilization. However, Iceland derives 84.3% of its primary energy from indigenous RERs (64.1% geothermal and 20.2% hydropower) which cover 100% electricity generation (hydropower: 12279 GW h and geothermal: 4553 GW h in 2009) [8]. Hydropower is also utilized for more than 90% electricity generation in Norway (126,077 GW h in 2009). On the other hand, Finland and

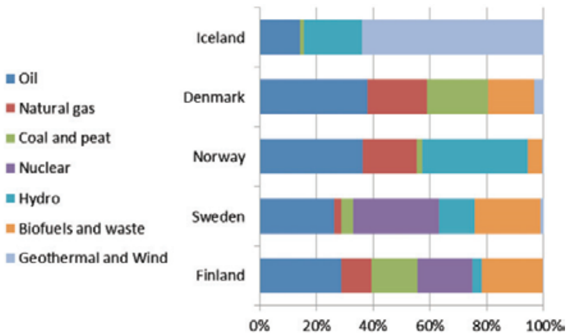

Fig. 1. Primary energy consumption in the Nordic countries in 2009 [6].

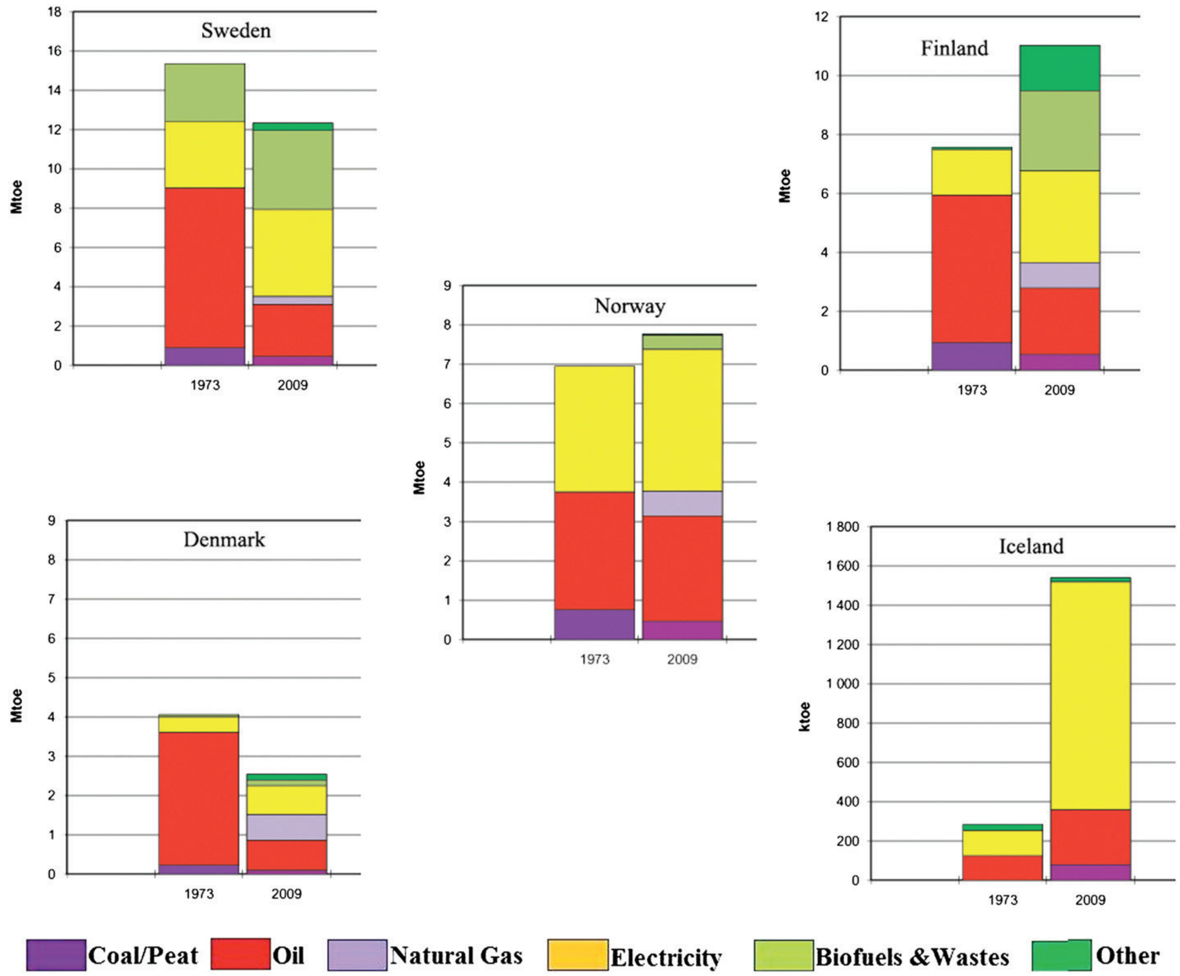

Fig. 2. Breakdown of sectorial final consumption by source in industry sector in the NCs [6].

Sweden are two of the leading bioenergy using countries in the world with 8586 and 11,323 GW h electricity generations in 2009. The national target for Finland is to increase electricity production from biomass in which the major part derives from forest industry [9,43]. In recent years, pellets market is one the rapidly developed industry in Sweden and makes Sweden as one of the world's leading producers and users of pellets in energy supply. Finally, Denmark has a leading role in wind power and the expansion of wind power is an important goal in Danish energy policy and supply.

The above show that the main energy policy of the Nordic governments is to diffuse RE utilization providing different regulations and mechanisms. Table 2 reviews some of the regulations categorized based on country. Next two sections review the strategic and tactic perspectives of the decisions and policies based on a qualitative research.

3. Research methodology

The aim of this research is to understand the strategic aspects of RE development in the NCs. The study helps policy makers and researchers to study how the NCs take action and respond to the challenges of their energy security, and environment by diffusion of RE utilization.

The data come from three primary resources: direct observation of the authors, analysis of statistics reports published by related international agency such as IEA, EIA, European Commission, and scientific references in the fields of energy, investment and management. Approximately 3000 pages of documents and articles include annual reports, detailed government, project reports, and published investigations were reviewed. To organize and extract data and create the conceptual framework, the NVIVO 9(QSR) software was used. The software helped us in three main ways: managing data, managing the ideas, and querying data [10–12]. By analysis of articles, observations, and reports, the authors began to understand how RE has been promoted in the NCs. Therefore, different layers of RE development were identified that play as the barriers or encouragement factors. While some of them have a cultural or a political nature, others have an economic or an environmental structure. Four main layers based on the strategic thinking were defined to categorize each factor: dimensions, characters, objectives, and key schemes. Fig. 4 illustrates the conceptual framework of the analysis.

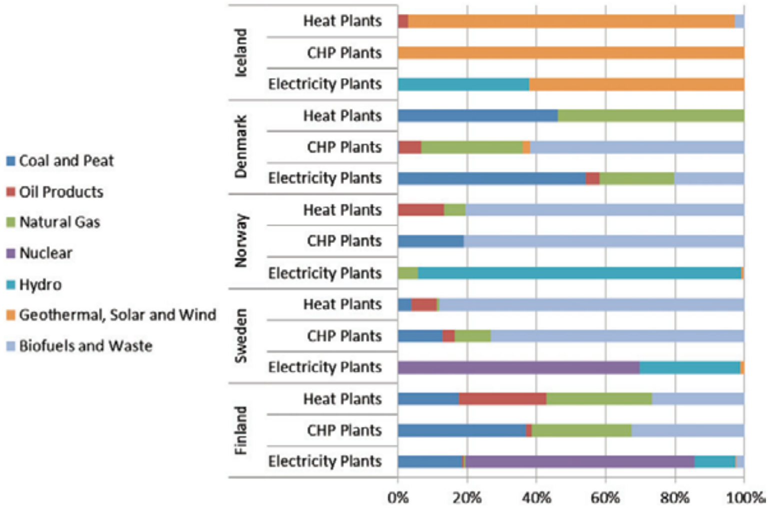

Fig. 3. Energy consumption mix for electricity and heat plants, 2009 [3,6].

Table 2
Some regulations related to RE promotion in the NCs.

Country	Selected regulation plan	Core themes (selected)
Finland	– Long-term Climate and Energy Strategy (2008) – Future—National Strategy to Implement the Kyoto Protocol [39]	• Preserve/improve the diversity of Finland's energy system and the security of energy supply • Increase the volume of indigenous energy sources and their share of total energy consumption during the period 2005–2025 • Increase markedly the share of renewable energy sources (e.g., bio energy) • Import less energy to reduce its percentage of total consumption [40,48]
Sweden	Climate and energy targets by 2020 [41]	• 40% reduction in greenhouse gas emissions. • At least 50% renewable energy. • 20% more efficient energy uses. • At least 10% renewable energy in the transport sector [41].
Norway	– "greenhouse gas emission allowance trading (2004), – White Paper no. 18: security of power supply (2004) [32]	• More pro-active approach to the climate issues. • Increase the installation of small scale hydro power • Secure an effective Nordic power market [32].
Denmark	A Visionary Danish Energy Policy 2025 (2007) [27]	• A minimum 15% reduction in the use of fossil fuels compared with today. • Preventing an overall increase in energy consumption, while sustaining economic growth. With this in mind, the energy saving initiative will be increased to 1.25% annually. • The share of renewable energy must be increased to at least 30% of energy consumption by 2025. • A doubling of publicly funded research and development into and demonstration of energy technology to DKK 1 billion annually from 2010 onwards [27].
Iceland	Climate Change Strategy to reduction of net emissions of greenhouse gases by 50–75% until the year 2050, using 1990 emissions figures as a baseline (2007) [42]	• Greenhouse gas emissions will be reduced, with a special emphasis on reducing the use of fossil fuels in favor of renewable energy sources and climate-friendly fuels. • Attempt to increase carbon sequestration from the atmosphere through afforestation, revegetation, wetland reclamation, and changed land use. • The government will foster research and innovation in fields related to climate change affairs and will promote the exportation of Icelandic expertise in fields related to renewable energy and climate-friendly technology. • The government will prepare for adaptation to climate change [42].

4. Discussion and analysis

4.1. Dimensions of policy making in renewable energy development in the Nordic region

A policy is typically described as an idea or plan to guide decisions and achieve rational outcomes. The purposes of strategic decision-making to diffusion of RE in the Nordic region can be summarized in three main dimensions: self-sufficiency, balancing trade-off, and sustainability (Fig. 5).

The first and important aspect of RE development in the NCs is to reduce the consumption of fossil fuels and increase the dependency of indigenous resources (self-sufficiency) [13]. It means low risk for security of energy supply by increasing diversification for oil and coal importers such as Finland, Sweden and Iceland. For instance, while Iceland was one of the poorest European countries during the 20th

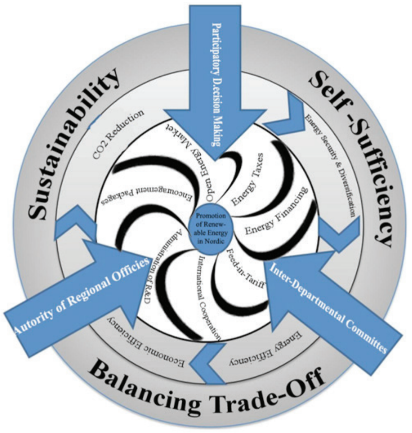

Fig. 4. Conceptual framework of the research.

Fig. 5. Dimensions of policy making in NCs.

century with full dependency to peat and imported coal, today it is a country with a high standard of living in which roughly 85% of primary energy is derived from indigenous RER [3].

Second, as RE is available locally, it helps in economic and technologic growth of the region that brings new job opportunities and social welfare development (balancing trade-off). In other words, RE industry has created new jobs, business and investments, of which many of them are in rural areas of Finland, Sweden, and Norway [12,14]. For instance, more than 200 private entrepreneurs with more than 4000 job opportunities are active in the biomass plants to supply heat to almost 500 locations in Finland [44].

Finally, the reduction in the consumption of carbon-based fuels reduces the pollution and environmental impacts (Environmental sustainability). It is noteworthy; sustainability in this research is covered just one dimension of sustainable development model (environment). Generally, the NCs' programs in controlling carbon emission are among the world's successful plans [15].

4.2. *Effective characters on decision making related to RE policies in the Nordic countries*

Different groups of stakeholders affect public policies and the process of decision-making [16]. Three main characters influence on promotion plans of RE development in the NCs. They penetrate on the related decisions and policies of the Nordic governments and are completely visible in some key schemes (Section 4.4). Fig. 6 illustrates the main characters influence on decision and policy making in the NCs.

The first character is participatory decision-making. The studies indicate that the successful Nordic policies related to diffusion of RE are supported by community organizations and citizens before implementation [3]. In other words, the public and academic, interest groups, and business sectors are adequately involved in the decision making process, particularly in RE policy formulation [17]. The second character is the role of inter-departmental committees. Inconsistencies decline of government energy policy and execution is the result of this character in RE programs of the NCs. The third character is role and authority of regional offices, universities, and companies in development of RE project. This character increases the role of regional (municipalities) in decision-making and implementation process of RE development in the NCs [18].

4.3. *Objectives of diffusion of renewable energy in the Nordic countries*

Several policy objectives exist as the sub-groups of policy-making dimensions in the RE development in the Nordic region (Fig. 7). The objectives show different perspectives of diffusion of RE including engineering, social, and management viewpoint and can be broken down into four specific elements (Fig. 7).

4.3.1. *Energy security and diversification*

Security of energy supply is one of the important debates among citizens and governments of the NCs. In response, diversification is defined as the heart strategy to achieve to a certain level of energy supply. Diversification in energy supply sources can reduce vulnerability of supply disruptions from a particular source. It can also reduce the market power of any one supplier and the risks of higher prices. Studies show that Finland and Sweden have two of the top diversified energy portfolios among other developed countries [3].

4.3.2. *Energy efficiency*

Energy efficiency means producing specific amount of services using less energy, or maximum output obtained from a given amount of energy resources by keeping resource waste to a minimum [12]. The promotion plans of energy efficiency and conservation in the Nordic region are justified from five

Fig. 6. Characters of policy making in NCs.

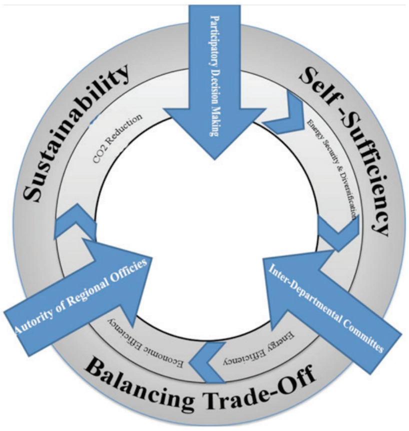

Fig. 7. Objectives of RE policy making in NCs.

viewpoints. First, the NCs especially Finland, Sweden, and Norway are high energy intensive region because of their cold climate. Second, in Finland, Sweden, and Norway the population density is widely sparse with long distances. Third, the energy consumption intensity in the Nordic industries is generally high [43]. For example, the forest and paper industry in Finland alone consume 63% of industrial energy demand [5]. Fourth, the high standard of living in this region causes high energy consumption [3]. Finally, the concerns related to environmental impacts of fossil fuel devices forced to note to energy efficiency. Energy efficiency can be even discussed from energy security and related uncertainties.

The IEA reports imply that the NCs have high energy efficiency. For example, Sweden needed 0.18 toe of primary energy for each USD of gross domestic product (GDP) that is in the efficient region in 2006 [19]. During 2005–2008, the Swedish government introduces subsides which allows to owners of houses to obtain a grant for installation of new windows with a maximum *U*-value of 1.2. [19]. Resultant decreased energy intensity about 25% averagely in 2008 compared to 1990 in Sweden and Finland [19]. Norway also offers grants for energy savings in homes, buildings, and outdoor equipment areas [20]. Recently, the energy efficiency policies in the NCs are increasingly guided by EU directives and projects.

4.3.3. Economic efficiency

Clough defines economic efficiency as maximizing outputs obtainable from a given set of inputs, or minimizing inputs required obtaining a given set of outputs [21]. Economic efficiency related to the diffusion of renewable energy in the Nordic region consists of two types of efficiency:

– Technical efficiency: Producing a given output at the lowest possible cost due to known technologies and environmental limitations [22]. For example, as Finland has about 150 days winter season, one of the challenges of wind turbines is blades freezing. Operating cost-effective blade-heating system under icing conditions is a good example of this consideration.
– Allocative efficiency: allocating existing stocks of resources and technical knowledge to offer or produce a service or a commodity that buyers value most highly, as indicated by their collective willingness to pay for them. As an example, there are different electricity seller companies in the Nordic countries that offer different kinds of electricity with competitive price (e.g., green electricity or normal electricity) and customers can select and by their electricity.

4.3.4. CO_2 reduction

CO_2 reduction is defined minimizing CO_2 emissions from fossil fuel burning caused by human activities. It is carried out on the demand side as well as on the supply side through efficiency improvement, reducing energy consumption, utilizing some alternative energy technologies, and using a less carbon/cleaner energy [23].

Several efforts have been done related to CO_2 reduction in the NCs. For instance, the Danish government presented the Danish climate strategy for future efforts of climate change in 2003. They have implemented the EU scheme for greenhouse gas emission allowance trading which has regulated CO_2 emissions from January 2005 [24]. In Norway, a law for greenhouse gas emission allowance trading was entered into force in January 2005 along with EU emission trading system [25].

4.4. Key schemes of diffusion of renewable energy in the Nordic countries

To promote the RE utilization, governmental support schemes are essential. These schemes are different and depend on the government policies, resources etc. However, there are common diffusion schemes in the NCs that following are reviewed.

4.4.1. Energy financing

The first and important scheme in the Nordic region is energy financing. It includes direct government investment on the RE technologies and efficiency solutions, supports of private sector investments, financial supports of R&D programs, etc. For example, the Ministry of Trade and Industry Energy Department in Finland grants energy aid for investments in RE sector such as up to 30% government co-financed for construction costs of RE plant [26]. There are also several same finance supports in Sweden and Denmark [20,27]. Norway has lower finance support compared to Finland, Sweden, and Denmark. However, wind power projects can be granted about 25% of the total investment costs for investment support covering in Norway [28]. The Norwegian government also supports maximum 40% of the investments in the heat-processing of biomass program that is aimed at the entire chain from harvesting and transportation to processing and trade with biofuels [7].

4.4.2. Energy taxes

Energy taxes are central instrument of energy and environmental policy among the NCs. Generally, taxes aim to curb the growth of energy consumption and steer the production and use of energy towards alternatives with less emissions (even by subsidies). Nordic's energy tax system is very diverse and comprises many exemptions. It includes different taxes on electricity and fuels, CO_2 emissions, and levy systems on NO_x and sulphur emissions. Taxes are different depending on the fuel is being used for heating or in transport, by manufacturing industry, energy industry or households. Even for electricity, the amount of tax depends upon demands on resource, geographical location, and seasons. Energy taxation scheme in the NCs can be categorized in two parts: tax incentives and subsidies, and taxation.

4.4.2.1. Tax incentives and subsidies. Studies show that the most important scheme to diffusion of RE in the NCs are subsidies and tax incentives. For example, Finland has regulation related to tax subsidies paid for power production based on RERs [29]. Subsides are between 10% and 30% of the investment costs of the biomass plant [46]. Biomass plants also receive a subsidy per MW h almost equal to the industrial electricity consumption tax.

On the other hand, Denmark has provided subsidies such as defined energy saving measures in buildings and production processes via sale of energy saving certificates to utility companies. This country has also promotion packages (e.g., tax exemption) for hydrogen powered cars [30].

4.4.2.2. Taxation of fossil fuels. The debates among economists show that the best policy instrument to reduce carbon emission is carbon tax [38]. In the Nordic region, tax must be paid for fossil fuels especially for heat production. This policy improves the competitiveness price of bio energy and other resources. As an example, Table 3 shows the Finland's energy taxation introduced by ministry of environment in 2011.

4.4.3. Open energy market

Another main driver of RE promotion in the NCs is open energy market. The goal is to make RE utilization competitive. The Nord Pool Spot and Nordic electricity exchange are two of this open market liberalization (excluding Iceland because of geographical situation). The Nord Pool Spot is one of the first free electric-energy markets in Europe and World and is largest measured in volume traded (TW h) and market share in the world. The Nordic region has also a transparent and fully independent (non-government) network regulator, and most of the power grids are open to all competitors [20].

4.4.4. Encouragement packages and green certificates

The NCs have tried to improve the knowledge and awareness of their citizens about RERs and conservation by development of promotion programs in different levels from the kindergartens to universities. Energy week is one of these promotion programs that are organized annually in different cities of the NCs [31]. Annual campaigns to promote energy savings in buildings are other examples that are organized by the NCs. The role of social media and networks (e.g., TV and Facebook) is also important in the promotion programs. Currently, much attention in Sweden and Norway is directed to the green certificates. In Sweden, certificates are issued to producers of RE and all end-users. The electricity certificate system is one of the main instruments of promoting renewable electricity in Sweden [32]. Under this system, all Swedish electricity generators using eligible technology receive a certificate for each MW h of electricity generated. Eligible technologies are solar, wind, small hydro (up to 1.5 MW) and bioenergy, as well as peat in CHP plants. This policy will continue until 2030 to provide long-term stability for investors [20].

In Norway certificates have integrated with Swedish certificates market. Certificates are also issued for production of wind power, solar power, geothermal energy, bio energy, wave energy, small hydro power, increased production in existing hydro power plants, and new hydro power [32].

4.4.5. Administration of research and innovation and policy instruments

As discussed in Section 4.3, the objective of research and development in the field of energy and RE management is to strengthen economic growth, diffuse use of energy resources and ensure that environmental considerations are taken into account. The competitiveness of RER is also promoted through investment in long-term technology research and development [45]. While most of the overall research funding in the energy sector is provided by public sectors, the results are mostly implemented by private sectors in the NCs.

Most of the R&D funds are allocated to user-driven research programs which increase the competitiveness of energy markets. The most important public or government owned organizations being responsible for administration of R&D, innovation, and policy instruments within RE and energy efficiency in the NC are shown in Table 4 (plus the NCs' universities):

4.4.6. International cooperation

Research show that the NCs involve in cooperation with different international RE projects, especially EU projects. In other words, participation in international cooperation is a main priority and an important supplement to national research efforts in the NCs. Each of the NCs (especially Finland and Sweden) is primarily involved in cooperation within other NCs, EU authorities, and the International Energy Agency (IEA). For example, the Nordic Energy Research Program (NEFP) guides a part of the activities of the former Nordic Energy Research Program [33]. One of the main objectives of NEFP is to develop energy cost-effective reduction of use and development of RERs and related technologies [32]. It is achieved by strengthening collaboration among the universities, colleges and other research institutions as well as developing active research networks in the various levels (national, regional, and international cooperation).

4.4.7. Feed-in-tariff (FIT)

FIT is a mechanism designed to accelerate investment in RE utilization [34]. Although U.S. is the birthplace of FIT, more than 35 countries around the world use this policy in their RE development programs. [12,13,35]. Currently, feed-in tariffs in place provide different types of RE generation facilities a premium payment over a long-term period for each kW h of electricity fed into the grid in the NCs [13].

For example, the Danish policy of FIT is to refund the full CO_2 tax of wind turbines and a partial refund of the energy tax [36]. The distribution companies have to buy all of the electricity produced by wind turbines in the NCs especially in Denmark [37].

5. Conclusion

This study showed how the policies and decisions of RE promotion in the NCs have provided a successful case to be followed by other developed and developing countries. As the

Table 3
Energy taxes in Finland in 2011 [47].

Fuel	Energy tax	CO_2 tax	Security of supply fee	Total
Heavy fuel oil [EUR/t]	87.90	97.2	2.8	187.90
Hard coal [EUR/t]	54.54	72.37	1.18	128.09
Peat [EUR/MW h]	1.90	–	–	1.90
Natural gas [EUR/MW h]	3.0	5.94	0.084	9.024
Pine oil [EUR cents/kg]	0.188	–	–	18.79
Electricity: Tax class I [EUR cents/kW h]	1.69	–	0.013	1.703
Electricity: Tax class II (industrial user) [EUR cents/kW h]	0.69	–	0.013	0.703

Table 4
Most important R&D supporters and policy makers of RE in the NCs.

Number	Country	Institutes
1	Finland	• The Finnish Funding Agency for Technology and Innovation(Tekes) (www.tekes.fi) • Fortum (http://www.fortum.com) • The Ministry of Trade and industry, energy department (www.ktm.fi) • Technical Research Centre of Finland(VTT) (www.vtt.fi) • Motiva (www. Motiva.fi) • The Ministry of Environment, administration of environmental policy (www.vyh.fi)
2	Sweden	• Swedish Research Council (Vetenskapsrådet) (www.vr.se) • Swedish Energy Agency (Statens Energimyndighet) (www.energimyndigheten.se) • the Swedish Agency for Innovation Systems (VINNOVA) (www.vinnova.se) • The Swedish Competition Authority (Konkurrensverket) (www.kkv.se) • The National Board of Housing, Building and Planning (Boverket) (www.boverket.se) • The Swedish Environmental Protection Agency (Naturv · rdsverket) (www.naturvardsverket.se)
3	Norway	• Norwegian Research Council (www.forskningsradet.no) • Enova SF (www.enova.no) • Innovation Norway (www.invanor.no) • The Norwegian Water Resources and Energy Directorate (NVE) (www.nve.no) • Gassnova (www.gassnova.no) • The Norwegian State Housing Bank (The Housing Bank) (www.husbanken.no)
4	Denmark	• Danish Energy Agency (www.ens.dk) • Danish Ministry of the Environment, Environmental Protection Agency (www.mst.dk) • Danish Climate and Energy Ministry, Energinet (www.energinet.dk) • Danish Agency for Science, Technology and Innovation (www.fi.dk) • The Danish National Research Foundation (www.dg.dk)
5	Iceland	• Innovation Iceland (www.nmi.is) • The National Energy Authority (NEA) (www.nea.is) • Iceland GeoSurvey (ÍSOR) (www.geothermal.is) • The Icelandic Regional Development Institute (www.byggdastofnun.is)

result of the complexities of different RERs and technologies, it is impossible to attain successful implementation by a single dimensional approach. A mix of policy is the key driver to increase the installed capacity and energy generation from RE technologies, reductions in cost and price, domestic manufacturing capacity and related jobs and public acceptance. Therefore, a strategic analysis approach was presented to pursue continual RE promotion and shown diffusion layers of RE development in the NCs.

For future research, the authors present their suggestions from two different viewpoints. First from a strategic viewpoint, the dynamic capabilities of RE development programs in the NCs can be described to understand and compare each strategy and policy. The results can be compared by EU projects to identify the current and future opportunities and threats. Second, EU scholars and scholars of other developed or developing countries can implement the introduced framework to compare and get ideas in their case studies. It would help to identify the strengths and weakness of each strategy and policy in selected country or the NCs.

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Evaluation of renewable energy development in power generation in Finland

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Renewable energy resources have historically played an important role for heat/electricity generation in Finland. Although diffusion costs of renewable energy utilization are higher than fossil fuels and nuclear power plants, other policy aspects and operation costs of renewables cover this gap particularly in high dependent countries to fossil fuels. The current paper discusses the role of renewable portfolio in the Finland's energy action plan during 2011–2020. A system dynamics model is constructed to evaluate different costs of renewable energy utilization by 2020. Results show that total costs of new capacities of renewable energy systems as well as operation and maintenance costs of current systems bring 7% saving compared to total costs of new natural gas power plants (as a sample for second scenario) in Finland. © *2013 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4855095]

I. INTRODUCTION

Energy security concerns along with consumption growth are rapidly rising in importance in almost all countries in particular high dependence countries to imported fossil fuels such as Finland. In response, renewable energy resources (RER) are a solution to reduce dependency on imported energy and provide social and environmental benefits. To decrease the dependency and improve security of energy supply, utilization of RER has been debated by Finnish governments and policy makers. However, speed of new RE development plans particularly wind power has lagged that of other European countries in recent years in Finland. Compared to 27 European countries, Finland had almost low capacities of wind power (19/27), solar power (17/27), and solar heating (23/27) in 2010.

To succeed diffusion programs of renewable energy(RE) development, different strategies such as technological improvements, increased economies of scale, and strong policy support should be contributed in both developed and developing countries.[1] Nevertheless, compared to traditional energy sources, promotion of electricity/heat generated by RER is limited because of its relative investment high costs.

This study compares the costs of RE development and fossil fuels according to the Finnish energy action plan for electricity/heat generation by 2020. Due to the complexity of such studies, as well as different factors effects on costs analysis, the system dynamics approach is implemented to analyze the effectiveness of RE policies.

The work is organized based on the following sections: Energy structure, supply, and consumption in Finland are reviewed in Sec. II. In Sec. III, the role of RE utilization in Finland is discussed. Indeed, important RERs and their potentials are also reviewed. Related polices and government's schemes to RE utilization in Finland are described in Sec. IV. Different parts of RE and fossil fuels system's costs in Finland are reviewed in Sec. V. Finally, a system dynamics model for cost analysis of RE utilization during 2011–2020 is proposed in Sec. VI.

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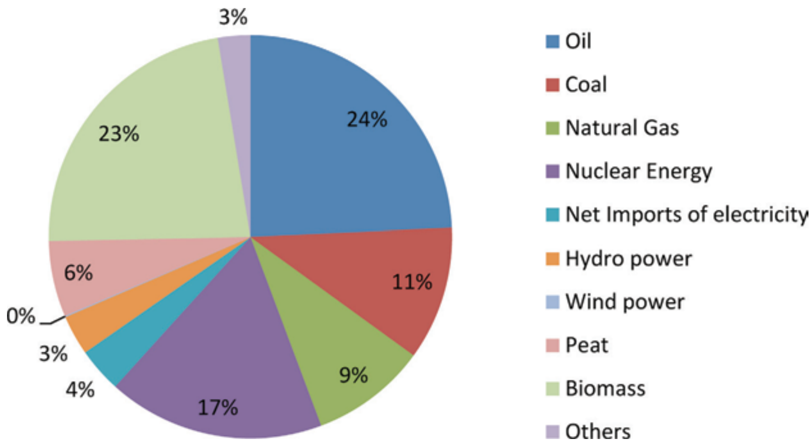

FIG. 1. Share of each energy source in total energy consumption in Finland in 2011.

II. ENERGY STRUCTURE IN FINLAND

Finland is one of the northernmost countries in Europe with a population of 5 429 894 (0.72% of Europe).[2] The country is one of the developed countries from economic and social welfare indicators. It is also one of the most energy intensive countries because of a cold climate, its energy intensive industries, wide sparsely populated areas with long distances, and a high standard of living.[3] In 2011, the total energy consumption in Finland was 1 392 279 TJ with 52 Mt CO_2 Emissions.[4] Figure 1 illustrates the primary energy consumption in Finland by sources in 2011.[4] As figure shows, the share of fossil fuels and RERs were around 44% and 28% in 2011.

Due to the Finland's cold climate, electricity and district heating systems have key roles in residential and industrial sectors. In 2011, the share of Finnish industries in electricity consumption was about 48.7% of total electricity consumption. Figure 2 shows the end use of energy in different Finnish sectors with special focus on main Finnish industries in 2011.[4] While total electricity consumption in Finland was about 84 241 GWh, industrial sector consumed more than 41 000 GWh of this consumption. While forest and paper, metal and chemical, and engineering industries represent 80% of Finnish industrial products and services, the forest and paper industry alone consumes more than 50% of electricity of the industrial sector (20 858 GWh) (25% of total energy consumption).

In 2011, the electricity generation by mode of sources was 22.3 TWh for nuclear power, 12.3 TWh for hydropower, 14.2 TWh for coal and peat, 9.2 TWh for natural gas, 1 TWh for oil

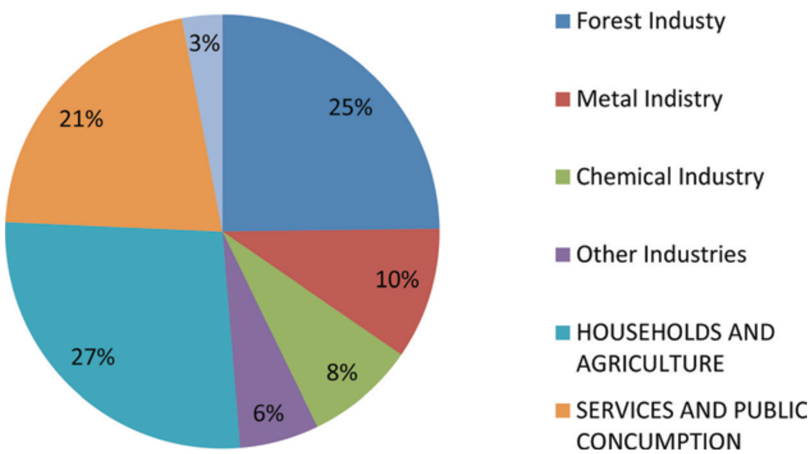

FIG. 2. End use of energy in different Finnish sectors in 2011.

and other fossil fuels, 10.1 TWh for wood fuels, 0.5 TWh for wind power, and 0.4 TWh for other renewable sources.[4] The combined heat and power (CHP) plants have around 43% of the electricity/heat generation in Finland categorized in two groups of industry (17.7%) and district heat (26.1%).[4] About 13.9 TWh of electricity also was imported based on different agreements with neighbor's countries in 2011 (e.g., Nordpool).

III. RENEWABLE ENERGY UTILIZATION IN FINLAND

RERs in particular biomass has important role in the primary energy supply of Finnish strategies. According to the Finland's national action plan for electricity/heat generation from RERs, the share of RE should be increased to 38% of the gross final consumption by 2020.[5] For instance, while the share of wind power among other RE alternatives was less than 1% of the total RE supply in 2009, it should be increased to 15% by 2020. Table I shows the amount (TWh) and share of RERs in total energy consumption in some years.[4]

The principal RE source in Finland is Biomass that makes about 86% of the total RE utilization. The availability of biomass resources is distributed in 15 areas in Finland. Some examples of bioenergy are firewood, bark, sawdust, forest chips, demolition wood, pellets, and briquettes. About 70% of the bioenergy was produced by the forest industry in Finland in 2010.[6] The country is the third with highest capacity of biomass power generation in European Union (EU) after Germany and Sweden.[7] The major uses are in the industries particularly paper and wood industry.

Hydropower is the second largest RER utilization in Finland. In 2011, 205 hydropower plants generated 12.3 TWh electricity that had a share of 11.2% among RERs in Finland. Approximately 90% of electricity generated by hydropower comes from large-scale hydropower.[8] This source has little potential for development as most of the possibilities for growth have been already used. However, small-scale hydropower is important for local development that receives government's supports. According to the Finnish policies (National Climate and Energy Strategy), small-scale hydropower plants (<1 MW) can benefit through the energy tax exemption. The capacities over 1 MW do not receive any electricity production support in Finland.[8]

The utilization of wind power is the fastest growing among other RERs in Finland.[9] Wind power has also the highest average annual installed capacity in Europe (around 11.5 GW per year) that should be increased to 14 GW by 2020. Although this source was carried out for the first time in 1992 in Finland, the electricity generated by wind power should be rise to 6 TWh by 2020.[10]

In 2009, solar photovoltaic modules produced 5 GWh of electricity in Finland (mostly in universities and research centers).[3] Diffusion challenges of solar energy utilization in Finland are categorized in three terms: Geographical feasibility, commercial, and technical. Because of Finland's geographical location, the solar radiation is not noticeable compared to some European countries such as Germany, France, and Italy. However, due to the long daylight hours in the summer months (more than 20 h), some regions such as Ostrobothnia (Coast's West) have good potential for solar development in Finland.[9]

Finally, the classical forms of geothermal energy (hot and dry rock or steam) are not economically feasible for utilization in Finland. Thereby, this source is restricted to utilization of

TABLE I. Amount and share of renewable energy resources in total energy consumption in Finland.

	TWh	Share %
1991	57.6	18.4
1996	71.5	20.5
2001	87.3	22.9
2006	101.8	24.5
2011	109.3	28.3

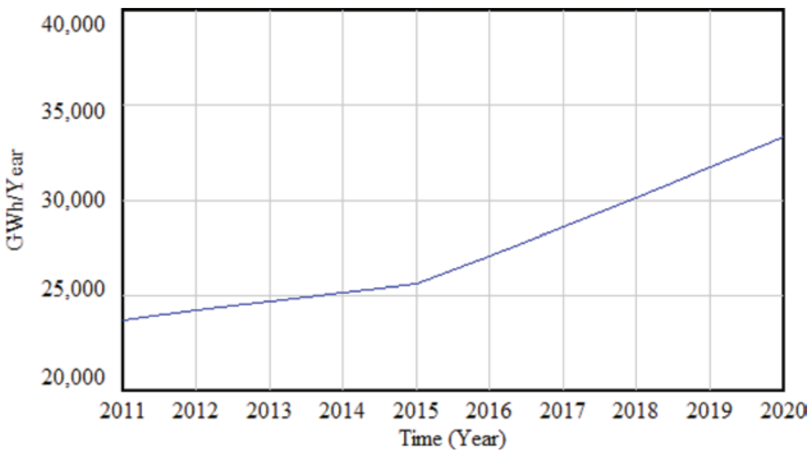

FIG. 3. Electricity/heat generated by RERs based on Finnish Action plan (GWh/year).

ground-heat with heat pumps. In Finland, heat pumps are mainly used for space and hot water heating in single-family houses from boreholes, surface sediments, lakes, and rivers. In 2011, 3.5 TWh energy produced by heat pumps with 13.6% growth compared to 2010.[4]

IV. POLICIES RELATED TO RENEWABLE ENERGY DEVELOPMENT

According to the studies and based on the Finnish energy action plan, the amount of electricity/heat consumption in Finland will be changed from 265 959 GWh in 2012 to 285 177 GWh by 2020 (7.2% growth).[11] Meanwhile, the amount of energy contributed from RERs should be rise to 33 420 GWh (Figure 3).

The process of RE development in Finland is described in different layers.[3] The layers have strategic, policy, and practical targets that provide a portfolio of political, technological, managerial, social, and cultural schemes (Figure 4). Table II summarizes each layer and their related schemes.[3]

V. COSTS OF RENEWABLE ENERGY UTILIZATION

Investment is a key point for diffusion of RE technologies. Specifically, to utilization of RERs economically reasonable, they should be adopted pervasively by supports of the government and contributions of the private sector. Research show that financial measurement that indicates the required investment and other costs of RE utilization (e.g., maintenance and operation), as well as efficiency of each energy source (performance) are two key criteria for RE promotion.[1] For instance, today wind energy is cost-competitive in many increasing cases and is being developed even in the absence of any government support. While efficiency and reliability of the wind turbines have increased, the capital costs have been halved over the last 30 years.[26] On the other hand, the cost of solar photovoltaic (PV) technologies is being fall quickly as demand is rising with costs declining by 19% with each doubling of global capacity.[25] Following each criteria and their amount to electricity/heat generation by RER are reviewed.

A. Energy conversion efficiency of energy sources in Finland

Efficiency has various definitions in different sciences. One of the definitions of energy efficiency is related to energy conversion efficiency (η) that means using less energy to provide the same or improved desirable output. In a wider definition, the efficiency of electricity/heat generation is mixed with annual exploitability index to show the performance of energy sources.[12]

Two main fossil sources for electricity generation in Finland are coal/peat, and natural gas. While the share of coal/peat in electricity generation by fossil fuels was 61%, natural gas had a

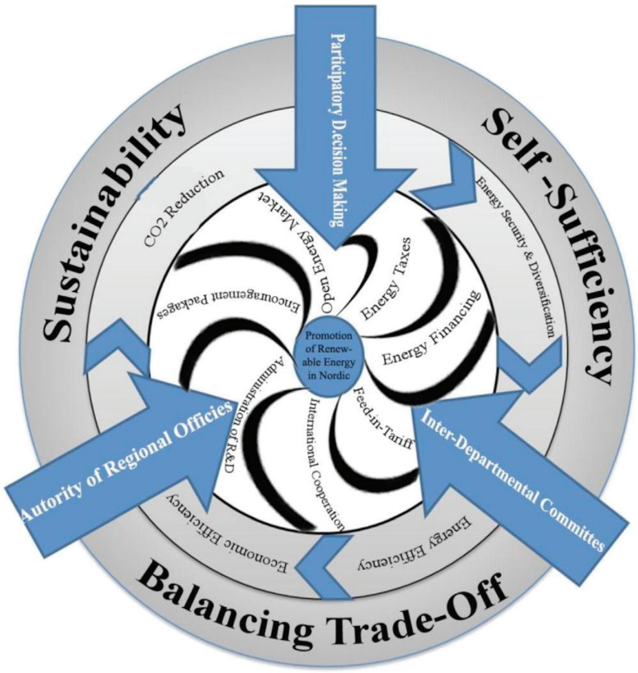

FIG. 4. Layers of RE development in Finland.

share of 37% in 2011.[29] However, the natural gas has many advantages compared to coal. For instance, natural gas burns more cleanly than coal and other fossil fuels. It is also more efficient compared to coal/peat.[30]

According to the report of the US Energy Information Administration (2013), the capital cost of the natural gas power plants is almost a quarter of the capital cost of coal/peat power plants.[31] Natural gas can be easily transported via pipelines. Even though the natural gas is cleaner than coal and oil, it still contributes a large amount of carbon. From supply viewpoint, Finland has 100% dependency to imports of this source.[32]

The costs of RE utilization and development (first scenario) in this article are compared with natural gas as a replacement fossil fuel (second scenario). The reason is because of the role of greenhouse gas reduction in the Finland's national action plans. In other words, to launch the system dynamics model of RE cost analysis, the researchers assume that the new capacities of fossil source for electricity/heat generation are natural gas power plants.

Indeed, the main objective of the current article is to present and implement a system dynamics model for cost analysis in renewable energy industry. Therefore, natural gas is a scenario for system dynamics model and the presented model can be updated with new scenarios such as nuclear power plants.

The main biomass source in Finland is wood used in the CHP plants. Wood residual chips (forest chips) are the cheapest available wood fuel and used as mixture with milled peat.[3] As the costs of generated electricity by wood are clearly higher than other sources, there are not any power plants for just electricity generation by wood in Finland. CHP plants in Finland are working with a maximum power output capacity of 30 MW.[17] If the CHP plants are used for electricity/heat generation, the investment cost of a merely electricity producing power plant are around 3000 €/kW with efficiency around 35%.

On the other hand, statistics show that the average peak load utilization of wind power plants time was 1789 h per year in the year 2006.[13] In this study, a peak load utilization time of 2000 h per year with 40% energy conversion efficiency is estimated for biomass power plants. A lifetime of 25 years is also used for wind turbines. Finally, the energy conversion efficiency of 60% for hydropower, 20% for solar PV and thermal, and 20% for heat pumps are estimated to electricity/heat generation.[14]

TABLE II. Different layers of strategic analysis of diffusion of renewable energy in Finland and the Nordic countries.

Layer	Description	Sub-layer	Aim
Dimensions	To show the purposes of diffusion of RE utilization	Self-sufficiency	To reduce consumption of fossil fuels and increase the dependency of indigenous resources
		Balancing trade-off	To help to economic and technologic growth of the regions
		Sustainability	To reduce pollution and environmental impacts
Characters	To identify main stakeholders affect public policies and process of decision-making	Participatory decision-making	To have the supports of the community organizations and citizens
		Inter-departmental committees	To have a comprehensive and coordinative decision making
		Authority of regional offices	To increase the role of regional s (municipalities) in decision-making
Objectives	To show different perspectives of diffusion of RE	Energy security and diversification	To reduce the dependency to the external resources (energy imports)
		Energy efficiency	To produce specific amount of services using less energy
		Economic efficiency	– Technical efficiency – Allocative efficiency
		CO_2 reduction	To minimize CO_2 emissions from fossil fuel burning caused by human activities
Key schemes	To describe different policies or regulations related to diffusion of RERs utilization	Energy financing	To direct government investment on the RE technologies and efficiency solutions
		Energy taxes	To curb the growth of energy consumption
		Open energy market	To make RE utilization competitive
		Encouragement packages and green certificates	To improve the knowledge and awareness of the citizens about RERs
		Administration of research	To manage research and R&D funds
		International cooperation	To share and crate the knowledge
		Feed-in-tariff	To accelerate investment in RE utilization

B. Cost data of renewable energy utilization

The costs of energy sources utilization to electricity/heat generation are categorized in the four main items including initial investment (cost of capital), operations and maintenance costs (O&M), cost of fuel, and costs of greenhouse gases (e.g., carbon emissions). Selling price, taxes, and subsides are not included in the costs discussed in this study. Beyond the effects of technology development on prices decreasing in RE technologies, the overall price level of RE systems has remarkably risen in recent years (because of construction prices such as metals and other materials used in the power plant components and fuel prices).

To increase the validity of current article and provide a similar scale implementable for other countries or cases, costs of renewable energy utilization calculated by the US department of energy are used in this study (except fuel cost and emission cost). That reference is the most valid and reliable source of energy costs analysis.[15] However, data would be different according to different calculations and references and the years. While the investment costs are based on the estimations until 2017, value added costs such as taxes are not included in the study. Indeed, we assume that new combined cycle gas turbine plants are located near the existing natural gas network in Finland, if the policy makers want to develop electricity generation via fossil fuels. Therefore, the connection fee does not contribute in the investment cost. The investment cost of the combined cycle gas turbine plant is estimated 26.8 €/MWh. The O&M costs also is proposed 3.1 €/MWh. As the prices of fossil fuels have recently risen, the natural gas prices are assumed 40.5 €/MWh. According to the EU regulations, an additional cost for fossil fuels should be also added as greenhouse gas emission price. The emission price is estimated 60 €/tonCO_2 for period 2013–2020.[17] According to the statistics, the "life cycle analysis" of CO_2 emissions for natural gas to electricity generation is about 469 gCO_2/kWh.[16] The electricity production costs has been calculated with emission prices of 60 €/ton CO_2 in this study.

For RERs, the investment cost of a wood power plant is assumed 43.7 €/MWh. The fuel prices are also estimated as peat 8.90 €/MWh and wood chips 13.4 €/MWh. The O&M costs is also estimated 10.6 €/MWh. The level of investment in wind power plants (on-shore) is estimated around 64.1 €/MWh. However, the investment cost level depends on the market volume, competition situation, project size, and regional conditions.[17] Based on the operation experience of existing wind power plants, the O&M costs of wind power plants is estimated 7.5 €/MWh in Finland, in which the bigger units size decrease the O&M costs.

In 2009, the average cost of installed solar panels systems was 5.8 €/W installed capacity in Germany, $3.5 €/W in Japan, and ranging from 3.8–8 €/W in the United States.[18,25] Therefore, 2 kW capacity solar panel system would cost between 7100 € and 15 000 € installed depending on the location. About 20% additional costs should also be added to the named costs (e.g., batteries).However, the prices of solar technologies dropped by 50% in 2011 due to adoption of new technologies in related industries.[19] In this study, the investment price and O&M cost are assumed 130 €/MWh and 6.7 €/MWh in Finland.

The cost of installing a heat pump using ground-heat is about twice the price of installing systems based on electricity. However, the running costs of ground-heat systems are much lower.[20] Thereby, the investment and O&M costs of this technology are estimated 58.9 €/MWh and 7.4 €/MWh in Finland. Finally, the investment and O&M costs of electricity generated by hydropower are approximately estimated 59.2 €/MWh and 3.1 €/MWh.

VI. SYSTEM DYNAMIC MODEL

System dynamics is a methodology based on system thinking to understand and model the behavior and activities of the complex systems over time.[21,22] The methodology is based on the feedback structure, meaning that decisions with specific goals alter the world and subsequently lead to new decisions.[23] The process of system dynamics analysis is comprised of six steps, which are (1) system understanding, (2) problem identification and definition, (3) system conceptualization, (4) simulation and validation, (5) policy/decision analyzing and improvement, and (6) policy/decision implementation. As Figure 5 illustrates, the main concentration of system dynamics is "understands the system," and all steps try to have feedbacks for system understanding. In addition, causal interactions of all main variables in a system are represented in the system dynamics as a causal loop diagram.

Through a review of existing literature among over 2000 pages of documents and articles including annual reports, detailed government, project reports, and published investigations, we have assessed the Finnish energy sector to (1) define the main problems and objectives of renewable energy utilization and (2) identify the key variables and policies. Through a review of existing literature, we investigated the causal relationships pertaining to dependency and renewable energy utilization. Then, the causal relationships are qualitatively examined. Indeed, the causal relationships between variables and formulating relationships are quantitatively examined via collecting relevant data. The integrated stock-flow diagram is developed to simulate and compare scenarios.

A. Conceptualization of renewable energy development in Finland

The causal loop diagram is to qualitatively visualize, understand, and analyze the system. The diagram consists of nodes (variables) and their relationships (arrows). Relationship of two variables can be positive or negative.[24] For quantitative analysis, the causal loop diagram is transformed to

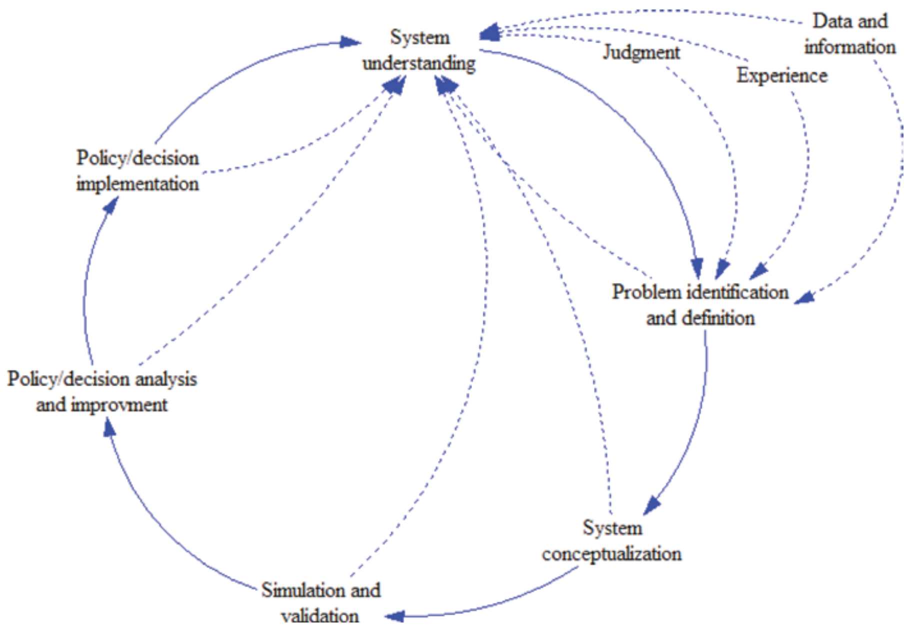

FIG. 5. Process of system dynamic analysis.

a stock and flow diagram. This diagram and stock-flow diagram play central role in system dynamics modeling. Figure 6 shows the inter-relations of the influencing factors in the frame of causal loop diagram. Among a number of variables within the subsystems of renewable energy development, only main variables that are related to our model are included in the figure.

Growth in energy and electricity demand positively affects dependency on fossil fuels system. Increasing dependency to fossil fuels means Finland will be more dependent to energy imports that bring risks and uncertainties. In response, government tries to overcome to dependency by introducing several policies such as development of RE utilization.[21] RE development policies consist different strategies including polices related to technology development and encouragement packages. By developing technologies, the costs of renewable energy utilization including construction, operation, and maintenance (O&M) decrease. Therefore, the capacity of

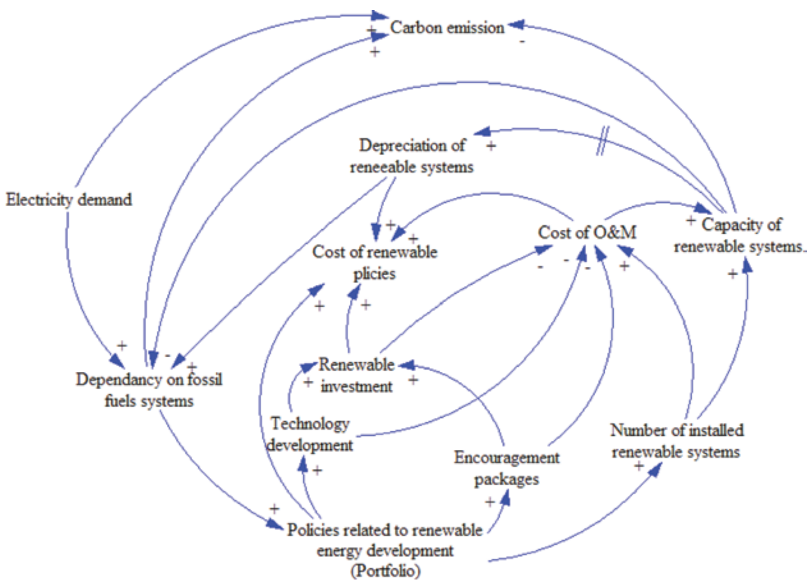

FIG. 6. Causal loop diagram of the renewable energy development.

RE systems increase. This not only decreases the energy dependency on external sources, it also negatively influence on carbon emission. On the other hand, the depreciation period of a renewable system affect dependency (increase) after a period (e.g., 20 years for wind power plants). It also affects costs of renewable policies (increase).

B. Dynamic analysis of renewable energy utilization plans

Based on the above causal loop variables, a system dynamics model is constructed to evaluate and compare effects of RERs on Finnish energy dependency during 2011–2020. To develop the quantitative model, we collect data about Finnish energy and renewables from the Statistics Finland, Finnish Ministry of Employment and the Economy Reports, and US Department of Energy. According to Finland's national action plan for promoting RE (document number: 2009/28/EC), Finland should have 77 TWh electricity/heat utilized by RERs by 2020.[4,5,10] To achieve the targets, different promotional schemes have been introduced. Table III reviews some of the important policies and targets for RE development in Finland by 2020.

There are five stocks in the proposed system dynamics model including, capacity of biomass electricity/heat, capacity of hydropower electricity, capacity of solar electricity/heat, capacity of wind power electricity, and capacity of geothermal electricity/heat. Total amount of electricity/heat generated by renewable resources is the sum of capacity of each RER. Figure 7 shows the system dynamics model of RE development in Finland. As figure illustrates, the capacity of each RER influenced by current systems plus new installations (based on the policies and plans) and decreased number of RER systems affected by delay time (depreciation). We assume that the depreciation periods of RER systems are 20 years for solar, 25 years for wind, 25 years for geothermal, 30 years for biomass plants, and 15 years for small hydropower. The number of increased RER systems (rates in the system dynamics model) is dirrectly affected by plans and government policies discussed in Sec. II and Table III. As disscused in Sec. V, the costs data(investment and O&M costs) are bsed on the data published by the US Department of Energy.[15] Figure 8 shows the total costs of electricity/heat generated by RERs during 2011–2020. These costs include current RE systems (O&M costs) and new installations during 2011–2020.

TABLE III. Overview some of the Finland's targets and policies to promote RE utilization.[10]

Renewable resource	Target in 2020	Some policy schemes
Biomass-wood	-Increasing the use of wood chips in CHP production and separate heat production to 25 TWh per year by 2020 (equivalent to 13.5×10^6 m^3 of wood chips)	-Support package comprises energy support for small-sized wood, -Feed-in tariff to compensate for the difference in costs between wood chips and alternative fuels, -Feed-in tariff for small CHP plants,
Biomass- Small-scale use of wood	-Maintaining the small-scale use of wood for heating purposes at its present level of 12 TWh,	-Electricity tariffs which vary hour by hour (Incentives to use wood as a source of extra heating)
Biomass-biogas	-Use of biogas should be increased to 0.7 TWh by 2020,	-Market-based feed-in tariff scheme
Pellets	-Target for use of pellets is 2 TWh in 2020	-Investments related to the use of pellets in renovated buildings will be subsidized with investment grants
Hydropower	-Increasing around 0.5 TWh per year of average water flow to 14 TWh in 2020	-Small hydropower is promoted by means of the existing investment support scheme
Wind power	-Wind power production will rise to 6 TWh by 2020	-Market-based feed-in tariff scheme funded from the State budget
Heat pumps	-Increasing to 8 TWh by 2020	-Heat pumps in renovated buildings will be subsidized with investment grants
Solar	-Increase to 10 MW by 2020	-For one-family houses, solar heating systems are promoted through the tax system by granting an offset for the household

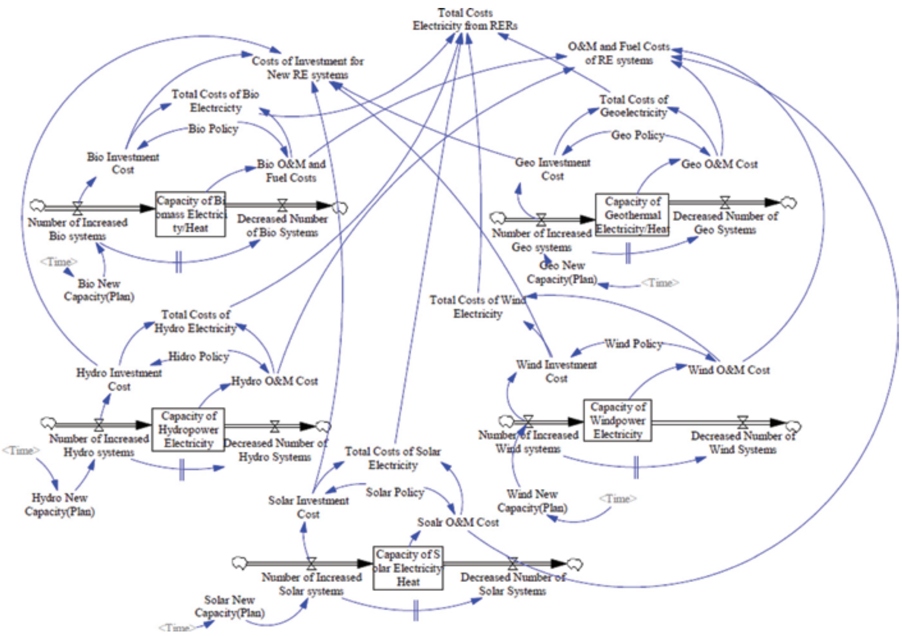

FIG. 7. Stock and flow diagram of the renewable energy development.

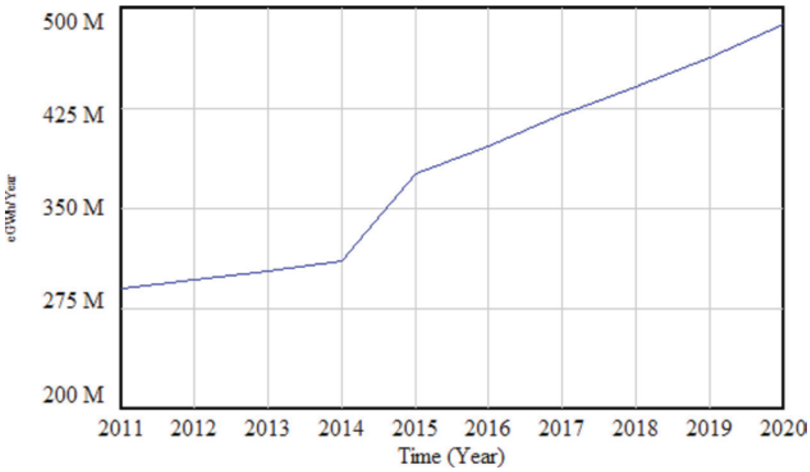

FIG. 8. Total Costs of electricity/heat generated by renewable energy resources ($\times 10^6$ Euro).

According to the simulation, the total costs of electricity/heat generated by RERs during 2013 and 2020 will be around 302 644 000 and 487 546 000 € (61% growth). As Figure 8 shows, a jump in costs increment will be occurred after 2014 that is related to the commercial development of hydropower plans (2014–2020) and solar and heat pumps (2018–2020).

Figures 9 and 10 show the total costs of RERs new instalations (investment costs) and O&M costs (for existing systems and new installations).

The total amount of electricty/heat generated by RERs should reach to 77 TWh that means 9622 GWh new RE systems installation during 2011–2020. To evaluate the advantages or disadvantages of this amount of RE utilization, the total needed costs of heat/electricity generated by RERs is compared with total needed costs of electricity/gas generated by natural gas power plants (as the main source of fossil fuel for electricity generation in Finland). Figure 11 compares each three parts of the costs for RERs and natural gas.

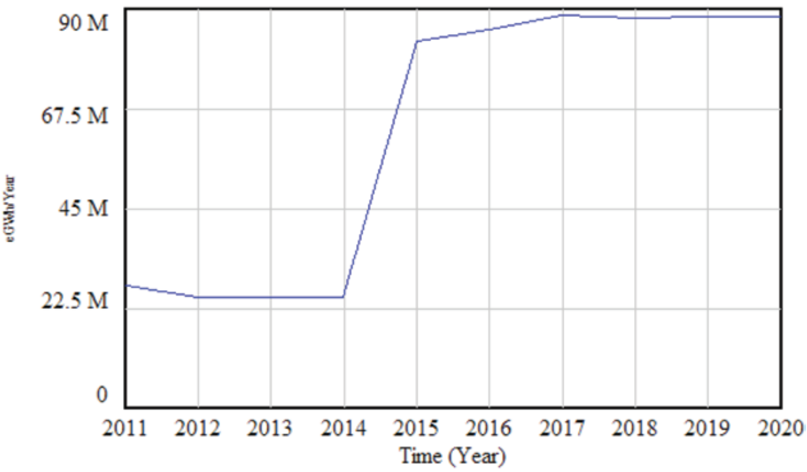

FIG. 9. Costs of new RE systems instalation ($\times 10^6$ Euro).

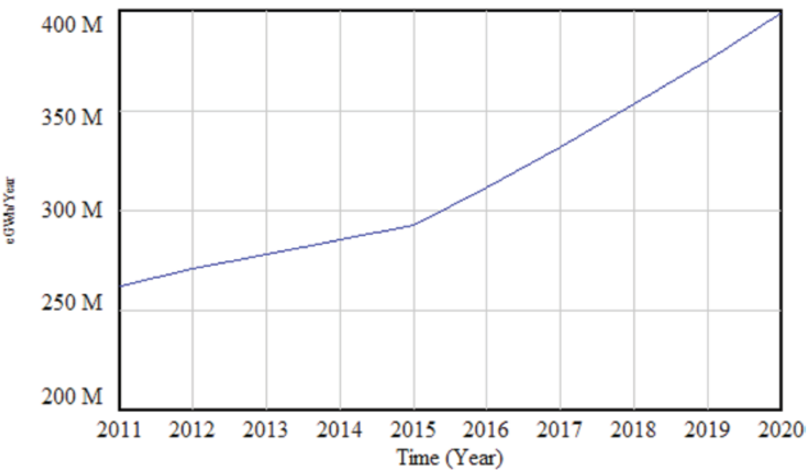

FIG. 10. O&M costs of RE systems (new systems and under operation) ($\times 10^6$ Euro).

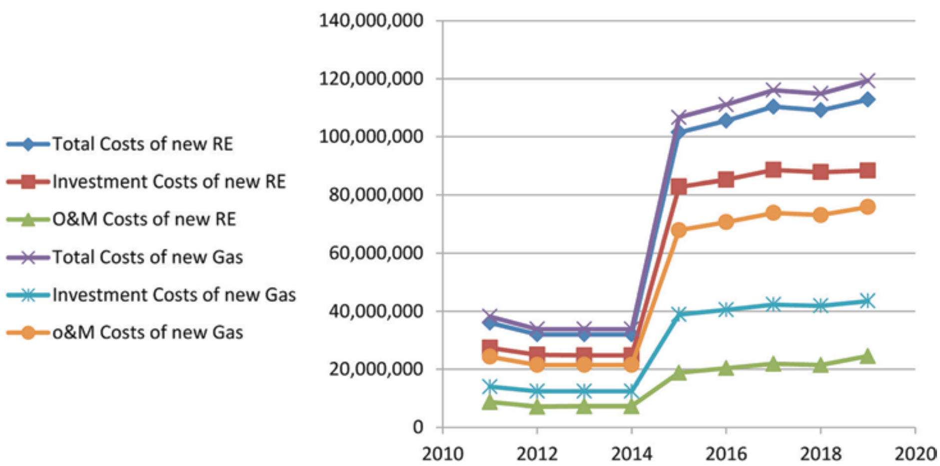

FIG. 11. Costs of new RE capacities compared to new natural gas power plants (Euro).

As figure shows, the average O&M costs of electricity generated by portfolios of RERs in Finland are almost 30% of the O&M costs of natural gas during 2011–2020. Some factors such as gas prices (imports) and prices of CO_2 emissions increase the O&M costs of electricity generation by fossil fuels. On the other hand, the investment costs for new RE capacities are about 2 times of natural gas investment for the same amount of capacity. Overall, the total costs of new capacities, as well as O&M costs of current RE systems bring 7% saving compared to total costs of new natural gas power plants during 2011–2020 in Finland (without calculation in O&M costs of current natural gas power plants). Therefore, due to 100% dependency of Finland on fossil fuels, long life cycle of RE technologies, and low O&M costs of RE systems, development of RE utilization is highly recommended.

VII. VALIDATION AND TESTING OF THE MODEL

Testing and validation of the models are very important in the system dynamics research.[27] As Kelton and Law (1991) highlight, if a model has not a "valid" illustration of a system, the model results serve little useful information about the real system. Model testing and validation in the current research are based on the matching the models' results with the real system. To test and validate system dynamics models two approach was implemented: model structure validation, and model behavior validation.[28]

According to the "structure validation,"the structure of system dynamics model is suitable if it is internally consistent with its assumptions and the causal structures contains the keys feedback loops for describing the model and real system. The models implemented in the current research response to these factors from two viewpoints. First, our system dynamics model describes the behavior of the system based on the identified variables and causal loop extracted by the researchers' observations and expert's opinion. Second, it was designed based on the real data, trends, and opinions of the professionals in the energy sector. In particular, the researchers tried to involve stakeholders and decision makers of the policy options from the beginning of the model building. Therefore, changes in the simulation forecast closely follow changes in the real world systems.

From behavior validation aspect, our system dynamics model were checked by two methods: (1) Reviewing the process of the modeling and results and comparing with historical patterns and (2) testing the results and comparing with the plans defined by EU and government (e.g., share of the RE in electricity generation according to EU and Finland plans).

VIII. CONCLUSION

Concerns such as growing energy demands, limitations of fossil fuels, threats of carbon dioxide (CO_2) emission, and consequently global warming have caused policy makers and governments to debate about security of energy supply and role of diversification in their energy policies. Due to the high dependency of Finland on imported fossil fuels, renewable energy alternatives play an important role in the Finnish energy and climate strategies. However, commercial development of renewable energy systems is highly dependent to the utilization costs. This article discussed about a system dynamics model to evaluate and compare effect of renewable energy development plans on Finnish energy dependency during the period of 2011–2020. Due to the electricity consumption growth, as well as future of fossil fuels and related risks, renewable energy utilization is the best strategy to response to energy demand in Finland.

As future research, different scenarios such as implementation of new nuclear power plants for energy future can be defined to compare with renewable energy development in Finland. Indeed, the created system dynamics model can be implemented in other countries and the results can be compared with the current work. Further, accurate analysis of each parameters of renewable energy utilization, strategies for cost reduction along with other factors such as combination of energy market, tax, and regulatory incentives are subjects that are suggested by the authors for future.

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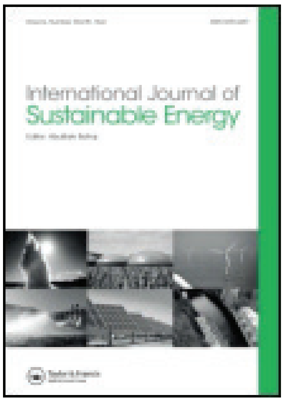

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Energy diversification in Finland: achievements and potential of renewable energy development

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Energy diversification in Finland: achievements and potential of renewable energy development

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Finland was an early adopter of several alternative energy technologies, particularly in biomass and hydropower energy for many years. The main policy in the Finnish energy and climate sectors is to increase the exploitation of renewable energy sources while reducing CO_2 emissions. Meanwhile, a successful energy policy should achieve three conflicting objectives: clean, cheap, and secure energy. The development of renewables in Finland has lagged that of other EU countries, particularly in fields such as wind power in recent years. This article discusses about the history, current status, and potentials of the major renewable and local energy in order of utilisation in Finland. It is seen that the major contributors to replacing carbon-based fuels are likely to be biomass and wind power, with geothermal and solar energy sources to play a lesser role.

Keywords: renewable alternatives; diffusion of renewable energy utilisation; energy policy; Finland; diversification

1. Introduction

Fluctuating carbon-based fuel prices, increasing world demand for energy, uncertainties in the oil and gas supplies arising from geopolitical concerns, and global warming are the challenges that Finnish citizens and government realise to have the secure and safe supply of energy (Lund 2007). In response, various strategies have been suggested and developed even in collaboration with other authorities (e.g. European Union) such as upstream investment in producing countries, utilising domestic and local natural resources, long-term contracting at premium prices, diversifying fuels and suppliers, developing dual fuel technologies, decentralised forms of utilisation, and efficiency and conservation.

Renewable energy (RE) alternatives play an important role in the Finnish energy and climate strategies. Among Organisation for Economic Co-operation and Development (OECD) countries in the world and Europe, Finland is one of the countries with the highest contribution to primary energy supply from RE (at three times the OECD countries and two times the OECD Europe). However development of RE, particularly in areas such as wind power, has lagged that of many

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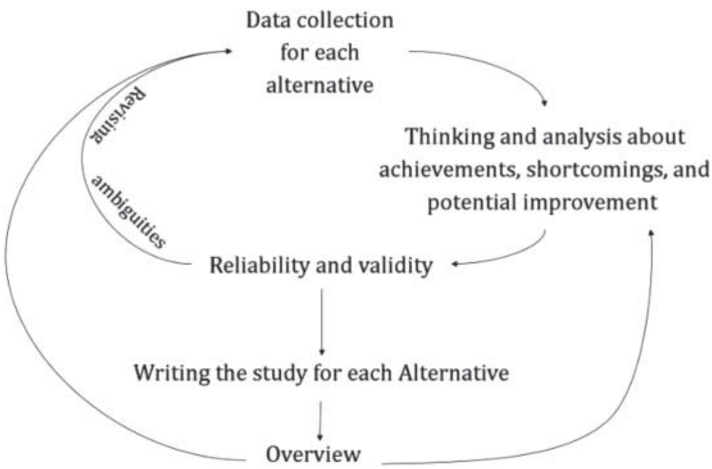

Figure 1. Framework of data analysing for the research.

other European countries in recent years (#14 in Europe in 2011) (Finland installed capacity 2011).

The current article discusses development of RE in Finland and overviews related to last actions and policies. To prepare a strong qualitative research, over 2500 pages of documents and articles including annual reports, detailed government, project reports, and published investigations were categorised and reviewed. Figure 1 illustrates the framework of data accumulation and analysis. According to the figure, after data collection in each of the five majors of the RE alternatives in Finland (biomass, hydropower, wind, geothermal, and solar), the main points were numbered and coded such as achievements, policies, and shortcomings. To manage and analyse the qualitative data, Nvivo9 computer software was used. NVIVO is one of the best research software to support qualitative and mixed methods research. The software helped us in three main ways: managing data (to organise and keep track of the annual reports, detailed government, project reports, and published investigations, and authors notes); managing the author idea (to categorise, organise, and provide rapid access to data and our conceptual idea related to the research questions); and querying data (to retrieve from relevant information for determining answers and interpretations). Therefore, each alternative was assessed and analysed. In the next step, the reliability and validity of analysis were checked and collected by Finnish professionals who are working in the RE sector to have an effective argument.

2. Background

Finland is the world's most northern industrialised country located in Northern Europe. It is the fifth largest and the most sparsely populated country after Iceland and Norway in Europe (Finnish Population Register Centre 2012; Local Finland – Front Page 2012). The Finnish economy is highly dependent on industrial products. The industrial sector represents more than half of the primary energy use and energy-related carbon dioxide emissions. As Finland is highly dependent on the external fossil fuels, risks appear arising from continuous fluctuations in energy prices as well as permanent increase in other costs such as transportation that create tensions in economic development goals (Valkila and Saari 2010). Although there are several solutions to respond to the risks and challenges, one of the simplest and more accessible options is diffusion of RE resources

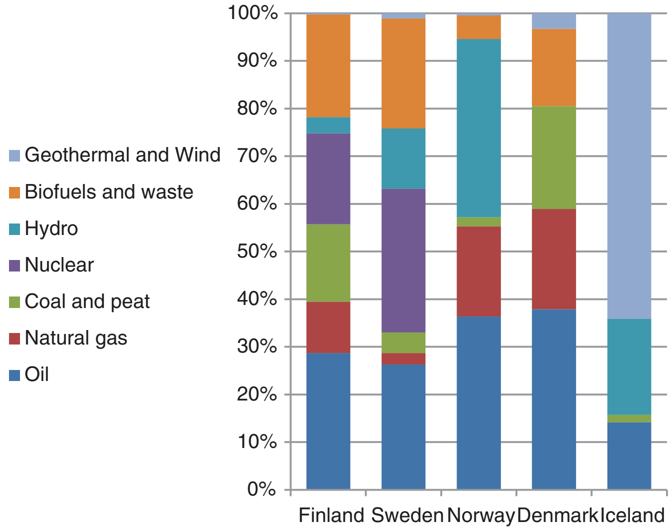

Figure 2. Primary energy consumption in Finland and other Nordic countries (Mtoe: million tons of oil equivalent), 2009 (IEA 2009).

utilisation. Despite Finland being one of the poorest countries in terms of own fossil fuel resources, it is among the top secure countries from the energy supply viewpoint. For instance, in the Nordic level, Finland has the highest degree of diversification in the energy supply sources (Aslani, Antila, and Wong 2012). Figure 2 illustrates the primary energy consumption in Finland and other Nordic countries in 2009. In Finland, the share of oil in energy supply has been substantially reduced from the 1970s (from 64% in 1973 to 28.7% in 2009) (Aslani, Antila, and Wong 2012).

According to studies, energy consumption per capita is high in Finland compared with other European countries in both per capita and per unit of gross domestic product (International Energy Agency 2000. Energy Policies of IEA Countries: Finland 1999 Review). The reasons are cold climate, industries' structure, long distances, and high standards of living (Aslani, Antila, and Wong 2012). While forest and paper, metal and chemical, and engineering represent about 80% of Finland's industrial production, the forest and paper industry alone consumes 63% of industrial energy (OPET report 9 2002). Since the major natural resource in Finland is forest with pasture

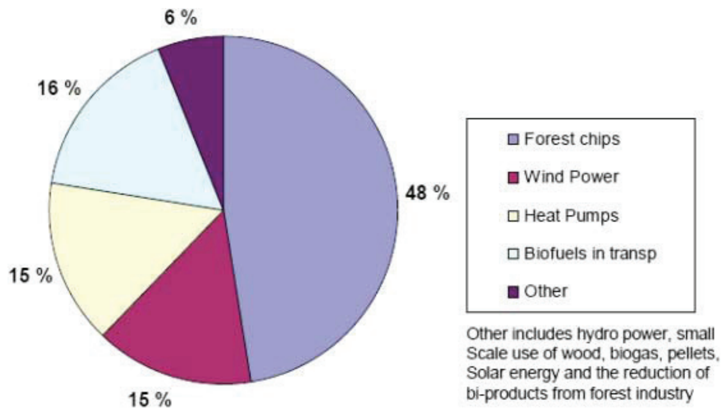

Figure 3. Increased use of RE in primary energy in Finland in 2020 in percentage (Promotion of Renewable Energy in Finland 2011).

nearly 86% of the total land cover, the principal RE source is biofuels (Salomona et al. 2011; Kara 2001).

Recently, other sources, particularly wind power, have increased their contribution in the Finnish energy security roadmap. It is expected that about 38% of the final Finnish consumption of energy will be from renewable resources by 2025 (32.2% in 2010; Sturc 2012). Figure 3 shows the plan of increased use of RE in primary energy during 2005–2020 by percent in Finland (Promotion of Renewable Energy in Finland 2011). For instance, while the share of wind power among other RE alternatives was less than 1% in the total primary energy supply in 2009, it should increase to 15% in 2020.

Following each of the important resources in terms of their history, current supply, potential, and possible barriers of development are reviewed.

3. Overview to renewable resources in Finland

3.1. *Biomass: achievements*

Biomass makes up about 86% of the total RE sources and 21.5% of the total primary energy supply in Finland (Figure 2; IEA 2009). The availability of biomass resources is distributed in 15 areas of Finland. Some examples of bioenergy are firewood, bark, sawdust, forest chips, demolition wood, pellets, and briquettes. About 70% of the bioenergy was produced by the forest industry in Finland in 2010 (Bioenergy in Finland 2011). The country is the third with the highest capacity of biomass power generation in EU after Germany and Sweden (RESAP 2011). The major uses are in industry, particularly in the paper and wood industry (Peura and Hyttinen 2011).

Biomass has a particular place in the Finnish energy policies. The annual use of solid wood in order of energy production is around 35 million m^3 (271 PJ) (OPET report 9 2002). Since private persons own more than 70% of the Finnish land forests, the bioenergy markets are local. Bioenergy is mostly utilised for heating in industries and population centres and more than 200 private entrepreneurs are active in the biomass plants to supply heat to almost 500 locations in Finland (Bioenergy in Finland 2011). Approximately half of the heating demand is supplied by district heating in Finland. The main producers of district heating are combined heat and power (CHP) plants (produce heat and electricity simultaneously) in cities as well as in small-scale regional heating plants. As combination of biomass and fossil fuel reduces their greenhouse gas emissions, they are used in CHP plants. In 2008, CHP plants had a share of 74% in district heating and 31% of the electricity generation in Finland (Salomona et al. 2011). The most commonly adopted CHP plants are in the range 2 MWe–20 MWe that are fluidised beds with steam turbines.

The reed canary grass (an agricultural source of biomass) is also used in heating plants in the multi-fuel boilers in conjunction with peat and wood fuels in Finland as the perennial and renewable source. It provides a better yield than other grasses grown for energy purposes (Forest in Finland 2012). However, while most of the yield in Finland is used in seed production, the plans should focus on using this product for combustion or a raw material of pellets.

Wood pellet is also a young market in Finland. It is produced from compacted sawdust, other wastes such as sawmilling, or other sources such as whole-tree removal or treetops and branches leftover. In Finland, the first wood pellet plant was established in 1998 (for central heating). Most of the produced pellet is exported to Sweden, Denmark, and Netherlands.

On the other hand, waste management based on source separation is one of the successful plans of the Finnish authorities for households and companies. The target of waste separation is to provide raw materials of recycling and production of recovered fuels for energy production (Forest in Finland 2012). The dry source-separated fraction from households and companies is the fuel of recovered fuel plants. There are several recovered fuel processing plants in Finland.

There are also mass-burn incinerators with waste burning capacities such as of 50,000 T (15 MW district heat).

Biogas is also a suitable fuel to use in transport or CHP plants. The product is made from the landfills, wastewater treatment plants, and biogas plants of various sizes, utilising agricultural wastes (Bioenergy in Finland 2011). In 2010, around 74 landfill gas planets (39) and reactor plants (35) were in operation in Finland and 34 reactor plants were under construction or planning. The outputs from landfill gas plants and reactor plants were 240 GWh (102 Mm^3) and 180 GWh (42 Mm^3) (Lampinen 2011). The main limitation of landfill gas utilisation is the lack of energy consumption.

3.1.1. *Shortcomings or potential improvements*

In Finland, there are three important limitations in energy production with biomass: supply, cost, and quality of the product. The first issue is related to the unbalanced distribution of biomass resources in the country and seasonal limitations that cause the heterogeneous development of biomass implementation. On the other hand, biomass is not necessarily a profitable business in Finland (Hakkila 2006). To improve the competitiveness of biomass resources, The Finnish government has increased the costs of other fuels through taxes. Finland is also planning to promote wood chips in energy production (to improve the quality of biomass products) with feed-in tariffs. Therefore, technological issues seem to be the main drivers of cost reduction in this industry that need governmental support (Ericsson et al. 2004). However, the main barrier is the support budget that is paid by Finnish municipalities and seems it is not sufficient (RESAP 2011).

From policy viewpoints, subsides and taxation are the main important Finnish drivers to promote RE utilisation from biomass. Subsides are between 10% and 30% of the investment costs of the biomass plant (Ericsson et al. 2004). Biomass plants also receive a subsidy per MWh almost equal to the industrial electricity consumption tax. Table 1 shows the energy taxation introduced by the Ministry of Environment in 2011 (Ministry of the Environment 2011).

However, both energy firms and other companies in biomass sector are facing constant changes in energy policy instruments (taxes, support mechanisms for power generation and supply chains). There is a need for more stability in governmental regulations or policies (RESAP 2011).

Finally, although the share of all biofuels in the transport should be 20% by 2020 (2% in 2008), one of the main prerequisites of this target is raw materials such as bio-oils, solid biomass, and industrial alcohols. Therefore, especially investments in raw materials are essential by research institutes and the private sector. Our study shows that the current condition of Finland is inconsistent with the defined targets. Further, biogas is also a suitable fuel to use in transport or CHP plants. The product is made from the landfills, wastewater treatment plants, and biogas plants of various sizes utilising agricultural wastes.

3.2. *Hydropower: achievements*

The Nordic region traditionally utilises hydropower as its main renewable electricity source. This source is the second largest RE resource for utilisation in Finland (Figure 2). About 205 hydropower plants work in Finland with a share of 15% in total primary energy supply (12,686 GWh in 2009). The main Finland's hydropower instillations were built during 1950s and 1960s. Approximately 90% of electricity generation from hydropower comes from large-scale hydropower. The performance of these plants has recently improved noticeably by replacing their turbines, generators, and control and automation equipment.

Table 1. Energy taxes in Finland in 2011 (Ministry of the Environment 2011).

Fuel	Energy tax	Co_2 tax	Security of supply fee	Total
Heavy fuel oil (EUR/t)	87.90	97.2	2.8	187.90
Hard coal (EUR/t)	54.54	72.37	1.18	128.09
Peat (EUR/MWh)	1.90	–	–	1.90
Natural gas (EUR/MWh)	3.0	5.94	0.084	9.024
Pine oil (EUR cents/kg)	0.188	–	–	18.79
Electricity: tax class I (EUR cents/kWh)	1.69	–	0.013	1.703
Electricity: tax class II (industrial user) (EUR cents/kWh)	0.69	–	0.013	0.703

3.2.1. *Shortcomings or potential improvements*

In spite of Finland having no special regulations or limitations for small- or large-scale hydropower development, the growth of the hydropower installations from this resource is low compared with other renewable resources such as biomass and wind. There are two barriers in the development of hydropower in Finland: physical and environmental concerns. In terms of physical, geographical and investment limitations restrict the development of hydropower. In fact, this source has only little potential for development as most of the possibilities for growth have been already used. Therefore, the feasibility of hydropower installations seems only as replacement investments in Finland (Wind Energy Statistics in Finland 2012a, 2012b). However, small-scale hydropower is important for local development that also has the governmental supports. According to the Finnish policies (National Climate and Energy Strategy), small-scale hydropower plants (<1 MW) can benefit through the energy tax exemption. The capacities over 1 MW do not receive any electricity production support.

3.3. *Wind power: achievements*

Due to the geographical situation of some of the European countries, the utilisation of wind power is the fastest growing areas among other renewable sources (Johansson and Turkenburg 2004). Wind energy plays a dominant role in power generation plans in Europe and Finland by 2020 (Figure 3). Compared with other renewable technologies, wind power has the highest average annual installed capacity in Europe (around 11.5 GW per year) that should be increased to 14 GW until 2020 (RESAP 2011). The European countries are also the world's leaders in total installed wind energy capacity.

In Finland, this source was carried out for the first time in 1992. Wind power growth in Finland is shown in Figure 4. According to the last official statistic, at the end of 2011, 131 turbines produced 199 MW energy. Until June 2012, the capacity of 137 wind turbines was 220 MW that shows a growth of 10% in the capacity in 6 months (Wind Energy Statistics in Finland 2012a). The Finland's objective is to increase the installed wind turbines to approximately 2000 MW by 2020. This target can be reached by the development of offshore as well as onshore wind farms.

Figure 5 shows the potential of wind power and locations of current wind turbines in Finland.

However, development of wind power has been lagging as compared to many European countries. The principal barriers to further wind development in Finland are environmental, social, and economic issues. Notwithstanding the slow growth of domestic wind capacity, there are considerable Finnish companies that are working in the wind power industry. The Finnish wind industry even has an important place in the world-class level. The Finnish industry has the technology to

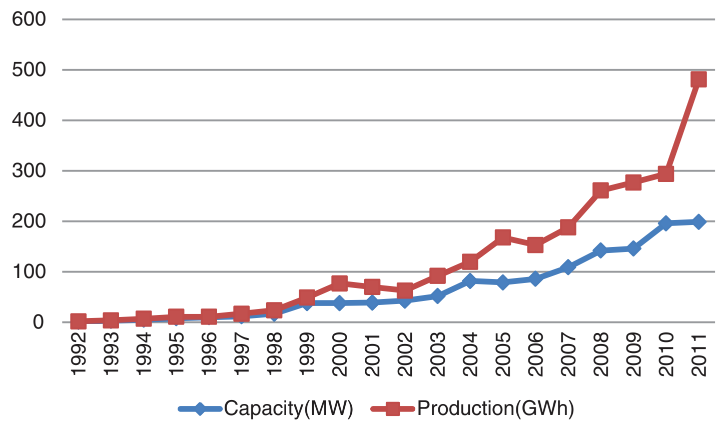

Figure 4. Installed wind power capacity (Wind Energy Statistics in Finland 2012a).

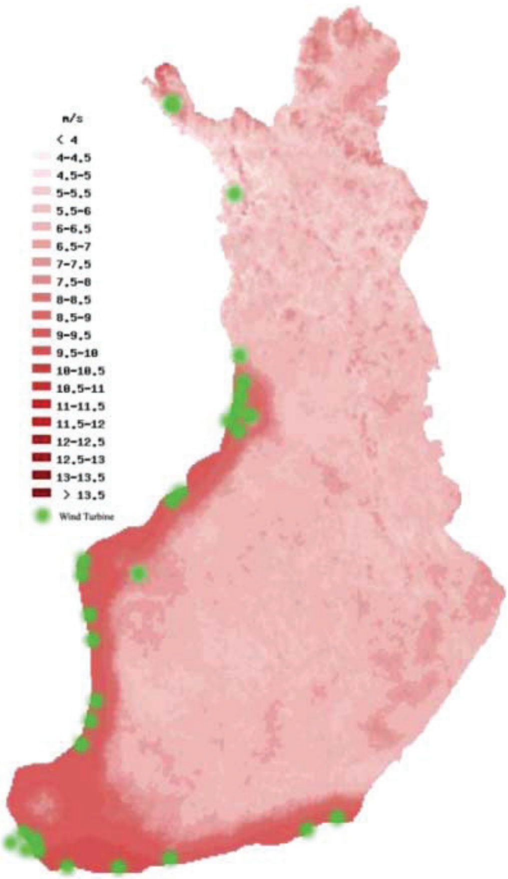

Figure 5. Potential of wind power and wind turbine sites in June 2012 (Wind Energy Statistics in Finland 2012b; Wind Atlas 2012).

produce main components of wind turbines (in different scales) such as gearboxes, different models of generators, blades, etc. This is an important driver to the diffusion of electricity utilisation from wind power.

3.3.1. *Shortcomings or potential improvements*

As we discussed, the barriers of wind development can be reviewed from three aspects including environmental, social, and economic. There are discussions among the governments and research institutes about the environmental impacts of wind turbines, climate conditions of the country, land-use restrictions, visible, and noise pollution that affect wind development (environmental–social). For instance, one of the existing challenges for wind turbines is blades freezing in Finland. Due to the geographical situation, Finland has about 100 days (southern and western) to 200 days (northern and eastern) of winter season. Therefore, blade-heating systems operating under icing conditions is one of the important aspects of co-operation between Finnish research bodies and industry that have export benefits for Finnish companies. Further, the support structures for foundation and installation of offshore turbines in the icy waters are another example of challenges and achievements of the diffusion of wind turbines in Finland. However, our studies show that this scope needs to be developed more in order to reach a cost-effective plan in Finland.

The cost of electricity generation from wind is also the economic aspect of the barriers of wind power utilisation (economic) and is an important factor from the investor's perspectives (Aslani, Naaranoja, and Zakeri 2012; Aslani et al. 2012a). If a private or public investor requires an early pay back on his/her money, the price level would considerably increase. Therefore, the governmental supporting systems play an important role to promote RE utilisation, particularly the electricity market, which is not a free market completely and different taxation, subsidies, and feed-in tariff have important roles on prices (Aslani et al. 2012b). Therefore, the Finnish government has introduced different support systems such as a feed-in tariff system that is being considered for onshore wind power investment subsidies on new investments (about 40% of investment for wind).

Due to technical abilities of Finnish wind power companies, small-scale wind projects, and restructuring related regulations to encourage investors are two diffusion drivers of wind power in Finland. Overall, to achieve the wind development targets, the country requires motivational solutions in back-up capacity, demand side flexibility, and market mechanisms for wind electricity.

3.4. ***Solar: achievements and potential improvements***

In 2009, solar photovoltaic modules produced 5 GWh and 7 GWh of electricity in Finland and Sweden mostly in universities and research centres (IEA 2009). In 2006, the collector area in operation was 16,493 m^2 (Solar Thermal Markets in Europe 2006). There are also good experiences for solar heating systems installed as extra source with oil-heated systems in the buildings (small scales).

The challenges to diffusion of solar energy utilisation are categorised in three terms: location, economic, and technical. Because of Finland's geographical location, the solar radiation is not noticeable compared with other countries even in Europe (Figure 6). In the latitudes that Finland is located (60°N and 70°N), the sun shining and day light are low particularly in winter (average daylight hours in winter season: 4 h). This provides big limitations for solar heating systems or solar power generation. Therefore, solar energy utilisation is less favourable than biomass and wind.

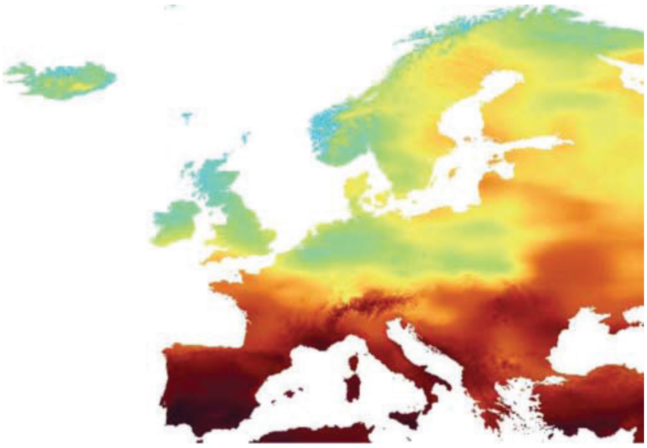

Figure 6. Solar radiation in Europe (Norden- Nordic Energy Research 2012).

On the other hand, solar energy utilisation with current technology is expensive and still needs innovations in the technologies to decrease costs and efficiency (economic). Quite apart from the expenses, there is also the problem of storing of produced energy (technical).

Due to increasing the exports of solar technologies in Finland, these issues would be considerable by research centres and companies to create the business value. The government also encourages solar thermal energy system in order to heating of domestic water supply. Although companies and public organisations may receive about 40% investment subsidies for solar heating, private houses do not receive subsidies yet. Thereby, development of solar energy is lagging behind due to a lack of governmental supports. Further, because summer cottages are an important part of Finnish culture (especially in June and July) as well as average daylight hours in summer (18 h), solar energy can play an important role to respond to the energy needs in the cottages. A feed-in tariff in solar energy for private households or small businesses can help in the diffusion of this alternative.

3.5. *Geothermal: achievements and potential improvements*

The classical forms of utilising geothermal energy (hot and dry rock or steam) are not economically feasible in Finland. Therefore, geothermal is restricted to utilisation of ground-heat with heat pumps. In Finland, heat pumps are mainly used for space and hot water heating in single-family houses from boreholes, surface sediments, lakes, and rivers. In 2008, the total number of installed ground-source heat pumps was approximately 46,000. About 7500 new heat pumps were just installed in 2008 with a 30% increase in growth (Kallio et al. 2011). There are aims to develop large-scale commercial projects such as office buildings, shopping, and logistics centres (Kallio et al. 2011). The target is to increase the net energy produced with heat pumps, regarded as RE, to five (TWH/Y) by 2020 (Renewable Energy in Finland 2009). However, industrial use of this technology is still small and need to be supported by Finnish energy policy makers.

The major barrier to increase using ground-heat systems is the price of heat pump systems. Although the running costs of ground-heat systems are much lower, the cost of installing a heat pump using ground-heat is about twice the price of installing systems based on oil or electricity. Therefore, investigations on technical issues of this system to decline the price is important to the promotion of this technology. On the other hand, knowledge and awareness about heat pumps are low among the general Finnish audience who should be considered by Finnish energy policy-makers (Kukkonen 2000).

4. Conclusion

To achieve diversity and energy security, the main goal of the Finnish government is to promote a higher share of RE alternatives in the total energy supply and consumption. Despite several done studies and projects by Finnish universities and research institutes related to development of RE alternatives, they are mostly documented as academic white papers or reports (Romo-Fernandeza, Guerrero-Botea, and Moya-Anegon 2012). On the other hand, most of the English published review papers (related to Finland) just focus on one renewable source, especially biomass (Helynen 2004). This article illustrated the history, potentials, and achievements of the major RE technologies in Finland. Economic and feasibility studies suggest the most likely candidates for RE development are biomass and wind power in Finland. Indeed, there are some special governmental supports for hydro, heat pumps, and solar too.

The article also suggested what would be the current barriers to development. Most of the barriers can be categorised in three groups: environment, cost, and policy. For instance, in the cases of hydropower and wind, environmental and resource consent issues are significant factors. However, the source has only little potential for development for hydropower. Due to the complexity of different RE resources, especially in Finland's geographic location and indistinct targets, the governmental supports are the key factors for development. Stability in governmental plans and programs related to utilisation from RE, and collaboration and joint investment with neighbours in renewable projects are two important subjects that the government and policy-makers should make note of.

The further studies can be carried out on the topics such as energy efficiency (from energy return on investment viewpoint) and profitability (production cost and economic) in Finland or other Nordic countries. Moreover, as we did not review the role and effects of nuclear power plants on diffusion of RE utilisation in Finland, investigations on the current and future of this technology along with alternative energy policies (conflict or parallel) is an attractive and important subject. It is also very important as the safety and desirability of nuclear power (and related) risks form an important part of the researcher's policy and decision-maker's debates.

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Renewable energy supply chain in Ostrobothnia region and Vaasa city: Innovative framework

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A B S T R A C T

Energy and environmental technology is one of the most important debates among citizens and the government of Finland. As development of renewable energy utilization depends on geographical situation, the policy and strategic decisions of renewable promotion should focus more on regionals studies. Ostrobothnia and its capital Vaasa are among the best regions with high potentials of new renewable energy resources including wind power, smart grids, biofuels, and geothermal energy in Finland. However, high penetration of renewable energies creates challenges from supply chain viewpoint including environmental grid operators and maintain reliable service. This article discusses the development and performance of renewables supply chain in Ostrobothnia region and Vaasa city. The presented framework provides managerial insights to policy makers of governments and municipalities, as well as researchers and other stockholders to consider different aspects of diffusion of renewable energy technologies in the regional levels. The contributions are also beneficial for further studies related to renewable energy development, sources, carriers, and services.

Contents

1. Introduction

Although carbon-based fuels are the main source of power generation in the world, they are losing their advantages because of their limitations and environmental and economic concerns [1]. In response, utilization of domestic and local natural resources plays an important role among the various replacement strategies.

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Studies show that Finland stands among the countries with highest contribution of renewable energy resources (RER) in primary energy supply [2]. The country is also an early adopter of several alternative energy technologies especially biomass, wind, and hydropower. The main policy of the Finnish energy and climate sectors is to increase energy security by exploitation of renewable energy (RE) while reducing CO2 emissions.

As development of RE utilization depends on geographical potentials, policies and strategic investigations on RE promotion should focus more on regionals and locations level. In other words, regions with good potential of human and technological resources are in priority for RE development and investment. This is important especially in the countries with high authority of municipalities like Finland. Due to the focus of Finnish government to new RERs including wind, solar, and geothermal, investigations show that Ostrobothnia and its capital Vaasa are among the high potential regions for RE portfolio utilization [18].

This article reviews the supply chain of RE utilization in the Ostrobothnia region and Vaasa to identify the flow of RE promotion. The east cost of Bothnia gulf (Ostrobothnia) is one of the high potential locations for wind power generation in Finland. Vaasa is also one of the sunniest cities in Finland and the Nordic countries. On the other hand, largest Finnish energy technology companies that are also among the world's leaders are located in Vaasa (e.g., WARTSILA, ABB, SWITCH, and VACON). As technological development is a key diffusion driver of RE utilization, companies located in this region help to speed RE adoption plans and research. Indeed, Ostrobothnia and Vaasa have a large amount of university students compared to population (in the fields of energy technology and business) and the research facilities focus on increasing efficiency of the entire energy chain as well as promotion of RE utilization in the regional level. As research scholars create the first stage of a robust regional RE development, the number of research institutes related to this technology is an important factor for RE promotion [3,11].

Above issues show that successful investigations on diffusion of RE utilization in the regional level should concentrate on the supply chains of RE development. Therefore, our article is organized as follows: Section 2 gives a brief review of the Ostrobothnia region and Vaasa city. Section 3 reviews the important energy indicators in Finland and discusses role of RE in the Finnish policies and governmental supports schemes. Section 4 presents the innovative research framework to show domains and approaches of the RE supply chain in the regional level. Finally, Section 5 and related sub-sections consider RE supply chain in the Ostrobothnia region and Vaasa city from dimensions introduced in the Section 4.

2. Brief review of Ostrobothnia region and Vaasa city

Ostrobothnia (in Finnish: Pohjanmaan maakunta) is a region located in the West of Finland. The region is 2.35% of the Finland's area and has 3.31% of the Finland's population [4]. There are 16 municipalities in the region that Vaasa is the biggest and its capital with more than 34% of regions population. Compared to population and area, Vaasa is one of the most industrial and well-developed cities in Finland. Economic of Ostrobothnia is highly depending on its industrial products, in which about 70% of produced products are exported. This is more than 30% of Finland's energy technology exports [5]. Vaasa also consumes about 40% of the energy demand in Ostrobothnia. More than 150 companies are working in Ostrobothnia and Vaasa in the fields of energy and RE technologies. More than 10,000 staff are also working in the energy sector in Vaasa (companies and services) that compared to population (57,000) is one of the top regions in the world. The plan is to increase staff to 20,000 in 2020 with development of energy companies and RE utilization. This facilitates the development of RE utilization and speed RE and smart energy development projects. In addition, Vaasa has more than 12,000 university students and two of the three Finnish companies with the highest levels of R&D investment are working in Vaasa (WARTSILA and ABB).

3. Energy indicators and role of renewable energy resources in the security of energy supply in Finland

The industry sector consumes more than half of the primary energy in Finland. As this country is highly dependent to the external fossil fuels, risks appear arising from continuous fluctuations in energy prices as well as permanent increase in other costs such as transportation [6]. Although there are several solutions to

Table 1
Some policies and support schemes of RE promotion in Finland [14].

Support schemes
Investment supports
Developing storage capacity
R&D supports related to RE technologies and energy efficiency
Tax incentives for electricity generation from RERS
Feed-in-tariffs
Taxation of fossil fuels

Fig. 1. Location of Ostrobothnia and Vaasa in Finland.

respond to the challenges, diffusion of RE utilization is one of the main policies of the Finnish government.

As of 2011, about 31% of the global final energy consumption came from renewables in Finland [7]. The most important energy resources are nuclear power, hydropower, coal, natural gas, and biomass fuels (e.g., wood and peat) [8]. Although new RERs including wind, solar, and geothermal have small shares but some such as wind power and heating with geoenergy (geothermal energy) are rapidly growing. The country is also a part of common Nordic electricity market and Nord pool spot (largest electricity market in the world) [9]. Based on the Nord pool spot, electricity is traded in two markets: Elspot (day-ahead market) and Elbas (intraday market). Approximately 120 companies with more than 400 power plants are generating electricity that about 205 of them (power plants) are hydropower plants [2]. The government's target is to increase the share of RERs utilization especially wind power. To achieve the target, different policies and support schemes have been provided (Table 1) [14].

A study describes different layers of RE development in Finland and the Nordic countries (Figs. 1 and 2) [20]. These layers create a portfolio of political, technological, managerial, social, and cultural issues. Table 2 summarized the identified layers and their related schemes.

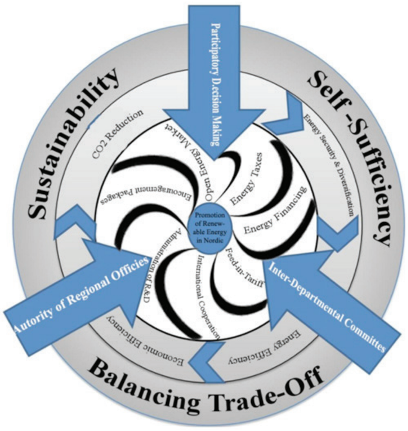

Fig. 2. Layers of RE development in the Nordic countries and Finland [20].

4. Renewable energy supply chain in Ostrobothnia and Vaasa: framework

Supply chain is all those activities and processes from exploitation of raw materials until the end use of products by consumers to provide a service/product for end-user. In general, supply chain consists of suppliers, producers, distributers, logistic service providers, retailers, and end-users [10]. Typical elements of supply chain include physical, information, and financial flows [3]. Due to the dominant business models in the Finnish RE industry, the framework of RE supply chain in Ostrobothnia and Vaasa is conceptualized as Fig. 3. This framework helps researchers and policy makers to identify and reduce the risks inherent in development process of RE utilization. According to figure, RE supply chain is characterized from two sides: domains and approaches. The domains cover the process of RE chain from resources to end-users. They create opportunities for business activities and are introduced in five main domains (Figs. 3 and 4).

The approaches of RE supply chain show different aspects of RE supply chain process from engineering, social, and management science. They cover all necessary elements of supply chain management. The first approach, policies and strategies, takes into account the role of municipalities and government on diffusion of RE in the region. Creating a development road map for each domain of RE chain and introducing supportive schemes (e.g., subsidies and taxes) are two subjects that are discussed in this approach.

Table 2
Different layers of strategic analysis of diffusion of renewable energy in Finland and the Nordic countries.

Layer	Description	Sub-layer	Aim
Dimensions	To show the purposes of diffusion of RE utilization	Self-sufficiency	To reduce consumption of fossil fuels and increase the dependency of indigenous resources
		Balancing trade-off	To help to economic and technologic growth of the regions
		Sustainability	To reduce pollution and environmental impacts
Characters	To identify main stakeholders affect public policies and process of decision-making	Participatory decision-making	To have the supports of the community organizations and citizens
		Inter-departmental committees	To have a comprehensive and coordinative decision making
		Authority of regional offices	To increase the role of regional s (municipalities) in decision-making
Objectives	To show different perspectives of diffusion of RE	Energy security and diversification	To reduce the dependency to the external resources(energy imports)
		Energy efficiency	To produce specific amount of services using less energy
		Economic efficiency	– Technical efficiency – Allocative efficiency
		CO2 reduction	To minimize CO2 emissions from fossil fuel burning caused by human activities
Key schemes	To describe different policies or regulations related to diffusion of RERs utilization	Energy financing	To direct government investment on the RE technologies and efficiency solutions
		Energy taxes	To curb the growth of energy consumption
		Open energy market	To make RE utilization competitive
		Encouragement packages and green certificates	To improve the knowledge and awareness of the citizens about RERs
		Administration of research	To manage research and R&D funds
		International cooperation	To share and crate the knowledge
		Feed-in-tariff	To accelerate investment in RE utilization

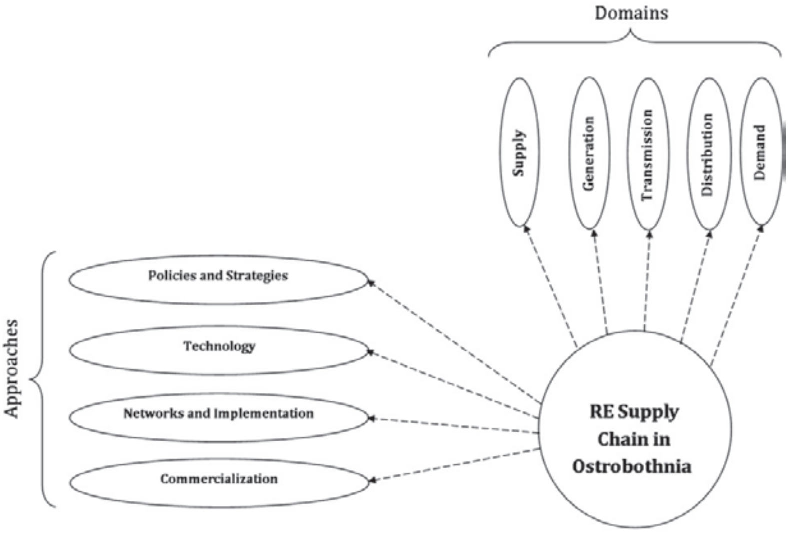

Fig.3. Framework of RE supply chain in Ostrobothnia and Vaasa.

Fig. 4. Domains of RE supply chain.

The approach “Technology” examines the ways to provide a successful use of RERs in the region. Evaluation and analysis of region's potentials in each domain from technological and infrastructure viewpoints are the focuses of this approach. “Networks and implementation” presents, analyzes, and designs high efficient performance of RE domains. Creating better value for customers and shareholders in each RE domains, quality of RE services, joint investments, and knowledge sharing with other regions are examples of this approach. Finally, “commercialization” includes the economic and investment issues of RE development in the region. Studies show that RE market is complex. In other words, while free market is encouraged in Finland, the government intervention or incentives should support new technologies and businesses in this market. To keep the research integration and due to the pages limitation, the approaches of RE supply chain are considered into each domain.

5. Domains and related approaches of renewable energy supply chain in Ostrobothnia and Vaasa

The process of renewable energy supply chain includes five main domains showed in Fig. 4.

5.1. RE supply in Ostrobothnia

The first chain, supply, includes resources that can be utilized in Ostrobothnia. The previous studies of authors show that factors related to feasibility affect RERs utilization (e.g., availability, annual exploitability, technologic and usage limits) [19,15]. Further, factors such as logistic possibilities and competition of a RER with other RERs limit use of a RER. In Finland, the main RE source is biomass and has a particular place in the energy policies. It made up about 86% of total RERs and 21.5% of total primary energy supply in 2009 [2]. While energy demand (heat and electricity) in Ostrobthnia was 4322 GWh/a, about 63% was supplied by RERs in 2006 [18]. Table 3 shows energy demand (heat and electricity) and share of RERs in Ostorobthnia and Vaasa in 2006 [18].

Table 3
Energy demand and share of RERs in Ostrobthnia and Vaasa [18].

Region	Energy demand(GWh/a)	Share of RERs (%)
Vaasa	1669	54
Ostrobthnia without Vaasa	2653	70
Total Ostrobothnia	4322	63

Most of the biomass resources (forest biomass) in Finland are distributed in 15 areas in Finland. Although the potential of biomass in the west coast is not rich as the center and east, biomass has a dominant share in energy demand in Ostrobothnia and Vaasa. However, biomass sources are not limited to forest biomass and utilizing biodegradable waste for electricity generation or heating production is also one of the potentials in Ostorobthnia. A new power plant that is being built in Mustasaari (in Ostrobothnia neighbor of Vaasa) is one of the last activities to convert waste into energy in the region. It starts officially to burn waste at the beginning of 2013.

The biggest bioenergy potential in Ostrobothnia region is about 1200 GWh in wood and 1000 GWh in straw [18]. About 500 GWh is the potential of wastes like manure, biowaste, sludge and other industrial wastes. Therefore, while biomass has about 2700 GWh energy potential in Ostrobothnia, energy demand is about 3000 GWh (without forest industry) [18]. This means with 90% energy conversion efficiency, about 80% theoretical self-support on this region can come by bioenergy.

The second important RE source in Ostrobothnia is wind power. Due to the coastline, wind energy has important role in power generation plans in Ostrobothnia and Vaasa by 2020(Fig. 5) [12,16]. Wind power not only is the fast growing source among other RERs, but also most Finnish wind companies are located in this region and Vaasa. Until 10.2012, the capacity of 146 wind turbines was

238 MW that shows a growth of 10% in the capacity in just six months [17]. The Finland's objective is to increase the installed wind turbines to approximately 2000 MW by 2020 [2]. The current capacity of wind power in Ostrobothnia is about 8.75 MW [17].

Although about 205 hydropower plants work in Finland and have a share of 15% in total primary energy supply, the hydropower has not commercial potential in Ostrobothnia because of outstretched situation. As most of the Hydropower possibilities have been already used (just in small scales), this source has little potential for development in Finland.

From solar energy supply, Ostrobothnia is one of the sunniest cities in Finland with more than 1900 sunny hours/year [2]. Based on geographical condition, Ostrobothnia is the best place for solar energy utilization in Finland and even in the Nordic countries especially in the summer months (June until August) that the daylight is more than 20 h. Specifically, as summer cottage is an important part of Finnish culture (especially in June and July) solar energy can play an important role to respond the energy needs in the cottages [2]. However, the potential of solar energy in the Nordic region cannot compare with south and even center of Europe.

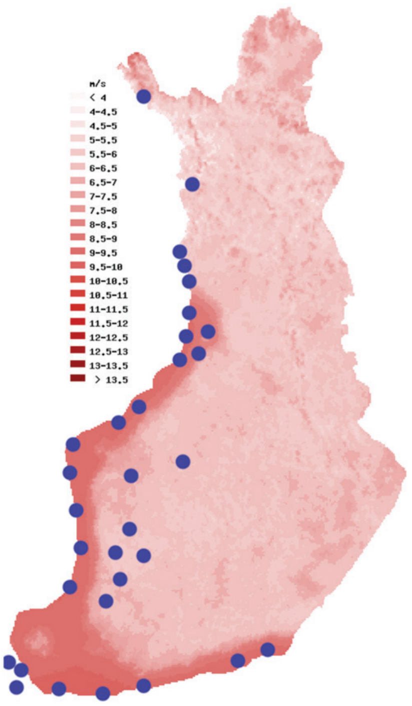

Fig. 5. Potential of Wind power and wind turbine sites in 6.2012[16] [17].

Finally, geothermal energy and heat pumps have good utilization potential especially for space heating and cooling, and hot water heating in single-family houses. The sources of this energy are boreholes, surface sediments in Bothnia gulf and lakes. In a larger scale, a low energy network was taken to utilize sediments of the seabed to produce heat in the Suvilahti residential area in Vaasa in 2008. This energy network is one of the first such used technologies in Finland to take off.

5.2. RE generation in Ostrobothnia

The second domain of RE chain is generation that is sometimes called production. Factors such as location, investments costs, operation costs, conversion efficiency, technology limits, and manpower are the effective issues in this domain and its related approaches. As discussed in 5.1., wind and biomass are two sources with high potentials for development in Ostrobothnia. Figs. 6,7, and 8 illustrate the simple process of energy generation/production for each named RER. The first part of these figures shows details of RERs in Ostrobothnia and Vaasa. The second part indicates the conversion process or primary outcomes. The last part of the process also illustrates the outcomes that are valuable from market and demand side. The demand side includes residential and commercial sector, industrial sector, transportation sector, and electric power sector.

There are a lot of energy manufacturers or engineering-service companies located in Ostrobothnia and Vaasa especially in wind power technology. More than 150 companies related to RE industry are working in Ostrobothnia and some such as ABB, SWITCH, CITEC, and WARTSILA are among the world's leaders.

5.3. RE transmission and distribution in Ostrobothnia

Electric power transmission establishes an important part of RE supply chain in Ostrobothnia. It covers the transport of electric energy generating power plants to loads that interconnects

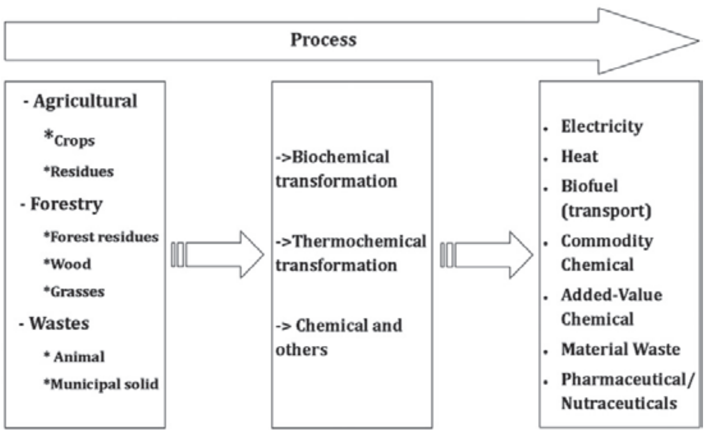

Fig. 6. Simple process of Biomass conversion technology.

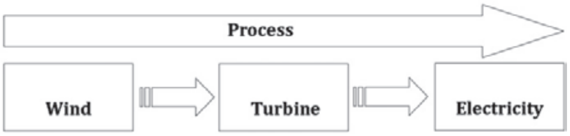

Fig.7. Simple process of wind power generation flow.

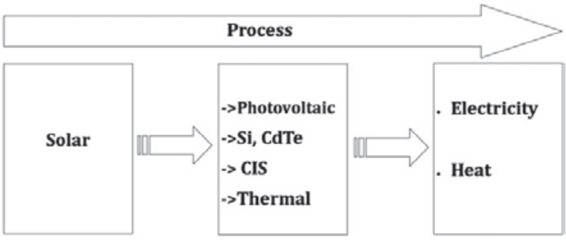

Fig. 8. Simple process of solar energy generation.

generators and loads and provides multiple paths among them. Electricity applications in Finland are not limited for lighting, refrigeration, washing and drying, and miscellaneous electric loads. Electricity is the main source of family heating and cooking systems too. Energy distribution also refers to different power generating or transmission technologies that could be combined with load and storage systems to improve the quality of electricity supply chain [13]. It encompasses variety of technologies, including RE distribution, such as wind turbines, solar power, micro turbines, fuel cells, load reduction technologies, reciprocating engines, and battery storage systems.

RE distribution has an important role in energy supply chain especially in the future plans of Finland. Improving energy security, reducing the fluctuations of electricity price, mitigating congestion in transmission lines, and providing greater stability in the electricity grids are examples of an efficient RE distribution system. RE transmission and distribution in Ostrobothnia are currently linked with traditional energy networks to support regional power needs. Since a significant share of generated electricity by power plants is lost before to reach to end-users, the Finnish government has supported related research projects and technologies to improve the efficiency of electricity networks (e.g., low-loss transmission technologies, controlling the systems of distribution, and reliable systems in the regions).

RE distribution can be as a complex system integrated with the electricity grid (including electricity/thermal generation, storage, and energy management) or a small or stand-alone generator to provide backup power at an electricity demand side. The small-scale generation (on-site power generators) can be owned by end users (consumers), the utility, or a third party. The energy distribution network in Finland and Ostrobothnia is turning into market place for decentralized energy production. Indeed, due to the importance of CHP (combined heating, and power) plants in the energy system in Ostrobothnia (and Finland), lean distribution technologies affect efficiency and energy costs of CHP applications.

As RE coupling with other distribution networks is a challenging process especially to balance the demand fluctuation within a period of time or to balance the intermittent or variability of RE resources, some projects like smart grids have been introduced to improve the efficiency of the networks in Ostrobothnia. The Smart grids project covers all aspects from energy production, transmission, and distribution to energy efficient building automation. It is also improving the maneuverability of power generation to the rapid response to demand even beyond the Ostrobothnia's boundaries. In this way, role of energy technology companies working in the region is completely significant to support and speed development plans. An example is ABB that supports technologies of remote monitoring and control, and automatic connections in the smart grids project in Ostrobothnia.

5.4. RE demand in Ostrobothnia

Energy demand is the amount of energy should be managed in different appliances within industries, transport, housing, etc. RE demand in Ostrobothnia have two major markets: electricity and heating (Table 3). Consumption market in Ostrobothnia is highly influenced by the economy situation and the weather. In good economic years and in colder winters electricity or heating demand is higher.

The electricity utilized from RE are distributed by service providers or retailers to the end users. There are two different electricity sales contracts in Ostrobothnia: green electricity and normal electricity (nuclear or other resources) that customers can select and. Despite all governmental supports (subsides and taxation), the electricity generated by RERs (green electricity) is still more expensive compared to normal electricity. Local energy companies are responsible for retail selling of electricity and some of them like Vaasan Sahko Oy have customers from locations outside of Ostrobothnia and Vaasa. As discussed in 5.3, small-scale renewable heating and cooling systems have been recently considered as new markets. The size of these systems ranges a few kilowatts to1 MW. Therefore, end-users can utilize RERs for their domestic usages such as heat pumps etc. As Fig. 9 illustrates, the demand side is not limited to the end-users. It covers other aspects of supply and includes a portfolio of products and services. Costs, government policies, substitution effect, and social and environment impacts are the most important concerns that exist from demand side of RE supply chain [3,10]. For instance, customer's willingness to buy a RE product or a service with lower price is an important issue that specially show itself in the competitive situations such as economic crisis and auctions. As geothermal, wind, and solar technologies are not mature in Finland, further cost reductions can be expected with technology development.

6. Discussion and conclusion

Utilization of RERs creates challenges in different areas from exploration to managing networks and demand side. One of the important but new disciplines in diffusion and adoption of RE

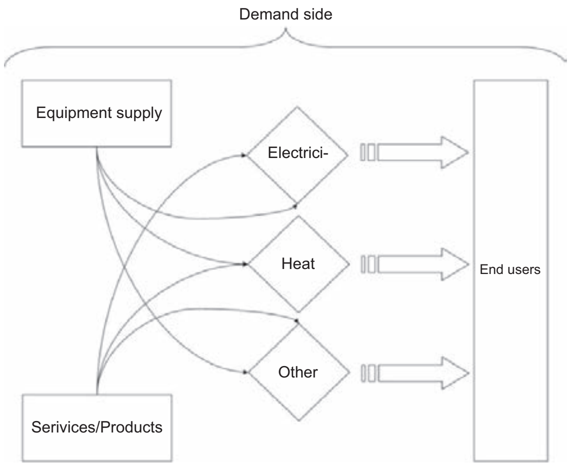

Fig. 9. Demand side of RE supply chain in Ostrobothnia and Vaasa.

utilization is RE supply chain. This study discussed RE utilization from supply chain viewpoint in Ostrobothnia and Vaasa. The work also showed how different domains and approaches help policy-makers to promote RE technologies in the regional or provincial scale. Given especial focus of Finnish government in new RERs including wind, solar, and geothermal, Ostrobothnia and Vaasa are good alternatives for RE investments in Finland.

Despite the successes, there are still shortages in the plans, process, and achievements of RE development in well-developed regions such as our case study. For instance, the necessity and role of local energy research centers and institutes in regional RE development is very important and they should have authority to manage and lead RE research and projects (from both commercial and technological aspects). On the other hand, new methods and technologies of RE utilization should be more considered in the policies of energy development. As an example, while 50% of wastes are utilized as energy in Sweden, about 10% are utilized in Finland. It seems Finland and Ostrobothnia need more attention to such development policies. In case biodegradable waste, since Ostrobothnia is one of the high developed and rich regions from social and economic indicators, the consumption and thereby amount of waste is high. Thereby, development of private waste power plants should be considered in the development policies of municipalities. Indeed, as geothermal energy has good potential in heating and cooling of large buildings (e.g., block of flats, schools, and libraries), polices should considered more to commercial aspects of this source.

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