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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

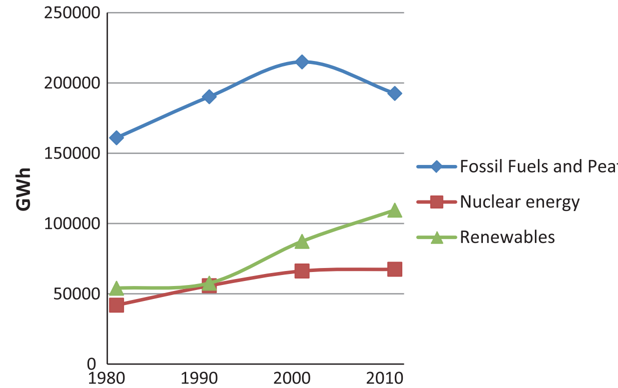

Fig. 1. Primary energy consumption in Finland by three main sources.

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

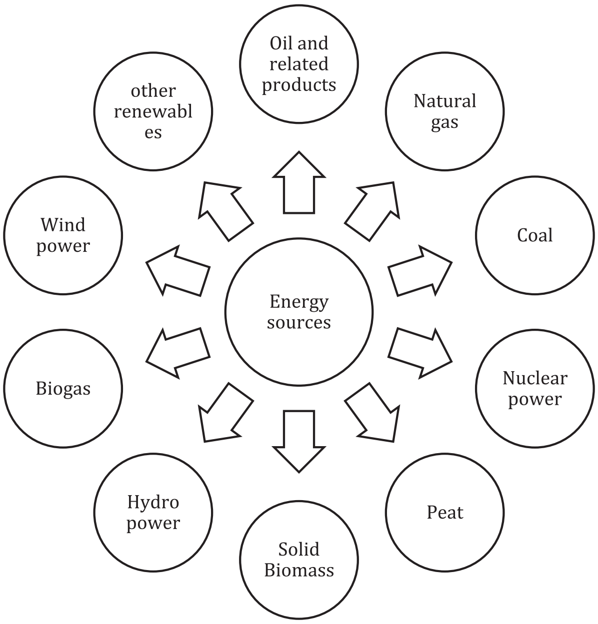

Fig. 2. Energy sources for energy consumption and electricity generation in Finland in 2012.

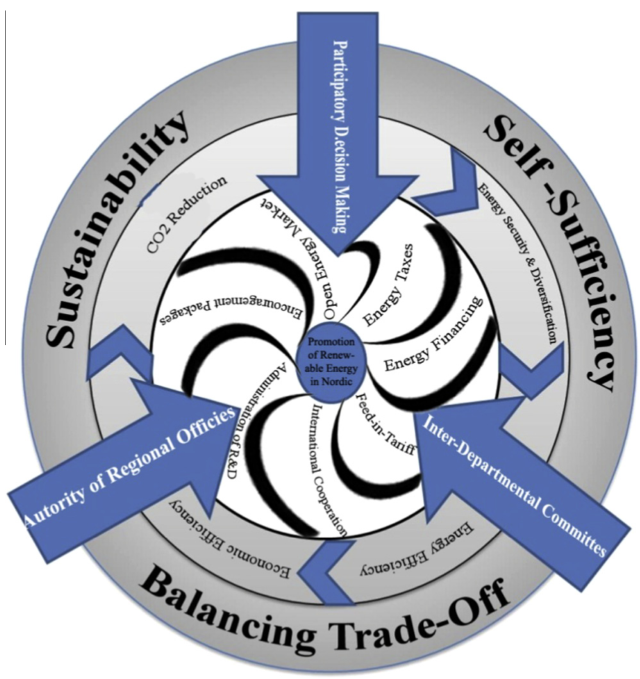

Fig. 3. Layers of RE development in Finland [14].

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

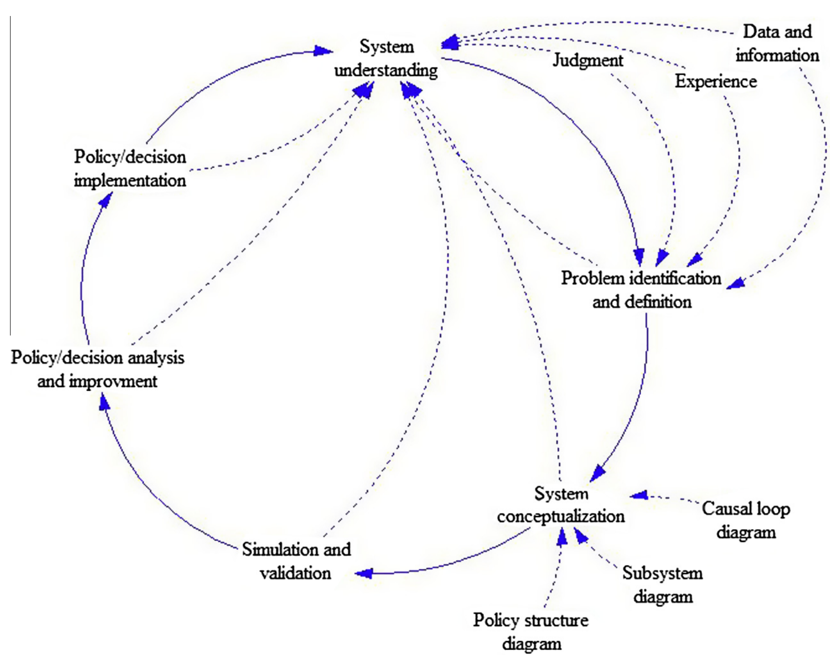

Fig. 4. System dynamics methodology.

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),

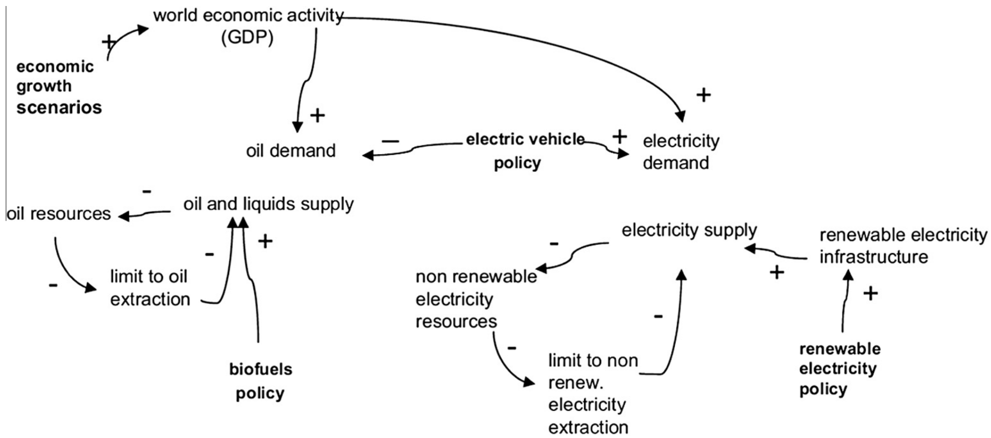

Fig. 5. Example of causal loop diagram defined in a research to assess the situation of renewable resources [31].

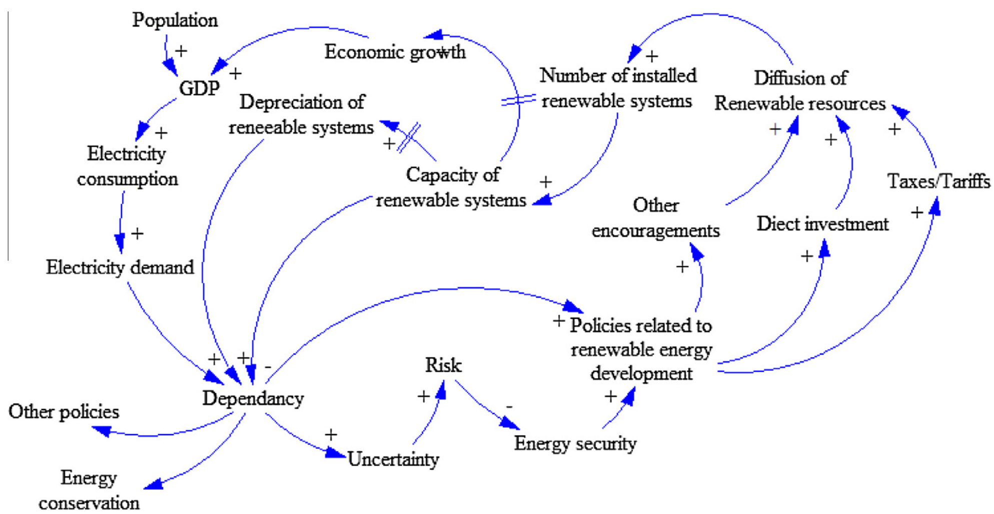

Fig. 6. Feedback structure of role of renewable energy in energy dependency and security in Finland.

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

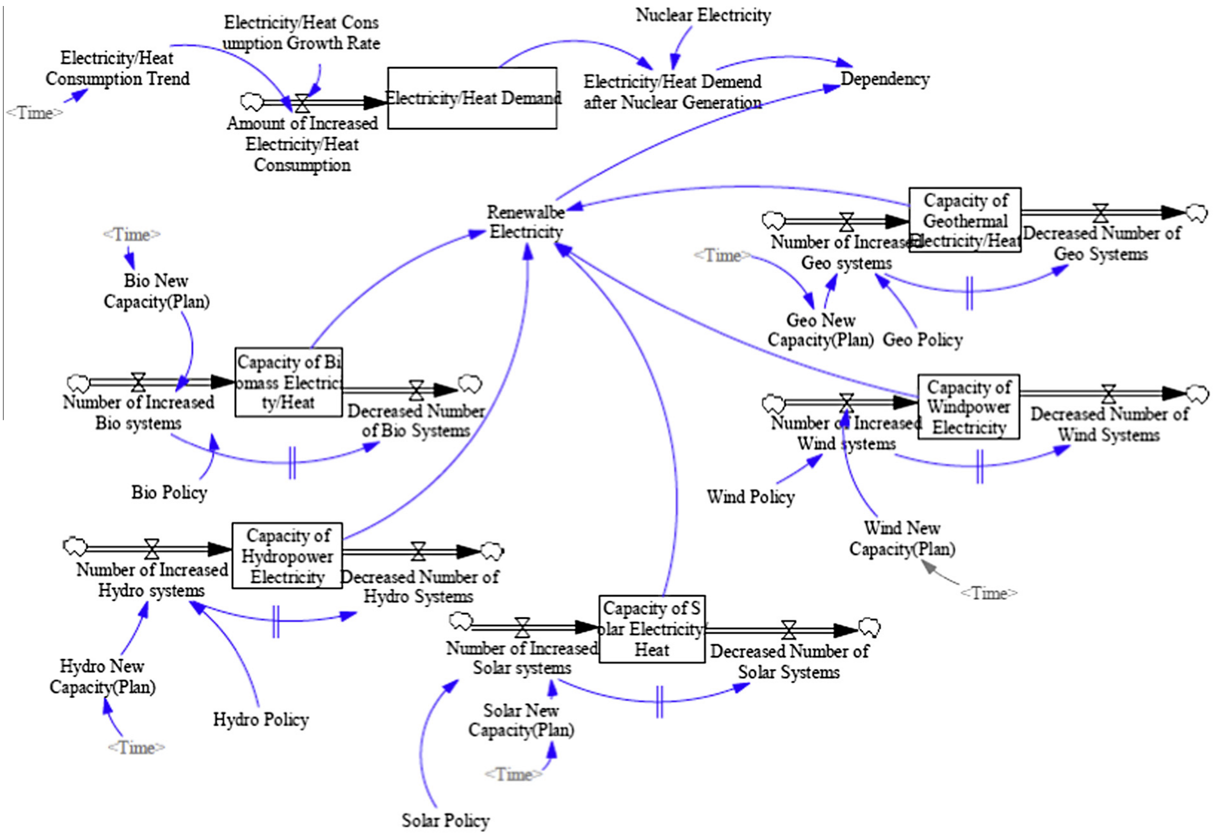

Fig. 7. The system dynamics model of renewable application policies in Finland.

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:

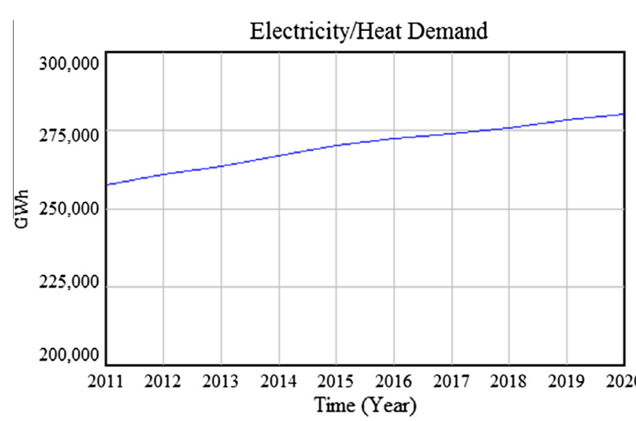

Fig. 8. Electricity/heat consumption demand in Finland.

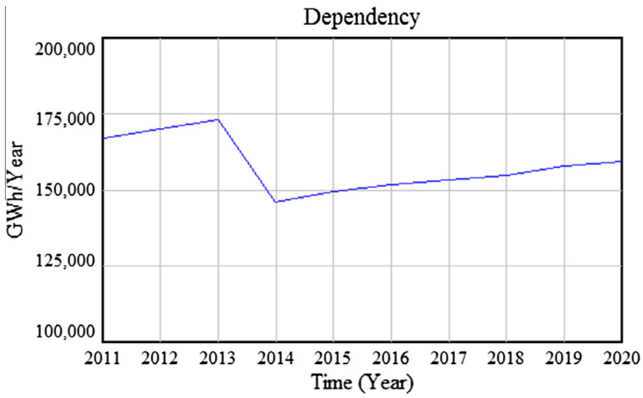

Fig. 9. Dependency based on the first scenario.

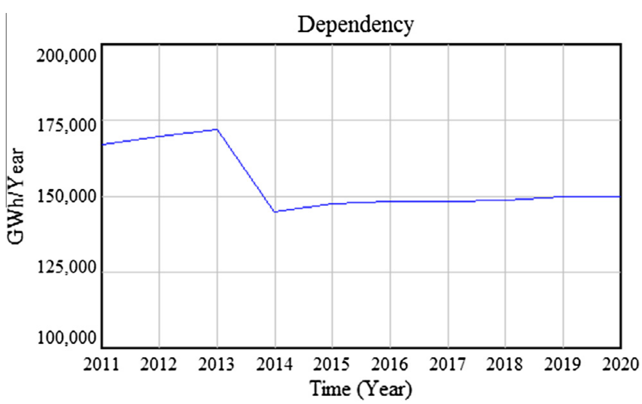

Fig. 10. Dependency based on the second scenario.

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

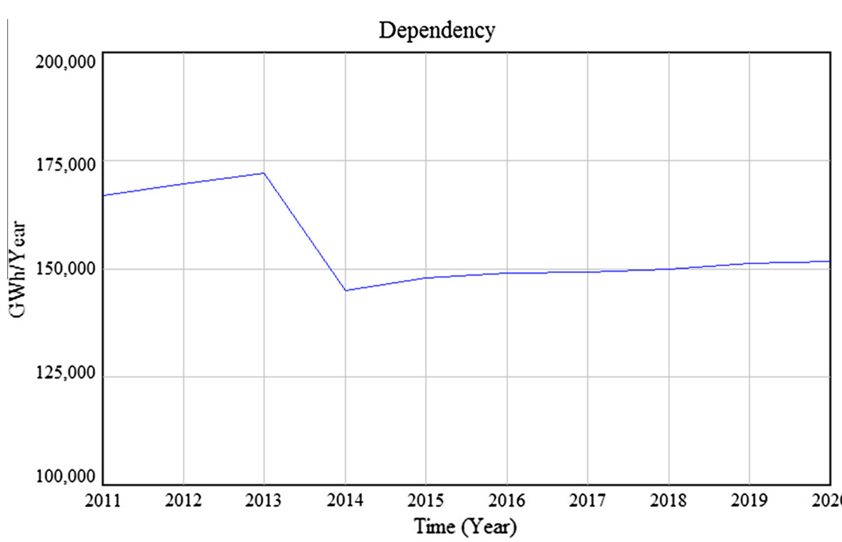

Fig. 11. Dependency based on the third scenario.

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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