Applied Energy 113 (2014) 758–765

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

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

Alireza Aslani [a,b,*], Petri Helo [a], Marja Naaranoja [a]

[a] Industrial Management Department, Faculty of Technology, University of Vaasa, Vaasa 65101, Finland
[b] Department of Engineering and Public Policy, College of Engineering, Carnegie Mellon University, 5000 Forbes Ave., Pittsburgh, PA 15213, USA

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.

ARTICLE INFO

Article history:
Received 29 March 2013
Received in revised form 3 July 2013
Accepted 6 August 2013

Keywords:
Renewable energy resources
Dependency
Finland
System dynamics

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

* Corresponding author at: Industrial Management Department, Faculty of Technology, University of Vaasa, Vaasa 65101, Finland. Tel./fax: +358 44 255 0010.
E-mail address: alireza.aslani@uva.fi (A. Aslani).

0306-2619/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apenergy.2013.08.015

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

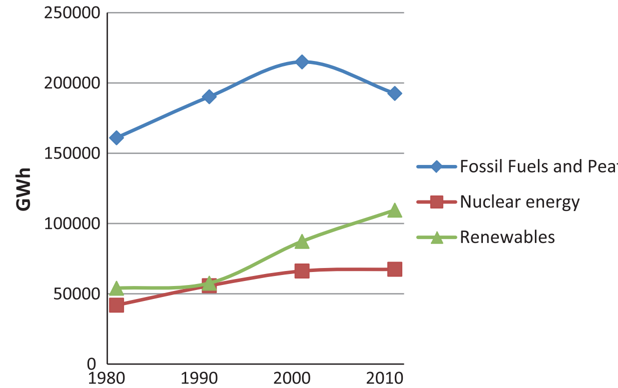

Fig. 1. Primary energy consumption in Finland by three main sources.

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