Energy Policy 116 (2018) 323–336

Contents lists available at ScienceDirect

Energy Policy

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

Effect of major policy disruptions in energy system transition: Case Finland

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ARTICLE INFO

Keywords:
Energy system modelling
Finland
Power-to-X
Renewable energy
Scenarios

ABSTRACT

Finland has ambitious climate targets and intends to ban the use of coal and halve the oil use by 2030, mainly based on traditional forest biomass and nuclear power. These policy choices, however, encompass sizeable risks for a low-carbon energy transition. Here we investigate alternative pathways for disruptive risks from such policies based on massive introduction on variable renewable electricity (VRE) with intersectoral coupling through Power-to-X technologies (P2X), also considering future demand uncertainties. We analyzed several risk-involving scenarios for years 2030 and 2050 using a national energy system model with 1-h resolution, which includes power, heat and fuel sectors. The results indicate that even in case of worst-case energy policy risks with nuclear and bioenergy, a feasible energy system solution can be found. Renewable energy resources were employed to their maximum potential levels with P2X flexibility options, especially Power-to-Heat. However, without energy efficiency measures, the present renewable energy resource base was not able to compensate for all primary energy fall-out, which would lead to higher system costs and CO_2 emissions. This implies that in case of high dominance of a few energy sources, an alternative pathway may require strong energy efficiency measures and developing further the renewable energy resource base.

1. Introduction

National energy systems are under ever-increasing political pressure to meet the stricter climate mitigation targets. The Paris Climate Accord from December 2015 (COP21) calls for governments to limit global warming well below 2 °C from the pre-industrial time (IEA, 2015a). The European Union plans to cut greenhouse gas emissions by 80–95% by 2050 (European Commission, 2012). To meet these climate targets there are several decarbonization options such as renewable energy, nuclear power, and energy efficiency. Each of these options have their strengths and weaknesses such as economical risks (deLlano-Paz and Martínez Fernandez, 2016), negative environmental impacts (Sokka et al., 2016), and risk of accidents (Sovacool et al., 2016).

Overall, major mitigation strategies reported involve similar technology options. The IEA 2 °C Scenario (2DS) (IEA, 2015b) relies much on energy-efficiency improvements, biomass, wind, and nuclear power, but also on carbon capture and storage (CCS). The EU Energy Roadmap 2050 (European Commission, 2012) presents similar options, but with a stronger emphasis on CCS. In the Nordic region, biomass, hydro power, wind power, and transport fuel transition are envisioned as key pillars for future CO_2 mitigation (IEA and Nordic Energy Research, 2016). Very seldom we find that such official scenarios consider the risks of losing one or several crucial mitigation options, or alternative paths in such a case. For example, some EU decarbonization scenarios rely on technologies still under demonstration or with low Technology Readiness Level (European Commission, 2011; Salokoski, 2017). Similarly the feasibility of CCS in long-term CO_2 mitigation strategies has been criticized (Lund and Mathiesen, 2012) and even the ambitious Nordic countries will face challenges in technology contingency, especially with CCS (Sovacool, 2017).

The risks and uncertainties related to the mitigation options can broadly be divided into four categories: technological, economic, environmental, and political. These are typically analyzed with scenario-based assessment methods. Literature in this field is ample. For example Jewell et al. (2014) and Gracceva and Zeniewski (2014) analyzed the energy security dimensions of low-carbon scenarios with techno-political risks such as nuclear phase-out and limitations with renewable energy. Spiecker and Weber (2014) used different political scenarios to analyze risks related to the transition of the European electricity sector until 2050. Knopf et al. (2015) assessed the impacts of various technological and institutional options on the European electricity sector in 2030 and especially on the renewable target. Fragkos et al. (2017) found out that the degree of electrification of final energy demand could play a critical role in a low-carbon transition in EU. This kind of

Abbreviations: CHP, Combined heat and power; CHP-DH, CHP in district heating; CHP-ind, Industrial CHP; O&M, Operation and maintenance; NPP, Nuclear Power Plant; P2G, Power-to-gas; P2H, Power-to-heat; P2X, Power-to-X; RES, Renewable energy sources; VRE, Variable renewable energy; V2G, Vehicle-to-grid

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https://doi.org/10.1016/j.enpol.2018.02.028
Received 26 June 2017; Received in revised form 14 February 2018; Accepted 15 February 2018

electrification could be enabled e.g. by Power-to-X (P2X) conversion of excess electricity (Lund et al., 2015). The studies above especially consider the risks related to CCS availability and nuclear power acceptance, but also introduce large amounts of emerging energy technologies such as offshore wind power and photovoltaics, which also cause risks in the mitigation strategies.

By definition, new and disruptive technologies carry a larger economic and technological risk than incumbent established technologies. Many scenarios, however, do not even consider such incumbent low-carbon technology pathways, or they overlook the risks associated with these options, which may be notable, but of different type and often not easy to quantify (e.g. political risks). An important question, if risks with incumbent low-carbon policies materialized, is the effects on the energy system and policies. What kind of alternative paths could work in such a case? In this paper we examine along these lines the Finnish energy policy case, whose exceptionally strong focus on nuclear power and bioenergy provide a highly relevant case for the analysis. A lower degree of diversification would also increase the overall risks (deLlano-Paz and Martínez Fernandez, 2016), also applicable to our Finnish case. Finland has very ambitious policy targets by 2030, stating halving of oil use and abandoning the use of coal.

This paper is organized as follows. Section 2 discusses the background of the case study. Section 3 describes the modelling methodology, the scenarios used in this study, and the input data. The results are presented and discussed in Sections 4 and 5, followed by conclusions and policy implications in Section 6.

2. The Finnish energy system and its policy risks

We first present the energy system and policy baseline for Finland.

Finland is situated in the northern part of the EU, characterized by a cold climate and very energy-intensive industry, representing half of all primary energy and electricity use. Fig. 1 shows the primary energy sources in Finland and in the EU. Finland differs from most of the EU through a much lower natural gas share, but a much higher utilization of renewable energy. The share of renewable energy in Finland is high, 39% of gross final energy consumption (2014), while the EU 2020 target for Finland is 38% (Statistics Finland, 2017). The main renewable energy source is wood-based biomass, explained by the huge forestry resource – actually Finland is the most forested country in Europe (IEA, 2013a). In electricity, nuclear (27%) and combined heat and power (26%) dominate, followed by hydro power (16%) and imported electricity (22%). On the energy consumption side (2014), 45% of energy goes to industry, of which over one half to forest industry alone, 26% to space heating, and 17% to transport.

The key elements of the Finnish energy strategies are to increase self-sufficiency while taking into account climate objectives and to ensure the competitiveness of Finnish industries (Finnish Ministry of Employment and the Economy, 2014). Due to lack of domestic fossil fuel resources, almost 70% of the primary energy is imported, which poses a risk for energy security. A key pillar in the energy policy is therefore domestic forest-based bioenergy, as well as nuclear power. Finland's decision to back traditional low-carbon energy may be characterized as a conservative energy transition, and may provide one solution to climate change mitigation, though short-term and not fully risk-free (Lund, 2017).

The current government policy on climate and energy from November 2016 (Prime Minister's office, 2015) has very ambitious goals by 2030:

- Share of renewable energy in final consumption to be increased to 50%;
- Self-sufficiency of final consumption to be increased to 55%;
- Share of renewable transport fuels to be raised to 40%;
- Coal will no longer be used in energy production;
- Use of imported oil for the domestic needs will be cut by half.

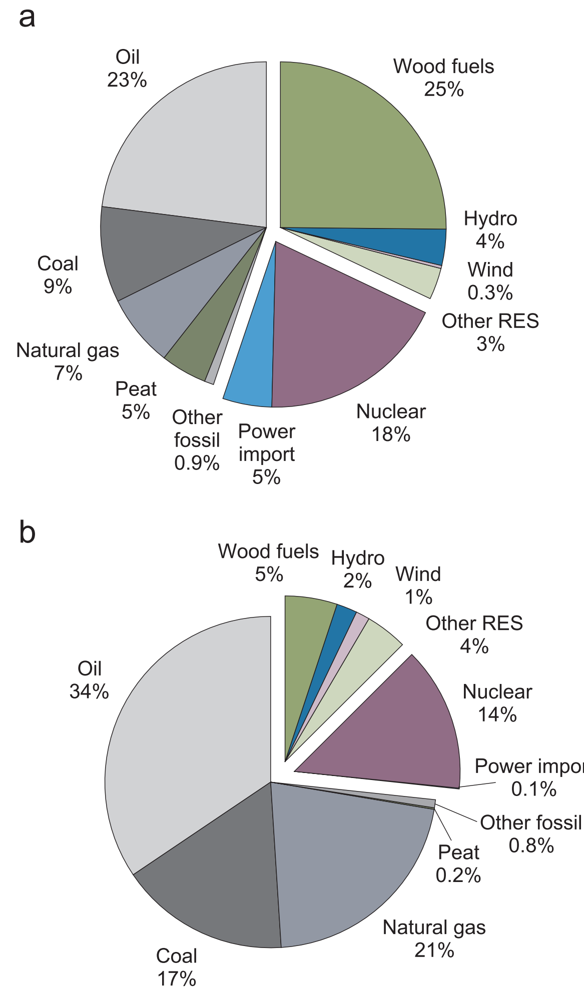

Fig. 1. **(a)** Primary energy consumption in Finland in 2014. **(b)** Primary energy consumption in EU28 in 2014. Source of data: Eurostat, 2017; Statistics Finland, 2017.

Furthermore, Finland follows the EU goals to decrease the greenhouse gas emissions by 40% by 2030 and 80–95% by 2050, compared to 1990 levels. It should be noted that the 2030 goals are reported for final energy consumption, and these shares are calculated according to the EU Renewable Energy Directive 2009/28/EC (European Parliament and the Council, 2009). In these calculations, hydro, wind and solar power, heat pumps, and biomass are considered renewable, whereas self-sufficiency includes all renewables, peat, and non-renewable waste. Nuclear power is not included in the self-sufficiency.

The rapid coal phase-out, which has world-wide been announced by five countries only, is viewed as challenging (Electrek, 2016). Furthermore, Finland's exceptionally high shares of bioenergy and nuclear power are rare among EU member states (see Fig. 2), which makes Finland an ideal case to study the effect of policy risk realizations involving biomass and nuclear. The combined share of both biomass and nuclear power is 44% of primary energy (2015) (Statistics Finland, 2017), and the government's plan means increasing their use to 58% by 2030 (Finnish Ministry of Employment and the Economy, 2017).

Both bioenergy and nuclear energy, though being already in wide use for a long time, include major risks. Nuclear power includes very controversial political issues (van de Graaff, 2016). While nuclear power is accepted in some European countries (e.g. Finland, France, and UK), there is significant opposition in other countries (e.g. Denmark, Germany, Belgium) (Edberg and Tarasova, 2016). The perception of the sustainability of nuclear power varies from country to country (Gralla et al., 2016). The impact of a nuclear phase-out on the national energy system level has been analyzed e.g. in Sweden (Edberg and