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Economic and environmental performance of electricity production in Finland: A multicriteria assessment framework

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ABSTRACT

Meeting environmental, economic, and societal targets in energy policy is complex and requires a multicriteria assessment framework capable of exploring trade-offs among alternative energy options. In this study, we integrated economic analysis and biophysical accounting methods to investigate the performance of electricity production in Finland at plant and national level. Economic and environmental costs of electricity generation technologies were assessed by evaluating economic features (direct monetary production cost), direct and indirect use of fossil fuels (GER cost), environmental impact (CO_2 emissions), and global environmental support (emergy cost). Three scenarios for Finland's energy future in 2025 and 2050 were also drawn and compared with the reference year 2008. Accounting for an emission permit of 25 €/t CO_2, the production costs calculated for CHP, gas, coal, and peat power plants resulted in 42, 67, 68, and 74 €/MWh, respectively. For wind and nuclear power a production cost of 63 and 35 €/MWh were calculated. The sensitivity analysis confirmed wind power's competitiveness when the price of emission permits overcomes 20 €/t CO_2. Hydro, wind, and nuclear power were characterized by a minor dependence on fossil fuels, showing a GER cost of 0.04, 0.13, and 0.26 J/J_e, and a value of direct and indirect CO_2 emissions of 0.01, 0.04, and 0.07 t CO_2/MWh. Instead, peat, coal, gas, and CHP plants showed a GER cost of 4.18, 4.00, 2.78, and 2.33 J/J_e. At national level, a major economic and environmental load was given by CHP and nuclear power while hydro power showed a minor load in spite of its large production. The scenario analysis raised technological and environmental concerns due to the massive increase of nuclear power and wood biomass exploitation. In conclusion, we addressed the need to further develop an energy policy for Finland's energy future based on a diversified energy mix oriented to the sustainable exploitation of local, renewable, and environmentally friendly energy sources.

1. Introduction

Several scientists have used economic and biophysical accounting methods as a basis for valuing natural resources, human-dominated processes, and man-made ecosystems (Brown and Ulgiati, 1999; Costanza et al., 1997; Farber et al., 2002; Franzese et al., 2008b, 2009a; Odum, 1988, 1996; Patterson, 2002; Ulgiati et al., 2011a,b). As a complement to "preference-based approaches" typical of Economics, biophysical accounting methods use a "cost of production approach". Biophysical accounting methods assess value based on the amount of resources invested to produce a product or service, thus resulting particularly useful to assess environmental performance and sustainability of systems and processes. Biophysical accounting provides an ecocentric value of systems and processes complementary to the anthropocentric value of economics. In so doing, it does not aim at replacing economic values but instead it provides additional information from a different point of view, from which public policy can benefit (Ulgiati et al., 2011a).

The development of national policies to ensure long term energy security and sustainable development is not an easy task (Lund, 2007). Economic and environmental aspects and constraints of alternative energy scenarios must be properly investigated before the guidelines of energy policies can be drawn. Understanding the dynamics of intertwined energy, environmental, and socioeconomic factors requires an interdisciplinary perspective as well as the use of multicriteria assessment framework (Franzese et al., 2011). To successfully overcome the fossil-fuel era, the system features of our societies need to be properly investigated by assessing driving forces and environmental constraints (Ulgiati et al., 2011b).

In this study, we integrated economic analysis and biophysical accounting methods to explore the environmental performance of electricity production in Finland at plant scale and national level. The main economic and environmental costs of different electricity generation technologies were investigated by evaluating economic features (direct monetary production cost), direct and indirect use

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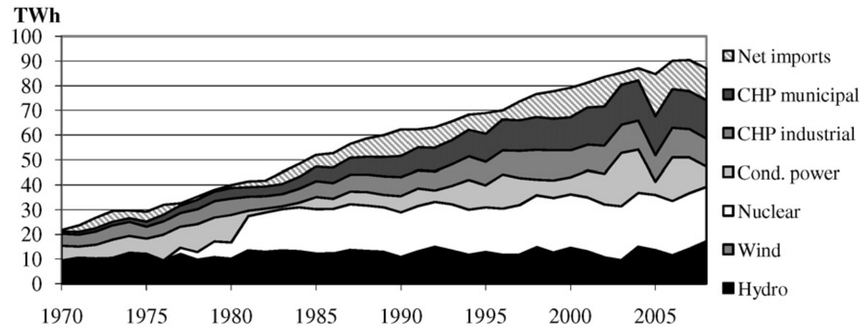

Fig. 1. Electricity consumption in Finland in the period 1970–2008.

Data source: Statistics Finland (2010).

of fossil fuels (GER cost), environmental impact (CO_2 emissions), and global environmental support (emergy cost). Three alternative scenarios for Finland's energy future in the years 2025 and 2050 were also drawn and compared with the reference year 2008.

2. Materials and methods

2.1. The Finnish energy system

Finland is located in Northern Europe and has a total area of 338,145 km^2 and a population of about 5,255,000 inhabitants. The GDP of Finland in the year 2008 was 184.6 billion Euros with the following composition by sector: 66.1% services, 30.3% industry, and 3.6% agriculture (www.stat.fi).

Since the early 1970s, Finland has been characterized by an active and successful energy policy (VTT, 2007, 2009). In 2008, the total energy consumption was 1.42×10^6 TJ and about half of both primary energy and electricity was used to supply its industrial sector (VTT, 2007). The Finnish energy system is very diversified, with an energy consumption supplied as follows: oil 25%, wood fuels and hydro power 25%, nuclear power 17%, natural gas 11%, coal 10%, peat 6% (Statistics Finland, 2010).

In 2008, the electricity consumption in Finland was 87.3 TWh, with an internal production of 77.5 TWh (Fig. 1). Combined heat and power (CHP) was the most important mode of electricity generation, accounting for 30.3% of the total electricity consumption. Nuclear power accounted for 25.3%, hydro power for 19.4%, condensing power for 10.1%, and wind power for 0.3%, while the net import of electricity was 14.6% (Statistics Finland, 2010).

For nuclear, biomass, and wind power there is potential to significantly increase over the next 30–40 years (Holttinen, 2008; Rintala et al., 2007). Instead, hydro power is unlikely to further develop in the future having already been exploited at its maximum rate so that additional exploitation is not allowed due to environmental protection and nature conservation policies (VTT, 2007, 2009). The future dynamics related to fossil fuel-based power plants will be strongly constrained by fuel price and availability as well as by emission trading (Bentley, 2002; Heinberg, 2009).

2.2. The cost analysis

The main aim of Cost Analysis is to evaluate the production cost of processes and products (Layard and Glaister, 1994). In this paper, the direct production cost of different technologies for electricity production in Finland was calculated both at plant scale and national level referring to the year 2008 and to different scenarios.

Production costs were calculated as the addition of annual investment costs and variable costs, including fuel, operating and maintenance, and emission permits. The annual investment costs were calculated as fixed annual installments, distributing the investment cost over the economic lifetime of the power plant. The annual investment costs were given by the annuity factor calculated as follows:

$$f = \frac{r(1+r)^n}{(1+r)^n - 1} \quad (1)$$

where f is the annuity factor, r is the annual interest rate, and n is the economic lifetime in years.

The estimation of electricity generation costs for municipal CHP plants was made by first allocating all production costs to electricity production and then subtracting the monetary value of produced heat from the total cost (IEA/NEA, 2005). The price of heat used for this calculation was 51 €/MWh, the average price of district heating in Finland in 2008 (Statistics Finland, 2010).

In this study, we assumed emission trading to be applied also in the future in the attempt to lead towards low-emission technologies. Consequently, according to Kossoy and Ambrosi (2010) and VTT (2009), we used a price of an emission permit of 25 €/t CO_2 in 2008, 30 €/t CO_2 in 2025, and 40 €/t CO_2 in 2050.

2.3. Discounting, uncertainty and sensitivity analysis

Discounting allows effects occurring at different future times to be compared by converting each future value to its current value. The choice of an appropriate discount rate (i.e., the interest rate used in determining the present value of future cash flows) is one of the most disputed issue in Economics (Philipert, 1999; Sterner, 1994; Weitzman, 1998). A proper discount rate is especially important for projects that involve long time horizons as in such situations the results of cost–benefit analysis can be very sensitive to changes of the discount rate (Gollier and Weitzman, 2010).

Moreover, input data are most often affected by non-negligible uncertainty. For this reason, a sensitivity analysis is needed to assess how small variations in input data affect final results (Cariboni et al., 2007). Sensitivity analysis is also important for scenario analysis as modeling the future involves uncertainty factors as well as planned or expected variations due to decision-making. The impact of such variations on the production cost of different electricity generation technologies was calculated by varying the following input data: interest rate, investment costs, fuel price, and emission permit price. According to IEA/NEA (2005, 2010), the interest rate was assumed to vary from 1 to 15%. The investment cost was assumed to vary between ±30% whereas, according to EIA (2009), the fuel price was assumed to vary from −25% to +100%. The emission permit price was assumed to vary from 0 to 60 €/t CO_2 according to VTT (2009). These input variables were firstly varied one factor at a time to evaluate their single influence on the