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Nuclear energy policy in Belgium after Fukushima

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HIGHLIGHTS

- Belgium decided to close nuclear plants between 2015 and 2025 to promote renewables.
- Hopes for a technically acceptable schedule reduced after the Fukushima disaster.
- The Belgian electricity system has been modelled with system dynamics (SD).
- SD shows that nuclear plants will be mainly replaced by fossil-fuel plants.
- SD shows that it is better for renewables to delay shutdowns or to replace plants.

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ABSTRACT

The Belgian nuclear phase-out law imposes closing down in the 2015–2025 period seven nuclear power plants (NPPs) producing more than 50% of the domestic electricity. This creates an urgent problem in the country because of the absence of well-defined capacity-replacement plans. Though a safety-of-supply provision in the law allows for a delayed phase-out, hopes for a technically acceptable schedule have reduced after the Fukushima nuclear disaster in March 2011. In this article policy investigations are made with system dynamics. A significant finding from such modelling is that, in contrast to common expectations, a too early nuclear phase-out will not serve the deployment of renewable energy sources and rational use of energy. It is indeed found to primarily benefit to fossil fuel, creating unwanted drawbacks regarding safety of supply, dependency on foreign suppliers, price volatility, and increased use of non-renewable and CO_2-emitting fossil fuels.

1. Introduction

After the Fukushima disaster in March 2011 polemic discussions pro or against nuclear electricity production arose. Europe, Germany, Switzerland and Belgium confirmed the closing-down policies. In this article the authors present a system-dynamics (SD) modelling of the Belgian situation for getting a more systemic insight into this complex issue. Belgium produced in 2003 about 56% of the total electricity demand with seven nuclear power plants (NPPs); only France has a higher percentage production of about 75%. The phase-out law has been set in place in 2003 (BFG, 2003): it foresees the closure of all Belgian NPPs between 2015 and 2025 after 40 years operating time; nevertheless, a provision in the law permitted a renegotiation on the shutting-down schedule of NPPs in case of safety-of-supply difficulties, several times pointed out by the Regulation Committee of Gas and Electricity, most recently in CREG (2011a, 2011b). A major rationale for passing the law is that the phase-out is favourable to renewable energy sources (RES) considered as being presently 'crowded-out' by NPPs. Several studies were commissioned by the government before and after issuing the law, to verify the feasibility. An overview of these studies is given in Table 1, and their main recommendations are also provided. All studies prepared before the Fukushima disaster were basically favourable to adapting the shut-down calendar, because it is not dictated by technical or safety rationale's. The government set in place in 2012 eventually rejected these policy recommendations in the wake of the Fukushima disaster, maintaining most of the 2015 to 2025 phase-out programme. The present SD analysis has been started by Friesewinkel (2008) at Université Libre de Bruxelles (ULB); Brans and Kunsch (2010) presented headline results. Though five years have passed since inception, not much has changed and the study remains pertinent in 2013, two years after the Fukushima disaster. The article is structured as follows: Section 2 gives an overview on the System-dynamics (SD) methodology and references for energy modelling; it is also discussed why this approach has been chosen. Section 3 presents the general context of the problem; soft SD based on feedback analysis is giving first conclusions about the dynamic consequences of the unchanged

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Table 1
A survey of governmental studies on the electricity market in Belgium. (RES = renewable energy sources).

Study Year	Methodology	Phase-out recommendations
Ampère (2000)	Scientific analysis by university professors of the electricity-production potential in Belgium of traditional and non-conventional sources.	It is not indicated to discontinue the successful nuclear programme contributing to low costs and important CO_2 emission reduction.
CE2030 2007	PRIMES economic model of energy systems from the Belgian Planning Office using a number of scenarios with and without nuclear and different CO_2 reduction objectives.	RES are limited for fulfilling CO_2 emission reduction objectives; developing carbon capture and storage (CCS), and keeping operational NPPs beyond 2025 would bring a substantial relief.
GEMIX 2009 2012 (revision after Fukushima)	Comparison of several studies from Belgian and foreign sources, including Greenpeace (2011) in the 2012 revision. The whole energy system including transport is considered.	The deployment of RES is independent of other components in the energetic mix given the environmental constraints. The actual phase-out schedule may lead to a production deficit not necessarily covered by imports in the absence of available foreign capacities and interconnected transport grids.

phase-out law. These conclusions are strengthened by means of quantitative SD simulations in the following sections. The general structure of the quantitative SD model is described in Section 4 by detailing the supply and demand sub-models, and how they are connected; indicators for evaluating the merits of policies are introduced. Section 5 defines policies and their variants, the data and hypotheses made in the simulation model. Section 6 presents the main results of the simulations; policies are scored for ranking purposes, regarding their merits with respect to indicators. Section 7 gives conclusions, compares the results with other studies, and discusses the limitations of the model and possible future improvement work. Policy recommendations are given in Section 8.

2. System dynamics

2.1. Overview of SD

System Dynamics (SD), first developed by J.W. Forrester at MIT, Boston (Forrester, 1961), is a policy-aiding instrument for addressing socio-economic issues. SD is based on the principle that the dynamics of systems can be understood from internal structures while exogenous influences, privileged in econometric modelling, can influence the system, but do not explain its dynamic behaviour. Therefore feedback loops (FBLs) play a preeminent role. In the first '*Problem definition*' step modellers fix the system boundaries defining the validity domain of the model, and identify the problem symptoms; in the second '*Conceptualisation*' step, *influence diagrams* (*IDs*), also *called causal-loop diagrams*, are setup, starting from simple *mental model* with few key variables to more complex IDs containing more variables important for later modelling. Main feedback loops (FBL) are identified for establishing a *dynamic hypothesis*, and for eventually proposing structural changes. The ID in Fig. 1 describes the installation of new production capacities after a plant decommissioning. The gap-closing is done with one negative FBL, called a '*goal seeking loop*'. Some explanations on this diagram are as follows:

- A link between A→B is given a positive sign if a change in A produces a change in B in the same direction, e.g., increasing demand increases the gap, therefore (+); it is given a negative sign otherwise, e.g., increasing supply diminishes the gap, therefore (−).
- A closed loop, i.e., a FBL has the (+) polarity when it contains zero or an even number of (−) links; it has the (−) polarity when it contains an odd number of (-) links.
- Positive loops (+) are self-reinforcing or growth loops, the positive polarity is indicated in a curl spinning clockwise or counter-clockwise following the loop direction.

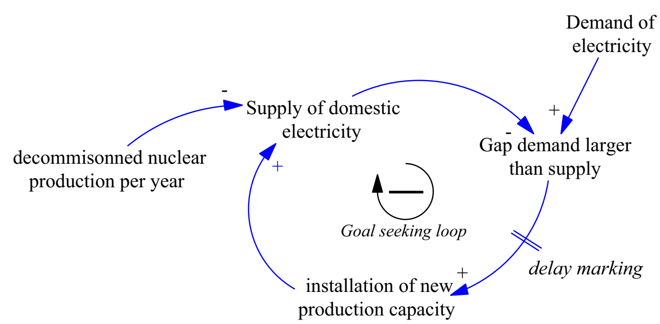

Fig. 1. An influence diagram with one negative goal-seeking feedback loop.

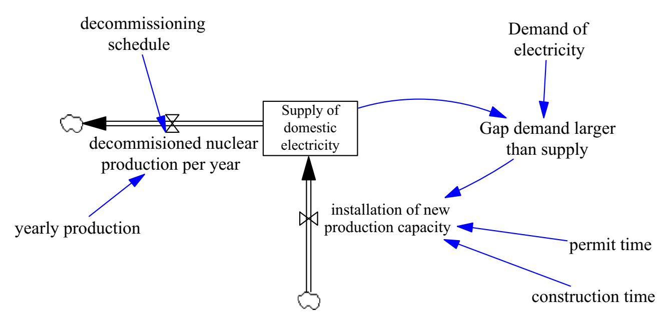

Fig. 2. The stock-flow diagram corresponding to the influence diagram in Fig. 1 with one stock, two flows, and a number of auxiliaries for calculating the flows. Clouds indicate the boundaries of the system.

- Negative loops (−) are self-correcting or *goal-seeking loops*: a change in any variable within the loop gets damped, e.g., the gap demand-supply is reduced. The negative polarity is again indicated in a spinning curl.

Quantitative SD modelling strengthens soft FBL analyses by performing numerical simulations. Detailed IDs with quite more variables are then needed, and physical units are given to each variable. State variables are called 'stocks': they are represented by rectangular reservoirs. The variation rates of stock per unit of time are called 'flows': they are represented as an ingoing or outgoing valve, according to the sign. 'Auxiliaries' are added to the model to calculate the flows. Initial values are provided to compute the stocks by numerical integration from initial time t_0 (here 2005) to current time t. The authors used VENSIM DSS32 (1988–2002) for setting up IDs, modelling and simulations. Tests were performed to verify both validity and numerical accuracy, and the coherence of physical units. Fig. 2 shows the stock-flow diagram – also called Forrester diagram, corresponding to the ID in Fig. 1. It is seen that additional auxiliaries are needed for setting up equations for the links and for flow calculations.

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