Energy Policy 54 (2013) 72–86

Contents lists available at SciVerse ScienceDirect

Energy Policy

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

An energy security management model using quality function deployment and system dynamics ☆

Juneseuk Shin [a], Wan-Seon Shin [a], Changyong Lee [b,*]

[a] Department of Systems Management Engineering, Sungkyunkwan University, 300 Chunchun-dong, Jangan-gu, Kyunggi-do, 440-746, Republic of Korea
[b] University of Cambridge, Institute for Manufacturing, Department of Engineering, Cambridge, 17 Charles Babbage Road, Cambridge CB3 0FS, United Kingdom

HIGHLIGHTS

- We suggest an energy security management model for developing economies.
- We identify a consistent set of key components, indicators and policies by using QFD.
- A coherent and practical system dynamics model based on QFD's output is constructed.
- The model is applied to the Korean gas sector as an example.

ARTICLE INFO

Article history:
Received 21 April 2012
Accepted 13 October 2012
Available online 23 December 2012

Keywords:
Energy security
QFD
System dynamics

ABSTRACT

An energy security management model using quality function deployment (QFD) and system dynamics (SD) is suggested for application in public policymaking in developing economies. Through QFD, experts are guided toward identifying key energy security components, including indicators and policies, and in making these components consistent, focused, and customized for a particular country. Using these components as inputs, we construct an intermediate complex system dynamics model with a minimal number of crucial interactions. Key policies are simulated and evaluated in terms of the improvement of key indicators. Even with little data, our approach provides a coherent, useful, and customized energy security management model to help policymakers more effectively manage national energy security. To demonstrate its advantages, the model is applied to the Korean gas sector as an example.

1. Introduction

Northeast Asian countries have recorded an eye-popping economic growth over the last several decades, due mainly to a focus on securing access to oils and fossil fuels (von Hippel et al., 2011a). Recently, driven by increasing dimensions of risk and uncertainty associated with energy security, these countries have initiated new energy policies to address not only a constant match of supply and demand, but other economic, environmental, and technological factors as well (von Hippel et al., 2011b). Having in common characteristics of weak investment in energy infrastructure, Northeast Asian countries are seeking new concepts for general and workable frameworks of energy security. As noted in some recent studies, however, country-wise differences exist. These country-wise differences effectively mean that some causal relationships in the general energy model cannot be equally applied to all countries (Padeny, 2002). For instance, oil production in Iran is not a function of global oil price, but rather depends on OPEC's share (Kiani and Pourkfakhraei, 2010). Thus, it is necessary to customize models and policies, particularly for countries with unique characteristics.

The Republic of Korea (ROK) is a typical example of a country facing these problems. Although the growth rate has recently become moderate, ROK has been facing an overall constant growth in the annual demand for energy. The growth rate of the annual total primary energy supply (TPES) in ROK fluctuated from 8% to 14% in the 1990s, then slowed to less than 5% in the 2000s, and is expected to stabilize around 2% in the near future (Kim et al., 2011). Growing demand is the crucial component challenging the energy security of ROK. At the same time, new restrictions on supply have occurred, including global climate change, the use of new renewable energy, and increased international competition among energy importing countries. Thus new energy sources and technologies, as well as energy saving policies, are required to ensure a sufficient energy supply for the growing demand. This holds all the more true given that ROK is highly dependent on energy imports.

* Corresponding author.
E-mail addresses: cl539@cam.ac.uk, akuta7@snu.ac.kr (C. Lee).
☆ This article has not previously been published and is not under consideration for publication elsewhere.

0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.10.074

Many countries face similar problems, and thus are setting new energy policies based on concepts of enhanced energy security that sufficiently consider their own unique national characteristics. Accordingly, a new concept of energy security has become a center of interest for researchers and policymakers. Since the 1970s, a number of studies have suggested operating definitions and concepts. With little exception, however, these studies have focused mainly on sources for a stable energy supply (Costantini et al., 2007; Löschel et al., 2010). Typical supply-oriented definitions can be found in previous studies by the MIT Working Group, the IEA (International Energy Agency), and others.

These previous studies commonly aim at reducing economic loss due to the volatility of energy prices and the physical unavailability of energy sources (Bohi and Toman, 1996; IEA, 2007; Samuels, 1997). These concepts have been increasingly challenged on every front because they focus too narrowly on the issue of energy supply. Thus, new energy security concepts have emerged that incorporate major risks and issues from environmental, technological, socio-cultural, and military sectors, and are thereby more comprehensive (von Hippel et al., 2011b). To improve energy security, national energy security policies must build on the new, more comprehensive concepts.

Policymakers should design and set policies in motion, and thus need models to monitor, analyze, forecast, and manage energy security. For this purpose, economic models have so far been favored. As diverse factors have become involved in the global landscape of energy security, however, there is increasing interest in more complex models for energy policies. Many models have been introduced and tested. Among them, researchers in the energy policy domain have suggested that the system dynamics (SD) approach is advantageous because it provides a better understanding of complex interactions among various factors. Driven by the development of SD energy models such as FOSSIL 2 in the U.S. in the 1970s, a number of SD models have been developed and refined to design, analyze, and evaluate U.S. energy policies (Ford, 1983; Ford and Bull, 1989; Naill, 1973; Sterman, 1983), as well as energy policies in EU countries such as France (Roche, 1989) and the UK (Bunn and Larsen, 1992; Bunn et al., 1997). Further, SD energy models have spread to other countries, including Egypt (Choucri et al., 1990), India (Chowdhurg and Sahu, 1992), Iran (Kiani and Pourkfakhraei, 2010), and New Zealand (Bodger and May, 1992), among others. For many years, SD energy models have been continuously revisited and refined in the U.S. and EU (Chi et al., 2009; Wu et al., 2011).

Despite these efforts, outside of U.S. and EU countries, practical adoption of SD energy models is very limited. As noted in previous studies (Padeny, 2002; Urban, 2007), these limitations are mainly due to data unavailability and poorly customized models. Any country will have some common factors with U.S. and EU, but will also have its own unique energy characteristics. Major differences should be taken into consideration as the focus of discrete and customized policies. Also, data about some of the energy variables in U.S. and EU models is rarely available in some countries, including Korea. With missing variables, conventional models are difficult to build, and consequently do not perform to expectation. Thus for countries with limited data for all energy variables, it is better to build and use an intermediate complex model focusing on the unique energy characteristics of each country with basic energy variables than to use the full-scale complex energy models of the U.S. and EU. Energy security is an urgent problem. Accordingly, policymakers need to have on hand a practically useful model.

This is why the present study suggests the joint use of QFD and SD. QFD enables policymakers to identify a customized set of key energy security factors through a consensus of experts, clarifying the focus of national energy security policies. With these factors, the SD approach provides a good way of structuring the causal relationships between key and subsidiary factors. Using the system dynamics model, we can monitor changes among factors and energy security, and also analyze effects of energy policies. Put another way, our primary objective is to provide a practical and immediately applicable way of managing energy security.

Most recently among energy sources in Northeast Asia, the use of natural gas has expanded in substitution of oils and other fuels (von Hippel et al., 2011a). Provided that system dynamics models are most useful when relevant energy systems are in transition, the Korean natural gas sector is chosen as an illustrative example of the advantages of our method (PMO, 2008).

This paper is structured as follows. After investigating the concept of energy security in Section 2, we describe the overall research framework in Section 3. In Section 4, the application of QFD to the Korean natural gas sector is presented to derive key energy security components, indicators, and policies. The SD model is constructed, described, and validated in Section 5. Policy scenarios are developed, simulated, and discussed in Section 6. The paper finalizes with conclusions.

2. Energy security

Many existing definitions of energy security are based on the notion that an uninterrupted energy supply is crucial. Traditionally, the concept of energy security has focused on securing access to supplies of oil, but the concept has subsequently widened to cover the influence on energy security of other energy sources, price volatility, supply chains, political stability of oil nations, and other factors (Chevalier, 2006; IEA, 2007; Jenny, 2007). Recent studies continue to add new key factors such as global climate change, making the concept of energy security more and more comprehensive (Kruyt et al., 2009; von Hippel et al., 2011b).

Another thing to note is that the concept of energy security should vary according to the various characteristics of different countries, such as geopolitical conditions. Some even argue that the concept has different meanings to different people at different moments, and thus it is difficult to provide an exact definition for energy security (Alhajji and Williams, 2003). Thus recent studies have been trying to identify major attributes that define the differences in energy security, including the volume of natural resources, the power of governments to set energy prices, and the ability to plan for the future (von Hippel et al., 2011b). To establish effective energy policies, the concept of energy security needs to be customized to different countries with due regard to their differences and unique characteristics.

Seeming to be contradictory, two trends are actually complimentary. By sharing a common understanding of new comprehensive concepts of energy security, a country can minimize potential conflicts with other countries due to differences in concepts of energy security. This is why national energy policies in various countries are showing convergence rather than divergence (von Hippel et al., 2011b). Given the commonality of comprehensive energy security concepts, policymakers take into consideration country-wise characteristics in constructing the analytic framework and models to manage energy security on a global scale.

Some recent studies have made efforts to define new comprehensive energy security concepts with major components (von Hippel et al., 2011b). Others have tried to bridge the gap between the new concepts and current analytic frameworks, suggesting more appropriate indicators for components of the new concepts (APERC, 2007; Jansen and Seebregts, 2010; Kruyt et al., 2009; Löschel et al., 2010). Regardless, effective frameworks