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Building smart grid to power the next century in Taiwan

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ABSTRACT

Due to global climate concerns, many countries are developing energy policies to encourage low emissions and high efficiency. Taiwan's current practices should be modified for the emerging smart grid (SG) industry. Strategic policy and implementation plans that shift focus from original equipment manufacture (OEM) and original design manufacture (ODM) to a vertically integrated system involving suppliers and customers should be adopted to obtain success in the global markets. Government energy SG projects have been implemented over a short-term (2011–2015), medium-term (2016–2020) and long-term (2021–2030) to ensure steady supply, promote energy conservation, reduce carbon emission, increase green energy and facilitate a low carbon economy. Practical implementation of SG systems is the most effective way to reach these goals. In this paper, current smart grid statuses in some advanced countries are briefly reviewed. The implementation plans for smart grids in Taiwan are analyzed from the perspectives of strategic policy and cost-benefit. Then, gaps between supply and demand for new energy systems, opportunities for new industries, and suggestions for SG industries are discussed. Finally, recommendations for constructing an efficient and environmentally friendly SG in Taiwan for a low carbon society and sustainable development are provided.

1. Introduction

Due to increasing environmental awareness, rigorous regulations, growing demand for high-quality reliable electricity, and rising customer expectations, power companies face difficult challenges [1]. Replacing fossil fuels with renewable energy can reduce greenhouse gas (GHG) emissions and develop new industrial growth [1,2]. Renewable energy is still characterized by high production costs and low efficiency. Through digital information technology, the provision of reliable high-quality power supply and consumer oriented power demand service has become feasible [3]. Adopting a smart power system that integrates renewable energy technologies to meet changes in demand and supply is becoming more important [1].

Primary energy consumption in Taiwan was increased by 83.63% from 71.21 million kiloliters in 1994 to 147.45 million kiloliters in 2014, with an average annual growth rate of 3.71%, and 98.04% of this energy was imported [4,5]. In 2014 energy sources include petroleum (48.52%), coal (29.2%), natural gas (12.23%), nuclear (8.33%) and others (1.72%) [4]. In 2013, total GHG emissions were 248.70 million metric tonnes of carbon dioxide equivalents ($MtCO_2$) [6]. Per capita GHG emissions were 10.63 tCO_2 for 2013, one of the highest in Asia and far above the world average of 4.52 tCO_2 [6].

Reduction of GHG emissions is a pressing challenge for Taiwan. Research and development of renewable energy for power generation and vehicular transportation emphasizes GHG emissions reduction, and energy efficiency improvement (EEI) in residential, commercial, and industrial sectors. The Intergovernmental Panel on Climate Change reported that renewable energy and EEI have mitigation and adaptation synergies with climate change [7].

Taiwan is already working on conservation, greenhouse gas emissions, and renewable energy goals. The “National Energy Conservation and Carbon Emission Reduction Project” recognizes the importance of smart grid (SG) technology. The government of Taiwan authorized the “Implementation Policy for Smart Meter Infrastructure Construction” on June 23, 2011 to demonstrate smart meters. As renewable energy technologies have matured, the industry focus has shifted from supply side to environmental and demand sides [8,9]. SG technologies have been around for decades, but generation, delivery, utilization and pricing of electricity is changing. The impact of future SG scenarios on environments, societies and economies can be very uncertain. Analyzing complex SG policy and implementation plans using existing theoretical models are difficult. Most studies have focused only on technological trials and modeling, including benefits, security, energy efficiency, and cross country comparisons [1,8–11].

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This paper fills the gap by providing an overall strategic plan and a detailed implementation scenario for SG development. Past works on energy policy and analysis are reviewed in Section 2, and current statuses of SG development in some advanced countries are presented in Section 3. The existing methods for selecting implementation processes and promotion mechanisms and for selecting physical and technical measures are discussed in Section 4. Strategic plans and the cost-benefit analysis for the SG in Taiwan are presented in Section 5. Policy implications and recommendations are given in Section 6. Some conclusion remarks are made in the last section.

2. Literature reviews

2.1. Implementation processes and promotion mechanisms

2.1.1. Methodology

Energy research often involves a single discipline, but commercial applications require methods and knowledge from many areas [1]. Thus, the selection of a set of policies is a challenging task. Some studies, such as Kissel and Stefan [12], Negro and Hekkert [13], Laird and Stefes [14], Burns and Kang [15], and Miara et al. [16], employ qualitative analysis and provide general statements about relationships among categories of data. On the other hand, few quantitative models, such as Lin et al.) [1] and Das et al. [17], are employed in energy policy research. Studies related to SG policy are few and focused primarily on benefits, energy efficiency, security and business [1,10,11]. Some policies are recommended for only specific countries, for example [8,9].

Renewable energy projects should integrate expectations from stakeholders. Scenario planning addresses and limits uncertainty, and can improve capacity to respond to different future instances [18]. Multicriteria assessment (MCA) is commonly used to handle issues of generation, management and energy policy [19]. Combining a scenario plan and MCA, which considers a broad spectrum of social, economic, environmental and technical criteria, can reduce uncertainty in the future development of energy systems. In addition, stakeholders should be included in the decision making process [20]. Participatory technological assessment (PTA) uncovers social concerns and can increase acceptance through development of a common vision [21]. Many studies only stress the ecological, social, and economic components of sustainability through the monitoring of indicators, with few cases paying attention to the dynamic component. Sustainability is a system issue, not a technology or organizational issue [22]. However, such a system is rarely addressed in the renewable energy literature.

2.1.2. Factors impacting the strategic decision

Allen [23] and Freeman [24] stated that a successful policy framework in industry depends on a favorable combination of technology supply, market demand and a suitable environment. Innovation policies have been proposed by Rothwell and Zegveld [25] to cover technology policies, which are related to patents, technology education and basic infrastructure, and industrial policies, which are related to incentives, tariff and taxation policies, and industrial regeneration. These policies can be divided into 12 categories: scientific and technological development, education and training, information services, public enterprise, financial affairs, tax incentives, regulations and controls, policy-based strategies, government procurements, public services, trade controls, and overseas agencies. In addition, the consideration of a broad spectrum of social, economic, environmental and technical criteria for an energy policy framework is also important. Since SG development combines a diversity of sectors, the policy framework needs to be constructed from an overall and a systematic policy view [26]. Commonly-used tools for government technology policy include: (1) technical supply-side tools, including: cultivate scientific and technological knowledge and human power; provide market information and management skill services; provide financial resource support or subsidies; establish experimental development agencies; assist industrial development or introduce new technologies; (2) market side tools, including: develop the industrial structure, limit the number of firms; provide domestic subsidies and tax reduction; achieve trade agreements such as controlling the exchange rate, and signing tariffs and quotas; place legislative restrictions on foreign marketing and advertising activities; (3). political and legal environment to protect R & D achievements [25,27–30]. Kennedy [31] pointed out that technology policies proposed by the government should include: the creation of innovative environment, funding of research and development, development of manufacturing technology, acceleration of technology transfer, assistance of industry education and retraining, and careful selection of key industries and technologies. Newson [32] asserted that a government, in order to stimulate innovation, should proceed public policies from several different levels: (1) the overall economic, financial, and regulatory aspects, to attract business investment in innovation; (2) encouraging innovation, by focusing on regional environment with commercial benefits; and (3) regional investment in research and development, training, technology, relationship building, academic-industrial links, business intelligence, in order to facilitate local companies generating innovative results. Komiya [33] stated that industrial policies are policies made by the government to allocate resources among industries and activities among the firms within an industry. Chiang [34] asserted that national industrial policies are a range of policy tools to reallocate resources to some priority-selected industries when such allocation of resources cannot be made under normal operation of the market mechanism. Even though these industrial policies are artificial measures, they are not necessarily contrary to market principles, and a gradual strengthening of market mechanism may be possible when the policies are applied properly. The Council for Economic Planning and Development (CEPD) [35] stated that the government, in order to stimulate the industry, to improve the investment environment, or to confront market failure, needs to intervene and remedy market functions, and most importantly, the government should make necessary policy adjustments to promote industrial development towards desired directions when the environment changes.

2.2. Analysis tools

Cost-benefit analysis (CBA) can provide clear direction for policy making by evaluating the choices available to policy makers [36]. The discount rate establishes the value of time in economic analysis and is a critical parameter of investment and policy decisions [36,37]. Some examples are briefly introduced here. Noel and McComack [38] employed CBA to compare a vehicle-to-grid electric school bus with a traditional diesel school bus. O'Mahoney et al. [39] calculated the economic costs and benefits of carbon abatement to estimate the feasibility of an indigenous biomass resource.

Beginning in the early 70's with the 'Limit to Growth' model, system dynamics (SD) modeling has helped us to understand the behaviour of complex systems. Pietrapertosa et al. [40] brought together SD, life cycle assessment (LCA), and market allocation (MARKAL) techniques to thoroughly evaluate the external costs of energy systems. Chae and Park [41] employed the environmental benefits mapping and analysis program (BenMAP) to undertake the first local cost-benefit analysis and proved that integrated environmental strategies (IES), which address local concerns, outperform air quality management or GHG reduction measures alone. Recently, Shih and Tseng [42] introduced the Air Resource Co-Benefits (ARCoB) model to conduct a cost-benefit analysis for the economic feasibility of the sustainable energy policy guidelines for climate change mitigation. To evaluate demand side management, the American Department of Energy [43] reviewed performance of a wide variety of illustrative programs and integrated resource planning studies. These studies requires the collection of a substantial amount of information and assumptions on demand side options, including customer participation, customer response, and