博士学位論文審査要旨

2016年1月16日

論文題目： Assessment of Feed in Tariff Policy Impacts for Promoting Wind and Solar Energy Development in Japan
日本における風力発電及び太陽光発電開発に対する固定価格買取制度の影響

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要　　旨：

東日本大震災における福島原発事故を経験した日本にとって、エネルギー政策はもっとも重要な課題の一つである。本研究は、原子力の代替エネルギーとして注目されている太陽光や風力発電等の再生可能エネルギーの普及を加速する効果的な政策として日本のみならずドイツやスペイン等の海外諸国でも採用されている電力の固定価格買取制度を多面的かつ客観的に評価するため、精緻なシミュレーションを行うとともに、再生可能エネルギー関連の技術開発を含むイノベーション面からの評価を行った。

再生可能エネルギー市場の持続可能性を確保するためには、持続的に維持可能な固定買取価格の価格調整メカニズムを明らかにすることが必要である。本研究ではシステムダイナミックスの手法を用い、収益性を含む様々な重要要素を評価できる新しいシミュレーションモデルを提案することにより、動的な電力供給の変動パターンを評価できることを可能にしただけでなく、技術開発等のイノベーションによる再生可能エネルギーの発電コストの低減が化石燃料や原子力から再生可能エネルギーへ移行するプロセスにどのように影響するかという問題についても評価した。これは本論文の学術的なオリジナリティとして高く評価できる部分である。

再生可能エネルギーの固定買取価格制度における価格調整メカニズムは日本における安定的な電力供給における重要なトピックである。システムダイナミックスの手法に基づく離散型調整システムと連続型調整システムとの比較分析は現実適用性の面からも興味深く、学術の面だけでなく産業政策提言の面からもオリジナリティが認められ、同志社大学大学院総合政策科学研究科の博士論文に値するものと判断している。

なお、本研究では、連続型調整システムの優位性が示されているが、連続型調整システムを導入する際に生じる問題等についても議論が必要であろう。また、価格調整メカニズムに関連して、1日の中での太陽光発電での発電ピークと消費ピークのずれを調整するようなシステムの検討も必要であり、これらは今後の課題として更に本論文提出者によって研究されるべきものと考える。

よって、本論文は、博士（技術・革新的経営）（同志社大学）の学位論文として十分な価値を有するものと認められる。

総合試験結果の要旨

２０１６年1月１６日

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要 旨：
○総合試験実施日と時間：
2016 年 1 月 16 日 9：30～10：30

○専門分野に関する試験：公聴会における質疑応答により実施
質疑内容と評価：以下に示したように各質問に的確に回答しており、合格と判断する。
①本研究の学術的価値は何か？
・ 日本の重要な課題である再生可能エネルギーにおける固定価格買取制度のあり方をシステムダイナミックスという手法を用いて評価したこと。
②本研究の産業分野における価値は何か？
・ 現状の固定価格買取制度における共通のパターンと非効率性を発見し、解決に焦点を当て、複数のシナリオ分析を行い、市場の持続可能性を確保するための収益性と重要な要素を評価するための新たなモデリングアプローチを提供したこと。
③再生可能エネルギーの使用率を 20％とすると電力網全体がカオティックになると言われている。これへの対応策としては何が考えられるか？
・ 電力網内での電力蓄積のための蓄電池の採用などが考えられる。

○語学試験（対象となった語学名を含む）の内容
・ 母国語はアラビア語である。第 2 外国語である英語については同志社大学大学院ビジネス研究科グローバル MBA コースにおいて MBA 学位を取得しているだけでなく、査読付きの国際会議における発表の実績もあり、博士号にふさわしい語学力を有する。また、日本語での講義受講が可能なレベルの日本語能力も有する。

よって、総合試験の結果は合格であると認める。

博 士 学 位 論 文 要 旨

論 文 題 目： Assessment of Feed in Tariff Policy Impacts for Promoting Wind and Solar Energy Development in Japan
日本における風力発電及び太陽光発電開発に対する固定価格買取制度の影響

氏　　　名： Amin Hilal Ali Al-Yaquob

要　　　旨：

Provision of alternative energy sources in Japan was primarily motivated by the need for energy security and stability of supply. The oil shocks in the 1970s and the Fukushima accident in 2011 were the most significant events that shaped energy policy in Japan and set its current direction. After the oil shock, nuclear energy was considered a strategic option with an important role in the energy mix. Despite the anti-nuclear movements around the world, nuclear energy share in the Japanese energy mix continued to increase until 2011, and environmentalists have considered this an obstacle to renewable energy development.

Nevertheless, there have been significant budgets allocated for the research and development (R&D) as well as the promotion of renewable energy in Japan. Following the United States renewable energy policy, the Renewable Portfolio Standard (RPS) was adopted in Japan in 2003. However, its impact was deemed ineffective. The Feed in Tariff (FIT) policy was successful in European countries led by Germany, Spain and Italy and a partial form of it was introduced in Japan in 2009, using the German feed in tariff program as a role model. Its extended form was introduced in 2012. The following policy achieved a significant increase in the share of renewable energy and for solar photovoltaic (PV), in particular.

One of the primary reasons for the success of the feed in tariff is the guarantee of long-term, fixed revenue that reduces the risk to investors. These financial guarantees made the investment in renewable energy more attractive than with conventional subsidy programs, like the sunshine project in Japan. Moreover, the policy created a significant market demand, which offered a viable opportunity for the commercialization of the technological research and innovation that have accumulated over the last three decades. The feed in tariff policy, however, comes with significant fees that are passed on to electricity end users, which raise concerns about its justification. The electricity prices in Japan have increased 37% between 2011 when the feed in tariff surcharges were first introduced, and July 2014 (METI, 2014c).

Policy costs, in general, are justified based on policy objectives and the socio-economic benefits the policy is designed to achieve. Most of the research literature has focused on the financial and technological objectives of renewable energy promotion policies. In such analysis, the social benefits are not considered in the assessment; therefore, the renewable energy cannot be fully justified against lower-cost alternatives involving conventional energy sources. Therefore, critics of renewable energy development argue that it is not a cost-effective policy. Scholars like (Edenhofer, Hirth, et al., 2013) stressed that renewable energy promotion policies, like the feed in tariff, should be justified with multi-objectives and all benefits should be explored to reach a fair evaluation. For example, in Japan, green employment or local industry promotion is not listed among objectives of the feed in tariff policy. Moreover, carbon emission and the energy transition strategy are not tightly linked with the feed

tariff policy. The exclusion of these interactions does not reveal the full benefits of renewable energy strategy.

The literature shows that use of a feed in tariff policy has a strong link to innovation in renewable energy technologies, technology cost reduction, technology deployment, electricity sector reforms, electricity wholesale and retail price reduction, green employment, reduction of carbon emissions and even innovation in the energy industry. Most of the studies in the literature, however, have not conducted an integrated assessment of the effects of feed in tariffs that might act as a scorecard to evaluate policy outcomes and performance. Although the feed in tariff price and its general design elements might change and be reviewed periodically to adapt to market dynamics, this study argues that the reviews and amendments should also consider the direct and indirect effects on other sectors, not only in the electricity sector. In addition, assessments of amendments should consider the short and long-term effects imposed on society in general.

The motivation of this study is not only about justifying the cost of feed in tariff policy, or minimizing the policy cost, but also about distributing the timing of feed in tariff support in an optimized way. This is needed to consider the technological development and its cost dynamics locally and globally, the supply and demand of renewable energy deployments, and the required infrastructure planning, development, and coordination.

The aim of this study was to conduct a multi-objective assessment of the effects of feed in tariff policy in Japan. The impact assessment was intended to verify whether the national policies are aligned to achieve a common goal. In addition, it was intended to confirm whether the feed in tariff policy is helping to achieve the short and long-term policy objectives. It was intended to use the impact assessment to study the interactions between policies and their outcomes, to trace and investigate their shortcomings. The impact assessment is especially important because the energy transition and the decisions about the energy mix and the share of each energy source are mostly influenced by political, rather than economic or scientific, justifications. This can be seen clearly by the changes in energy policies that follow the change in the ruling political parties. The case study of Germany in this thesis shows that the energy transition process can take decades, when facing various political challenges and sometimes, public resistance.

The reasons for choosing wind and solar energy are that wind and solar are the fastest growing renewable energy technologies and that they constitute the largest share of renewable-energy electricity generated in Japan. According to an International Energy Agency report, wind and solar contributed to about 82% of the renewable energy deployments around the world in 2014 (IEA, 2015). There were several studies in which the growth of renewables, with a focus on wind and solar in particular, were discussed, along with their potential role in energy transition (Campoccia, Dusonchet, Telaretti, & Zizzo, 2009; del Río & Unruh, 2007; Energy, 2010; Esteban, Zhang, Utama, Tezuka, & Ishihara, 2010; Hirth, 2013; Jenkins, 2015; Lew et al., 2013; Lütkenhorst & Pegels, 2014; Patel, 2005; Tsuchiya, 2012).

Wind and solar have special characteristics. They both generate highly variable electricity because their power generation is largely influenced by daily and seasonal weather changes. From the energy forecast point of view, both solar and wind are highly unpredictable, as the output of a certain facility may drop from hundreds of megawatts to zero without early warning. Moreover, wind and solar are usually conceived as technologies that complement each other for day and night generation (i.e. solar power generation reaches its peak at noon, whereas wind energy generation peaks when it is cloudy or after sunset). They also complement each other in terms of the distribution of their natural resources and geographical locations. Wind turbines are usually installed in coastal and mountain areas (as well as in offshore areas), which have low solar insolation while solar is installed in flat areas or on residential and commercial rooftops. From a development point of view, these two technologies have low operational maintenance and do not require fuel (solar energy might be considered to have lower operation and maintenance costs when there are no moving parts involved). However, weather erosion, soiling, and many other issues are unique to the solar technology, and may increase the O&M cost to the level O&M cost for wind turbines). There is strong opposition to the investment in wind and solar technologies in Japan due to their high upfront costs. Whereas geothermal and tidal wave energy generation are comparatively mature technologies and can generate an abundant and stable supply of electricity at much lower costs, the cost trends of solar and wind are declining at a faster pace in comparison. The high renewable energy promotion incentives had a significant role in reducing the risk of investment in new wind and solar technologies and upscaling their mass production. The rapid decline of their technological costs will make them more competitive with other renewable energy technologies in the future, and signifies their contribution to the green energy transition. From the renewable-energy policy point of view, both of these technologies and their diffusion have been affected substantially by the introduction of the feed in tariff policy. Moreover, wind and solar energy, in particular, might face serious challenges should government policy support be suspended because the proper conditions (e.g., appropriate electricity market reforms), were not yet developed. Based on these reasons, I have found that these technologies are relevant and decided to study both wind and solar energy in my thesis.

The aim of this study was to assess the effect policy and investigate its role and impacts on supply, planning, and manufacturing, as well as climate change and energy transition. The study aims to fill knowledge gaps related to providing a comparative analysis of the experience in other countries related to feed in tariff design, challenges, and renewable energy planning. In addition, answers are provided to various criticisms of feed in tariff policy by discussing common scholarly arguments found in the literature. The research questions (RQ) included in this thesis research follow.

RQ0 What levels of FIT would guarantee profitable margins for PV installers in residential and non-residential installers?

According to many observers, the feed in tariff price announced for the photovoltaic energy in July 2012 was the highest in the world. The Japanese Ministry of Economy, Trade and Industry provided information that indicates 3% and 6% internal rates of return for residential and non-residential PV projects, respectively. However, critics claim that the tariff level is too high, and causes excessive burden on the electricity end users. Moreover, the high tariff price is expected to cause a boom and bust effect for the photovoltaic market, as has happened in similar cases in European countries. Environmentalists, on the other hand, find the tariff level appropriate because it could accelerate the supply of photovoltaic projects.

RQ1 By what mechanism, should FIT be dynamically adjusted to cope with market dynamics in Japan?

In other words, considering cost dynamics, how should the FIT price be dynamically reduced over time?

The feed in tariff price of photovoltaic energy is currently the most expensive compared to all other renewable energy technologies. This feed in tariff price, if not optimized dynamically, could result in 1) excessive profits for investors and project developers (the snowball effect), 2) increased the burden of sharing the cost of the FIT program (FIT surcharges passed to electricity consumers and taxpayers). Moreover, reducing the FIT as a reactive measure, due to information delays and or lack of proper control measures, usually results in catastrophic effects on market stability.

RQ2 How is the growth of renewable energy to be planned, given the limited infrastructure?

Despite calls for accelerating renewable energy development or increasing its share above the levels announced by the Japanese government, the limitation of the infrastructure raises serious challenges. The growth of renewables requires various regulatory and technical reforms to the electric transmission network.

RQ3 What effect does the FIT have on innovation in the renewable energy sector?

The multi-objective justification of promotion policies emphasizes the role of feed in tariff policy in innovation for technological enhancement and cost reduction. Recent literature indicates a broad range of results related to the effect of the feed in tariff on innovation. Moreover, some research suggests that the feed in tariff policy encourages practical innovation (learning by doing) for cost reduction and economies of scale rather than radical or disruptive innovation.

RQ4 What effect does the FIT have on energy transition in Japan?

The introduction of FIT policy has important effects on the transition to renewable energy in Japan as a mechanism to achieve renewable energy targets. The rapid growth of renewable energy affects the profitability of conventional energy generators, and eventually affects CO2 emissions. The potential for achieving a 100% transition to renewable energy is discussed.

The impact assessment of this study was conducted using an integrated method of system dynamics and case studies. The research utilised a mixed methodology that integrates the System Dynamics and Case Study approaches (Williams, 2002). Case Study (Yin, 2008) is a well-established methodology in social and management sciences for theory building. This methodology is widely used for its strength in exploring and explaining problems. Theories are developed from observing certain patterns recurring in the cases under study. It is very useful for comparative research where there is not enough data available for the new case to be studied. This applies significantly to this research (i.e. optimizing the feed in tariff for PV energy in Japan. On the other hand, because this research involves an optimization problem, case study methodology alone is not sufficient. It becomes essential to integrate Case Study methodology with a complementary approach that is appropriate for solving optimization problems.

System Dynamics emerged in the late 1950s, initiated by Professor Jay W. Forrester. Since then, it has been widely employed in the area of corporate strategy design, industrial management, and economy and policy analysis. System dynamics is the optimal solution for complex and dynamic problems that involve nonlinearity, time delays, accumulations, and human intervention. It is built on the fundamental principles of mental models, feedback loops, and stock and flow modelling (Cronin, Gonzalez, & Sterman, 2009; J. Sterman, 1994). These principles became the fruit from integrating various theories and philosophies like General System Theory (Ludwig von Bertalanffy), System Theory and Sciences (Kenneth Boulding and Herbert Simpson), System Approach (Norbert Wiener) and (Feedback Control Theory) to name a few (Barlas, 2002).

The thesis conclusions provide important contributions to the literature in several areas. The profitability of feed in tariff prices in Japan has shown that the self-consumption policy used for the residential sector may affect the payback period. This is especially true if differences in power consumption among households around Japan are considered. Given the geography of Japan, the solar irradiation resources are not equally distributed, and significant variation of solar electricity output can be expected. Consequently, high variation in the revenues generated will occur, with consequently different payback periods. It is recommended to have a FIT zoning system, where the FIT prices are based on the average solar irradiation of each prefecture. The model results also have suggested future tariff prices that maintain a certain level of profitability and so help in creating a sustainable

market in Japan for solar energy.
Long-term development analysis of the solar energy industry in Japan revealed some future limitations that could restrict its growth. Considering the legacy electrical system in Japan, the capacity of the electric grid is one of the greatest challenges to be overcome in the next decade. There is also a scarcity of land suitable for large-scale solar development, which could cause real estate prices to increase, which will shift market development towards the residential sector. This requires policy reforms providing land price control through special taxes, or providing permits for solar construction above agricultural land. Short-term development analysis showed that frequent price adjustment could help in reducing the 'rush to install' effects seen in Japan, as well as other countries like Germany. A continuous feed in tariff model versus discrete feed in tariff was discussed. Results showed that the continuous feed in tariff model provides a more robust and adaptive policy in relation to price changes. It also helps ensure that the new supply of solar energy occurs within intended capacity corridors.

A quantitative model of solar energy development on a limited grid was used to examine two major scenarios. The first scenario involved estimation of solar energy growth with plans for grid expansion. The second scenario involved estimation of solar energy growth when the reserve capacity of the electric grid now provided by fossil fuels, is supplied by solar energy. The results have shown that the second scenario provides faster growth for solar and other renewable energies. It also found that substantive resources could be saved if the second scenario is implemented to increase the growth trend of renewables, instead of increasing imports of LNG or crude oil.

The assessment results of FIT effects on innovation for renewable energy technologies were positive. Using patent count analysis, major companies contributing to research and development in the field of solar photovoltaic technologies were found to be increasing after the introduction of FIT policy in 2012. However, the impact of the cumulative patenting activity on cost reduction, or in generating cost-effective alternatives is questionable and should be investigated in further research. This is because the Japanese photovoltaic modules are still the most expensive when compared to similar modules manufactured in Germany, let alone those manufactured in China or South Asian countries. Because most recent policy research uses patent data limited to the year 2011 or before, further research should also focus on recent patent statistics obtained from different major patent offices. This will be necessary because heavy patent filing activity has shifted to the Chinese and Korean patent offices as primary filing offices. In addition, investigating innovation activity should not be limited to the statistical significance obtained from patent count data, but should also be combined with other measures to produce more accurate conclusions.

The effect of the FIT policy on energy transition has influenced the increase in renewables and decisions about the future energy mix, and ultimately, decisions about climate change mitigation. First, a literature survey showed that achieving a 100% renewable-energy mix scenario largely from wind and solar is highly arguable. The feasibility is not in question only because of the variability and predictability issues with wind and solar, and the technical instability these questions might cause to the transmission network. There are still serious questions about the long-term economics of these two energy sources. The assessment concluded that under the merit order effect, or priority dispatch scheme, the relative value of wind and solar energies decreases with higher penetration. This, in turn, reduces the return on investments of wind and solar facilities to the level when it becomes difficult to recover their investment costs. Therefore, renewable energy subsidy programs will have to be used to extend the sustainability of those facilities. Given that the future cost of solar and wind electricity will be competitive with conventional energies, it becomes necessary to ask whether the merit order scheme should be used in the future. In any case, a search of the literature has not provided a viable alternative to the merit order scheme.

The primary motivation in many countries for the addition of renewable energy was as a mechanism for climate change mitigation by reduction of carbon emissions, or more generally, reduction of greenhouse gases emissions. Despite calls for accelerating the share of renewables, especially wind and solar, GHG emissions were found to be increasing in countries like Germany and Japan. The impact assessment concluded that inconsistent strategies can void the effect of the FIT policy and all the efforts and cost spent to achieve its top priorities. This is in part because, over the short and medium term, renewable energy as a dominant share in the energy mix might be impossible without the support of conventional energy sources. However, the merit order scheme, which prioritizes the use of renewables ahead of fossil fuel technologies, makes fossil fuel technologies unprofitable. This policy creates a feedback response where the cost of fossil fuels decrease, thus again becoming more competitive than the subsidized renewable energies. Cases from both Japan and Germany demonstrated such market dynamics despite the massive budget provided to reduce carbon emissions. To be effective, climate mitigation policies have to be amended to support FIT policy. Moreover, limited support and controlled subsidies should be provided to fossil fuel-based power generators during the transition phase, until the renewable energy share, and related infrastructure technologies, become more reliable and resilient. Furthermore, the fossil fuel-based power generation market and fossil fuel investment should be monitored and controlled to limit the increase in GHG emissions.