An Analytical Framework of Socio-economic Modelling of Micro Nuclear Reactor Projects

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1. **Introduction**

As most of MNR projects are currently carrying out conceptual and basic design, however their socio-economics and business models are very uncertain. They need not only to overcome technical and licensing risks but also find sufficient markets. On the other hand, business modelling is a systematic process to explore the external opportunities(O) and threats(T) for finding potential markets and business products, and examine internal strength(S) and weakness(W) for capturing the markets with the competitive traits of the products. Against the backdrop, this study is to develop an analytical framework of business modelling to estimate socio-economics for the commercial application of micro nuclear reactors (MNRs) in the 2030s onwards. Chapter 2 explores potential markets for the MNRs. Chapter 3 and 4 examine competitive traits and business risks respectively. Chapter 5 explains how develop analytical frameworks to estimate socio-economics of MNR business to capture and improve the potential markets. Chapter 6 provides conclusions while summarizing research results and suggesting further studies.

2. Market opportunities

Because the MNRs have a very small production capacity, they are generally less economic than large NPPs and SMRs for producing base-load electricity. So, MNRs are expected to have different markets from those of larger nuclear reactors. MNRs can find their markets in remote areas where energy systems are separated from large power grids or reliable fuel supply. In this off-grid remote area, MNRs can respond consistently and reliably to base load demand without the risk of interrupting energy production compared to fossil fuels and especially renewable energies. Currently, a potential global market is estimated to be around 3 GWe (300 units of 10 MWe) in 2030-2035.

However, MNR's markets would be much greater than current estimation. In addition to off-grid remote markets, MNR can be used for industrial and residential purposes as a source of thermal and electric energy. But these markets are mostly in densely populated cities and industrial complexes. If the micro reactor has the function of passively inherent safety under any extreme conditions including complete loss of coolant scenarios with no possible release of radioactive material, the market for the MNRs can be greatly expanded to all types of micro grid markets from remote to urban areas. According GTM Research (2017), the micro-grid market in the United States is expected to more than double over the six years from 2017 to 2022. As of 2017, the US micro-grid capacity is 3.2 GWe and is expected to grow to 6.5 GWe by 2022 at an annual average of 14.1% increase over the next six years. This forecast sees that an additional $ 12.5 billion will be invested in the micro-grid business in the United States alone over the next six years, increasing the total business to more than $ 25 billion by 2022.

3. Competitive traits

The paradigm of sustainable development pursues balanced development of economic growth, environmental protection and social stability. As for the environmental compatibility, MNRs must be absolutely free from radiation hazards. After the Fukushima nuclear accident, the social concern of nuclear safety has been outweighing the benefit of nuclear economics and energy security. If the radiation risk of the micro reactors is eliminated in their life-time operation including radioactive waste management, they will be very likely to lead future energy systems while rarely emitting greenhouse gases including carbon dioxide and NOx and SOx, which affect global warming. In terms of social compatibility, energy security is of the utmost importance in the off-grid and stand-alone energy system. Once installed and operated, MNRs can be operated for a very long time, typically 4 to 5 years without interruption by weather conditions. As such, MNRs have high efficiency of fuel supply and storage. The resilience of MNRs means the ability to restore the power generation system on its own with the so-called black start and dispatchability functions when the system is broken. MNRs can be snatched out by malicious intention, when the reactor is being operated on a transportable. Therefore, the nuclear non-proliferation and physical protection need to be embedded in MNRs. The economic compatibility of MNRs represents high cost for energy production. However, this cons can be offset by the pros that MNRs could offer in other ways. Very small size and simplified design cause relatively very little amount of capital cost for the manufacturing and construction of MNR. Besides, most of manufacturing and constructing MNRs can be done in the factory so that the work quality can be maintained very high. Likewise, the MNRs are much easier to operate, maintain and dismantle. The MNRs can obtain a learning effect in case of mass production. The MNRs can be recycled when the lifetime of market is expired earlier than the design life (usually 60 years) of MNRs. In addition, the MNRs can economically respond to various demands for producing power and heat separately or together. Finally, the technical characteristics and behaviors of

MNRs can be directly tested on a real scale while simplifying relevant computer model.

4. Business risks

The socio-economics of MNRs tends to be influenced by several risks. As of now, there is a high risk of not being accepted by the public especially in urban areas no matter how good advantages MNRs offer. In the long run, there is a risk that government policies can be fluctuated in the course of MNR projects and their services. MNR projects can be delayed due to regulatory process. Although MNRs need very low capital cost, they still have financing risks.

Unlike large nuclear power reactors, however, the business risks ensued by MNR projects can be greatly reduced. This socio-economic risks tends to be mostly caused by technological characteristics, especially nuclear safety. If MNRs secure the inherent safety of the passive type without core melting, the fore-mentioned risks will no longer threaten the socio-economics of MNR projects. Then MNR business can be done only under the economic factors. Without any possibility of the leakage of radioactive materials in extreme situations, MNRs will not cause the pubic and politician to be of grave concern about nuclear accidents. In the same way, the risk of licensing is significantly reduced and the emergency planning zone is negligibly reduced. Some of MNRs are currently designed to apply an emergency planning area with a radius of about 25m. The high safety of can greatly reduce the cost associated with the safety system. In large nuclear power plants, the safety system is known to account for about 30% of the total cost. In addition, the reduction of capital cost contributes to lowering the risk of financing. No risk of nuclear accident can also make MNR business escape from the risks associated with damage compensation and damage recovery costs to be paid in the event of a radiation accident. Finally if there are no risk of nuclear accidents, MNRs can enter into the market in urban areas which has not been exploited.

5. Modelling socio-economics

Business modelling is a systematic and interacting process of entrepreneur's organized activities to turn ideas of new business into a reality by identifying the interacting paths between products and profit from the business. Based on understanding potential markets, and generic traits and risks of the business, the modelling need to decide their targets of the business in terms of socio-economics.First of all, this modelling should be developed in two levels. The generic module can be commonly applied to all markets, regardless of remote and urban areas while specific modules can address the specificity of each market. By combining the generic and specific module, business models can be tailored to both the specific needs of potential markets and the technical characteristics of MNRs as reasonably as possible. For the market defined with generic and specific modules, the modelling needs to analyze total costs and benefits generated by the new business. This socio-economics should be informed by the analysis of breakeven point that explains relationships among unit of sales (output), total costs for sales, total revenue from sales, and total profits and losses for a business. For this breakeven analysis, this paper employs the concept of social costs. Unlike the method of levelized cost of electricity generation (LCOE), the framework of social costs leads to comprehensively analyzing socio-economic costs and benefit while including external effects as well as the LCOE. To use the approach of the social cost, we follow the general principal of sustainable development. In other words, our study challenges to examine comprehensively socio-economic values of the MNRs in terms of economic, environmental and social compatibility. Economic compatibility refers to the question of how much the technical system could generate economic benefit and how much total cost is needed. Environmental compatibility can be evaluated by analyzing how much MNRs cause benefit or harm to ecological systems of nature. Social compatibility is evaluated by the impact of the MNR on social stability, such as energy and social security.

6. Conclusions

Using the framework of business modelling, this study developed an analytical guidelines for socio-economic modeling which can be applied to the business of MNR projects for two different cases such as remote and urban markets. In further study, first the framework should be more elaborated so that it can be applied to empirical studies. The business modelling should find breakeven points with social costs with the quantitative estimation for the FOAK and NOAK in both remote and urban area, respectively. By doing, the socio-economic cost and benefits of each business model should be comprehensively quantified in terms of economic impact, environmental footprint and the social effect.

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