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Revisiting Options Analysis for Long-Term Energy Projects

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Abstract: Energy supply is currently undergoing a major transition from fossil fuels to more sustainable sources such as renewables and nuclear. However, in the longer term, it is unclear whether these sources will be able to meet demand increases from the developing world, increasing population, and new uses of energy. A sustainable world may require more energy to counteract the impacts of climate change, for example, on the supply of clean water and food. Since it is uncertain whether distributed energy sources will meet this demand, new energy supplies might be considered. Some options considered already include more sustainable nuclear systems with use of thorium and fuel recycling, fusion, and large solar projects in orbit, the moon, or in deserts. Previous option analysis of these technologies are reviewed and updated based on current understanding. Potential extensions and approaches are identified for uncertainty estimation, incremental roadmapping, distinguishing serial and parallel technologies, the value of R&D information, and incentive strategies for realizing the economies of scale and learning-by-doing benefits.

Keywords: options analysis, renewables, nuclear power, research, uncertainty

1. Introduction

While it would be nice that future energy needs could be supplied by economically viable distributed renewable energy sources, there is still large uncertainties in the economic characteristics and the future energy demand. The demand is expected to increase due to increased population, continued diffusion of development towards first-world living standards, and additional energy needs through applications of new technologies or in the use to combat potential environmental impacts such as the need for fresh water through desalination. The characteristics in terms of life-cycle costs include lifetimes, maintenance costs, transmission and infrastructure costs, reliability infrastructure for backup costs, and how much costs will come down due to research and development learning curves , and scalability as the best lands are first developed. The rising demand of energy and other resources is seen in the rise of the commodity resource bureau spot index over the past 50 years with two jumps of a factor of two in both the early 1970's and the early 2000's [1].

To hedge this uncertainty options for larger base load projects might be considered. Options for these projects include larger renewable projects such as placing photovoltaic (PV) installations in deserts, in geosynchronous orbit, or on the moon [2]. Other non-fossil fuel large projects being considered include nuclear fusion, advanced nuclear fission with a closed fuel cycle, use of thorium, or advanced fast-neutron reactors such as the traveling wave reactor. Many of these projects were originally proposed over 50 years ago, with many being periodically evaluated for their technological and financial viability. By maintaining their research, an option or insurance, is maintained to reduce the risk of being left without an interim solutions at a later time.

The tightly coupled system of energy, environment, and economic issues involves a wide range of interested groups over a long period of time under significant uncertainty. Issues with this set of conditions, sometimes referred to as "wicked problems," often require trial solutions that are monitored and then modified since no detailed solution can be predetermined. The feedback and iteration improves the solution as uncertainty is reduced. This type of approach requires many foresight techniques such as multiple scenario development, identifying and measuring progress indices, updating flexible road maps, and the inclusion of multiple perspectives and objectives. While foresight techniques have often been applied in defense strategies, the importance of these complicated issues in energy, environment, and the economy suggest that these techniques could be beneficial. Many countries and regions are applying foresight techniques to decision making [3]. Recent projects involving foresight techniques in the United States include the National Intelligence Council's Global Roadmap and a framework to incorporate such techniques at many governance levels.

One tool to help understand both the trends and their uncertainty is real options analysis. Real options analyses facilitate assessment of flexible technology options in quickly changing situations with large uncertainties for actions that might be irreversible. These situations occur in technology driven decisions where technology, regulations, markets, and scientific understanding quickly evolve. Whereas traditional assessments rely on specific alternative actions with few flexible decision points, real options analysis, an extension of the financial community's options methods, also considers the impact of flexible decisions, such as delaying, switching, expansion, and abandonment, in uncertain conditions, such as fluctuating costs. This analysis is similar to the net present value tool but also has the ability to consider possible flexible futures under uncertainty. A number of authors have applied this technique to a range of energy research and development cases, including those for solar power satellites, thorium-based nuclear power, and federal renewable energy research. The key for these tools is to have a good estimate for the scenarios, then track the progress of the research and cost reduction through experience.

An example of flexible technology development is the well-known Manhattan Project conducted during World War II. The goal was to try to find a way to construct a nuclear explosive device (before the other side did). The most difficult part of the process was to collect enough special isotopic material to form a critical mass. Research showed that there were many potential ways to collect this material (including differential thermal diffusion, magnetic mass separation, gaseous diffusion, and reactor production), but it was unclear which were quicker and more efficient. As a result, many potential options were tried simultaneously. Some methods, after great investments, did not deliver as originally thought. Others were revised as research findings led to reconsideration of the priorities. The great uncertainty and motivation for the research was the threat that the other side (considered between Germany and the United States) would discover the secrets and use the new weapon first. As the war wore on, indications of German research in this area were observed and sabotaged. Near the end, when the decision of deployment was to be made, multiple limited successful special material collection techniques were implemented. Just before the final test of the system, the main motivator was reduced to zero (German surrender without nuclear weapons use).

2. Literature Review

Applications of real options analysis have included the evaluation of the research in renewable technologies [4,5] and the options for large energy projects [6-10]. Some more general analysis have been done evaluate the sharing of technology between developed and developing world to move away from carbon dioxide emissions [11].

The federal investment of the U.S. in renewable energy has been roughly a bit under $1 billion (in U..S. 2005 dollars) with a peak in the late 1970's reaching over twice that average. (This has been about a sixth of the federal investment in energy R&D with the other areas being fossil fuel, nuclear, electrical systems, and energy efficiency.) Analysis of this U.S. research in renewable energy has shown the while the net present value of this research is negative $35 billion, the value with the option to develop further with flexibility is over positive $30 billion [4]. The analysis done in 2003 showed that there still were positive marginal benefits to more R&D with the optimal rate of R&D leading to a positive options value of about $50 billion. A later analysis with refinements estimated the options value at between $40 and 100 billion (U.S. 2002 dollars) [5].

While options analysis has been done for large nuclear projects such as fusion [6], thorium fueled [7], and accelerator driven reactor [8] designs, a more generic analysis has been done for large projects and then specifically applied to space based solar energy [9-10]. The solar project would place PV solar cells in large array in geosynchronous orbit so it is always above a ground based microwave rectenna that very efficiency receives the power beamed from the converted PV electricity. The solar energy collectors would be in solar light at all times (as opposed to earth based which are not in direct light at night or on cloudy days). Besides this the intensity of the light is about 4 times that on Earth. The rectenna is mostly transparent to visible light so that it could be built above land used for other purposes such as agriculture. The analysis considered a 1 GW power system which was estimated to cast $11 billion and have a mass of 1,600 metric tons. The main uncertainty was in electrical prices which historically have 30% volatility/yr in costs. System costs were assumed to have a volatility of 20% per year. A relatively short time frame of 5 years was considered. The net present value of the system was negative $2.2 billion but options value (ie., deploying only when the electricity prices were increasing and the system costs decreasing) was $2.5 billion.

3. Needs and Model Proposal

To further use this type of analysis, much data, understanding and models need to be developed. These needs include the complicated nature of the uncertainty. Often the uncertainty might be grouped into an aggregate representative but more value is realized with some independence between sources of uncertainty being addressed. Historical learning curves might offer an insight into energy technologies although the simultaneous research, development and deployment activities might result in new learning curve behaviors. This is especially true with the development of systems with multiple integrated technologies. Examples of research in these topics are Gritsevskyi & Nakicenovic [12], Dahlgren [13], and Siddiqu [14].

Risks include market risks and technological risks. Concerns in markets risks include the price of fuels, the cost placed on carbon emissions, price of electricity, and learning curve rates as the technologies are commercialized and developed. The electricity price will depend on many of the technological developments such as storage devices and dependence of travel on electrical power. Technological risks include the level of research results, the ability to address the weak link in the technology dependency, the understanding of the environmental risks associated with each power source.

Technology dependencies might alter the analysis with the need for developing common technology or an alternative path that by-passes a technology. For example, in renewable energy systems, the variability of the generation along with the time difference between power generation and need, lead to a need to mitigate this unreliability. One solution is a battery or energy storage system which might also be used to perhaps facilitate the development of electrical transport.

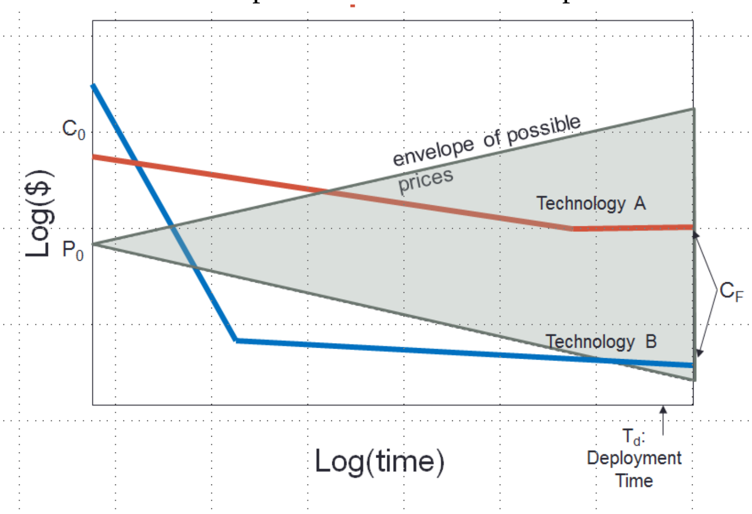

Figure 1. Diagram showing assumptions of a new multiple technology model. The model covers the research phase before a deployment decision. The costs of the technologies decrease as R&D funding is allocated. The relative advantage of the technologies are their costs and also the eventual capacity for generating power.

A new recursive model is being developed with the traditional binary real option analysis along with incorporating learning curves and a portfolio of competing technologies. Each technology has an initial cost (without any additional research), a final cost (with maximal R&D), a generating capacity, and a learning curve rate per R&D investment. At each step investments are made in selected technologies. The uncertainty in electricity price is modeled by binary geometrical random walk of the price as in the traditional ROA methods. At the end of the research period the technologies are deployed if their costs are lower than the electricity price. The costs are dependent on the amount of

R&D funding up to that point. The value of the deployment if the net present value of the future operation of the technologies at their capacity discounted by the interest rate. The model starts by calculating the final value of each potential state of price and research fund distribution. It then proceeds by steps backward in time, evaluating the value of each possibility leading to the future possibilities and weighted by the probability of the electricity price jump. This model can be easily implemented with recursive software.

4. Conclusions

While many advances and progress are occurring in researching, developing, and deploying distributed renewable energies, uncertainties still exist for their capability to economically support energy demand with the fluid situation of increasing population, diffusion of improved life-styles, and new energy dependent uses. One way to mitigate the risk of insufficient energy supply is to continue research into alternative large energy projects in both renewables (such as centralized PV locations) and nuclear energy (such as advanced fission and fusion projects). One tool to assist in the decisions to continue, delay, or abandon projects includes real options analysis. While this technique is often applied in commercial organizations, the use within government decision making is trailing. However, other researchers have explored various aspects of its potential application including evaluating and optimizing research investments for renewable and nuclear projects. While these investigations elucidate the issues, much work needs to be done to characterize the uncertainties, develop processes for revision, and implement in a complicated multiple technology environment. A new model was proposed for the simplified case of the research phase of multiple technologies which requires the characterization of the potential research. This analysis could be coupled with techniques being developed for long-range policy analysis that uses models to develop potential scenarios of global development.

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