Renewable and Sustainable Energy Reviews 82 (2018) 2693–2704

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Real options analysis of investment in solar vs. wind energy: Diversification strategies under uncertain prices and costs

Ardjan Gazheli[a,*], Jeroen van den Bergh[b,c]

[a] Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Edifici Z—UAB campus, 08193 Bellaterra, Spain
[b] ICREA, Barcelona, Spain & Institute for Environmental Science and Technology, Universitat Autònoma de Barcelona, Edifici Z—UAB campus, 08193 Bellaterra, Spain
[c] Faculty of Economics and Business Administration, and Institute for Environmental Studies, VU University Amsterdam, The Netherlands.

ARTICLE INFO

Keywords:
Investment
Real options
Renewable energy
Sunk costs
Uncertainty

ABSTRACT

In this paper we study a community or firm considering to diversify its investment in two distinct renewable energy technologies, namely wind and solar PV electricity. We assume technological learning curves as a function of cumulative capital investment. A real options approach is applied as it takes into account uncertainty about prices and learning, as well as irreversibility associated with investment decisions. We investigate three different cases, dealing with uncertainty about future electricity prices, and uncertainty about the speed with which learning drives the costs of wind and solar electricity down. We assess the minimum threshold for the stochastic price and the maximum electricity production cost that makes it optimal for the firm to invest in the two technologies. The results show that the learning rate affects the option to invest in but reducing critical threshold for exercising it. The greater the amount of capital invested, the more learning stimulates earlier exercising of the option to invest. The firm will then anticipate the option to invest and exercise it for lower critical threshold values if all capital is invested in one technology. If capital investment is diversified, the option should be exercised at a higher critical threshold. More uncertainty in energy prices or technology costs postpones the option to invest. Although investing in both solar and wind may be profitable under particular conditions of price and cost uncertainty, the theoretically optimal strategy is generally investing in only one technology, that is, solar or wind, depending on their relative initial costs and learning rates. This suggests that the practice in most countries of diversifying renewable energy may reflect a mistaken strategy.

1. Introduction

The energy sector is currently facing serious challenges connected to climate change and peak oil. For this reason, energy issues are high at national, European and global agendas. The easiest way to reason about these problems is by considering a most likely definite solution to the core problem, that is, the emission of greenhouse gases, notably carbon dioxide. Given that nuclear power involves serious concerns about calamity risks and long-term radioactive waste, renewable energy seems to offer the only definite solution. It can in principle support the supply of electricity and other types of energy carriers in a carbon-free way. Of course, this requires that renewable energy equipment, including all intermediate industrial and transport activities involved, are produced with carbon-free energy. In order to allow for a broad-scale adoption of renewable energy, it needs to produce electricity at market-competitive prices, possibly through price subsidies in the form of feed-in tariffs [7].

Renewable energy sources (RES) are considered to play a fundamental role in decreasing the above mention problems and creating new business opportunities. However, because of high initial costs of investments, low rates of return and uncertainty about future markets (competition, prices) and technological developments complicate firms' decisions on such investments [37,39]. Within renewable energy, one can identify wind turbines, water power, biomass energy (including biofuels), concentrated (solar) heat power, and solar photovoltaics (PV) as the main candidates for future dominance. However, which technology will ultimately emerge as the most attractive is uncertain. These are different technologies, with distinct initial costs and learning curves. A community or investor may want to diversify the investment in such technologies as a response to any uncertainty about their future costs and learning curves.

Traditional evaluation models such as cost-benefit analysis, usually guided by the net present value (NPV) criterion, fail to assess the strategic dimension of investments in RES by leaving out risk and uncertainty associated with future rewards [4]. More sophisticated evaluation techniques are needed to deal with these. One is real options theory which sees the firm as an investor holding a financial option. It

* Corresponding author.
E-mail address: a.gazheli@gmail.com (A. Gazheli).

https://doi.org/10.1016/j.rser.2017.09.096
Received 26 August 2016; Received in revised form 19 July 2017; Accepted 25 September 2017
Available online 06 December 2017
1364-0321/

gives it the flexibility to exercise the option now or wait (at a cost) in order to acquire more information on uncertain market (competition and prices) and technological conditions. In line with investments in RES, the initial investment cost is considered irreversible, that is, once the firm decides to invest, it kills the option and the investment cost is considered sunk. The aim of this study is to develop a decision-making model considering the factors affecting firms' willingness to invest in renewable energy projects, such as wind or solar energy (see Table 2).

The problem we try to solve in this article concerns the choice of a firm or community having to decide about how much to invest in two types of renewable energy technologies, namely wind and solar PV. The earnings from the two technologies are calculated as revenues minus costs (investment and maintenance costs). Revenues are obtained by selling the energy (electricity) produced with the two technologies (which is not storable) at a single market price. We consider three different cases with our model, motivated by the fact that one cannot solve the model for two learning curves (wind and solar) with both stochastic learning rates, or for one stochastic learning rate and a stochastic price. Even numerical analysis is difficult in these cases as no intermediate analytical solutions to work with are available. The three cases are: 1) a general case where the two technologies have different electricity production cost curves, with the solar technology starting at a higher initial cost than wind but showing a faster (steeper) learning curve and thus cost reduction rate; 2) a specific case where only the cost of solar PV electricity decreases over time according to a learning or experience curve, while the cost of electricity produced with wind technology is constant; 3) price as deterministic and the cost of the solar technology and its learning rate as stochastic. In the first two cases we consider uncertainty at the price level and solve the problem by finding the minimum price level and optimal timing, for which it is profitable for the firm to invest. We show the difference between the NPV method and the real option approach which takes into account important factors such as drift and uncertainty in the stochastic prices of electricity. In the third case, we investigate how the learning rate of solar PV and stochasticity of the cost of electricity production with this technology affect the decision to invest. We identify the maximum value in the production cost at which the firm is willing to invest a part of the capital in a determinate technology.

The reminder of the article is organized as follows. Section 2 reviews the literature on applications of real options theory to investment in renewable energy. In Section 3 the basic set-up for the model is presented, and general analytical results are derived. Section 4 offers numerical analyses of the three model cases. Section 5 concludes.

2. Real options and renewable energy

2.1. A typology of real options

Good investment decisions are an important condition for continuity of firms. Bad investments taken in the present can lead to unsustainable circumstances or even a bankruptcy of a firm. Hence, a solid method of evaluation of investments is required.

Investment tend to have three important characteristics:

– They are partly or completely irreversible, meaning that their initial cost is to some extent or totally sunk and cannot be recovered.
– There is uncertainty connected to future rewards. This can be addressed by assigning probabilities to future cash flows.
– The timing of investments is variable, meaning that a decision about them can often be postponed in order to acquire more information, even though this will usually not reduce completely uncertainty.

Traditional methods such as NPV or discounted cash flows (DCF) are used to evaluate investments. However, these methods are not very sophisticated in dealing with complex investments such as those in RES for example. The DCF approach for example is not ideal since it bases its prediction on the certain future rewards the investment will generate thereby not considering important aspects such as risk and uncertainty. The NPV on the other hand considers the investment as a now or never option, thereby leaving out the important option to postpone or delay an investment for the sake of acquiring information or waiting to see how market conditions develop. In addition, these methods do not consider the irreversibility of the investment cost. As the firm undertakes the investment, it will not be able in the future to recover the initial investment cost if market conditions turn out to be not favorable anymore.

Irreversibility and the possibility of postponing the investment in time are two important characteristics of investments. Thereby, a firm with the option to invest is seen as holding an "option" which is similar to a financial option. In this case the firm has the right, but not the obligation to exercise such option. When the firm decides to exercise the option, it "kills" the option to invest giving up the possibility to wait for new information (or more results of learning, innovation) to arrive that may be of vital importance [11]. By taking such decision the firm makes an irreversible step as it cannot divest should the market conditions turn out bad. This lost option value is an opportunity cost that must be taken into account as part of the costs of the investment.

Table 1 introduces the different types of real options, along with definitions and potential applications to the context of renewable energy technologies.

2.2. Real options theory applied to renewable energy investments

The energy sector has seen a major transformation in the last years. It has passed from a regulated and state owned sector to a privatized and deregulated one. Currently there are a large number of companies operating in the market thereby introducing a large uncertainty and making the sector highly competitive. Another characteristic of investments in this sector is connected to the high initial costs of investments in these technologies and the irreversibility of such investments. These factors opened the door for the use of real options theory for the evaluation of investments in energy.

The application of the real options technique for the evaluation of investments in the energy sectors has some history. The first application was by Tourinho [53]. Later on, Brennan and Schwartz [5] applied option pricing theory for the evaluation of irreversible natural resources in the Chilean copper mines. In the same years, the real options theory was used for the evaluation of investments in the oil industry [13,41,49].

In the period 1990–2000 real options theory was developed. Important contributions are Dixit and Pindyck [11], Trigeorgis [54] and Amram and Kulatilaka [1]. Later on, the theory was applied to investment in different fields, including the energy sector. Table 2 introduces the most important studies applying this method and summarizes their main features, such as the types of uncertainties addressed or the mathematical technique employed.

As shown in the table, these studies are mostly applied and focused on particular regions. The main objective of such studies is to test specific climate or energy policies for particular countries or regions. Other studies address general issues associated with investments in renewable energy.

3. Model set-up

Consider a firm or community that wants to diversify its investment in renewable energy by considering two options. In our particular case, we interpret the setting as the firm having to choose between investing in wind and solar PV energy. The earnings from the two technologies are calculated as revenues minus costs (investment and maintenance costs). Revenues are obtained by selling the energy (electricity) produced with the two technologies (which is not storable) at a single market price.