# Renewable energy investment under the risk of change in support schemes

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We consider the impact of a change in policy on investment in renewable energy. Our focus is how investment rates are affected by the probability of a revision of the current support scheme for renewable energy, aimed at incentivising producers to respond to market developments. For analysis, we use a real options model for investment timing under both market and policy uncertainty. We show that with the probability of a change from a feed-in tariff to a price premium, exposure to market risk increases. Assuming a change in risk exposure only, the expected value of an operating project remains unaffected by the prospects of revision. However, the potential increase in volatility of future revenues creates a value of waiting and thereby an incentive to postpone investment.

*Key words*: Real options, investment timing, renewable energy, regulatory policy, policy uncertainty, feed-in tariffs, green certificates, jump-diffusion processes

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## 1. Introduction

At present, many renewable energy projects are granted production support to ensure competitiveness. As renewable technologies mature, the current support schemes will very likely change from government-determined subsidies in the direction of more market-driven schemes or will even be terminated. As an example, this is reflected by the following quote from the European Commission guidance for the design of renewable support schemes (http://europa.eu, 2013): "As technologies mature, schemes should be gradually removed. For instance, feed in tariffs should be replaced by feed in premiums and other support instruments that incentivise producers to respond to market developments. Unannounced or retroactive changes to support schemes should be avoided as they undermine investor confidence and prevent future investment". As a result of a change of support scheme, investors become increasingly exposed to both policy and market risks. We take a real options approach to analyse the impact of such risks on investment incentives. In particular, we consider the timing of a new project in two cases: (i) the change from a fixed-feed in tariff to a feed-in price premium and (ii) the change from a price premium to a green certificate trading scheme. Whereas market risks evolve continuously over time, a change of policy occurs in a discrete fashion at some random future point in time. More specifically, we model electricity and certificate market prices by a geometric Brownian motion and a sudden change of scheme as a Poisson event. We distinguish between the situations in which investors believe that government commit to existing contracts of support and when it does not. In spite of the guidance from the European Commission, retroactive changes to support schemes has already been made in countries such as Spain, Italy and Czech Republic. To explicitly focus on the effect of a sudden change in risk exposure, we assume that government determines (i) the price premium or (ii) the certificate price such that revenues are unaffected by the change of scheme at the time of revision (we refer to a continuous revenue stream). For case (i), we show the following: As we model policy change as permanent, the expected value of an installed project after revision is clearly the same as that under an infinitely applied price premium, and hence, will vary with electricity prices. Before revision, however, the expected value of an installed project is independent of current electricity prices under the assumption of a continuous revenue stream. In spite of this, given that a future revision may occur, the value of the option to postpone investment varies with prices, and thus, creates a value of waiting. In general, with the potential increase in volatility of future revenues due to revision, there is incentive to defer investment and achieve higher expected project values. The risk of revision may, therefore, slow down the rate of renewable investment as foreseen by the International Energy Agency: "The expansion of renewable energy will slow over the next five years unless policy uncertainty is diminished" (http://www.iea.org, 2014). The idea is to investigate and quantify this adjustment of investment behaviour and the value of waiting under the risk of revision. Here, we derive the model for case (i), but expect similar results to hold in case (ii).

This paper is structured as follows: In Section 2, we model market and policy uncertainty. In Section 3, we present the investment problem when the investor faces an infinitely applied support scheme in the form of a feed-in tariff or a price premium and is either not exposed to uncertainty or exposed to market uncertainty only. In Section 3, we derive our model for investment timing under the risk that the current support scheme is revised and more specifically, that a feed-in tariff is replaced by a price premium. For now, we leave an infinitely applied certificate trading scheme and the replacement of a prices premium by certificate trading as future work.

## 2. Market and policy uncertainty

We distinguish between two types of uncertainty: market uncertainty and policy uncertainty. Market uncertainty relates to electricity prices and subsidy payments, and evolves continuously over time. In contrast, policy uncertainty, such as future revision of the current support scheme, occurs at discrete points in time.

When modeling market uncertainty, we let electricity prices $(S_t)_{t\geq 0}$ and subsidy payments $(K_t)_{t\geq 0}$ follow geometric Brownian motion processes such that

$$\begin{aligned} dS_t =& \sigma_S S_t dz_{St}, \\ dK_t =& \sigma_K K_t dz_{Kt}. \end{aligned}$$

Here, $\sigma_S, \sigma_K$ are constants that represent the volatilities of prices and payments, respectively, and $dz_{St}, dz_{Kt}$ are standard Brownian motions with $\mathbb{E}[dz_{St}dz_{Kt}] = \rho dt$. Hence, current values of the stochastic processes are known, whereas future values are log-normally distributed with means, variances and covariance that grow linearly with time. In the following presentation, we may occasionally refer to both electricity prices and subsidy payments simply as prices.

Remark 1. We aim to investigate the effect of differences in risk exposure under different support schemes. For this reason, we assume no trend in prices.

This definition of market uncertainty covers various market designs. A constant subsidy may be paid out either as a substitute for the electricity price, denoted by $\bar{K}$, or as an addition to this price, denoted by $\bar{k}$. Alternatively, the subsidy payment may vary stochastically over time, e.g. following the process above. Clearly, if the producer faces variations in either electricity prices or subsidy payments, our investment problem is a univariate real options problem. However, if faced with uncertainty in both prices our real options problem is bivariate.

Remark 2. A constant subsidy paid out as a substitute for the electricity price is usually referred to as fixed feed-in tariff (FIT), whereas a constant subsidy paid out on top of the electricity price is a feed-in premium (FIP). Finally, a stochastic subsidy payment on top of the electricity price can be seen as the market price of a tradable green certificate (TGC).

We model policy uncertainty as a Markov process $(\gamma_t)_{t\geq 0}$ with states $\{0,1\}$ such that

$$\gamma_t = \begin{cases} 1, & \text{if a policy change has occured in the time interval } [0,t), \\ 0, & \text{otherwise,} \end{cases}$$

with $\gamma_0 = 0$.

Remark 3. We motivate policy change by advances in technology. In particular, governments may eventually decide to revise the current support scheme as renewable energy technologies become increasingly mature. For this reason, we assume that policy change occurs only once such that the revision from one scheme to another is never reversed and further revising does not occur.

Denoting the jump-intensities of the Markov process by $\lambda_{ij}$, the above implies that

$$\lambda_{ij} = \begin{cases} \lambda, & \text{if } i=0, j=1, \\ 0, & \text{if } i=1, j=0, \end{cases}$$

for constant $\lambda > 0$. Roughly speaking, $d\gamma_t = 1$; that is, a change of policy occurs during a short time interval $dt$, with probability $\lambda dt$ . Furthermore, if $\gamma_{t-} = 0$ ($t-$ denotes the left-hand limit of $t$), then $\gamma_t = 0$ with probability $1 - \lambda dt$, and if $\gamma_{t-} = 1$, then $\gamma_t = 1$ with probability 1, such that 1 is an absorbing state. We assume that policy change is independent of the evolution of electricity prices and subsidy payments.

## 3. Support scheme with an infinite lifespan

We start by valuing a renewable energy project under a support scheme with infinite lifespan. We make the following assumptions. The project lifetime is finite and denoted by $T$. We assume constant expected production and that profit is proportional to this such that we can value a single unit of production. We consider a price-taking producer, whose instantaneous per unit revenue is determined by a government-determined tariff or premium and/or market prices for electricity and/or certificates. Assuming operating costs are constant, these can be incorporated into the investment costs, and to simplify the presentation, we therefore disregard these costs. We denote the required rate of return of the project by $\delta$ and assume that $\delta > 0$.

The following are well known results.

**Feed-in tariff** When subsidies are paid out as a constant tariff $\bar{K}$, by the net present value rule, immediate investment is optimal if and only if

$$\bar{K} \geq \frac{I}{r},$$

where we define

$$r := \frac{1 - e^{-\delta T}}{\delta}$$

to be an annuity factor. If immediate investment is not optimal, investment never becomes optimal.

**Feed-in premium** When subsidies are paid out as a constant price premium $\bar{k}$, we obtain the following by standard univariate real options analysis. For a given $S$, it is optimal to invest if $\bar{k} \geq k^*(S)$, where

$$k^*(S) = \frac{I}{r} - \frac{\alpha - 1}{\alpha} \cdot S, \quad \mathcal{Q}(\alpha) = 0, \alpha > 1,$$

and

$$\mathcal{Q}(\alpha) = \frac{1}{2}\sigma_S^2 \alpha(\alpha - 1) - \delta.$$

We assume that $r\bar{k} < I$; that is, the price premium is not by itself sufficient to justify investment.

Remark 4. Note that as opposed to standard real options literature, we express the investment threshold as the level of the subsidy required to trigger investment, as this may be the most interesting from a policy point of view. From an investor point of view, the level of the total revenue required to trigger investment will be of major interest.

## 4. From a feed-in tariff to a feed-in premium

We analyze the impact on investment timing of the risk that government may in the future replace a current fixed feed-in tariff may by a feed-in price premium. We assume that revision occurs at a random point in time and changes the dynamics of the revenue stream from deterministic (fixed feed-in tariff) to stochastic (feed-in price premium on top of electricity prices). We distinguish between the two cases, in which the investor believes the government either commit to existing contracts or it does not. If, however, revision only involves a change in risk exposure for investors, we show that the results are the same in the two cases. In the following, we consider two regimes, one in which revision has not yet occurred in regime 0, and one in which the support scheme has already been revised in regime 0.

Remark 5. We may distinguish between the two cases, in which the investor believes the government either does not commit to existing contracts or it does. We refer to the cases with or without retroactive revision, respectively.

In both regimes, the value of an operating project is the expected present value of future revenues streams, although the dynamics of the revenue stream depend on the regime. In the case with retroactive revision, the Bellman equations for the project values are

$$
\begin{aligned}
V_0(S,t) &= \bar{K} + \frac{1-\lambda dt}{1+\delta dt}\mathbb{E}[V_0(S+dS,t+dt)|S] + \frac{\lambda dt}{1+\delta dt}\mathbb{E}[V_1(S+dS,t+dt)|S], \\
V_1(S,t) &= S + \bar{k} + \frac{1}{1+\delta dt}\mathbb{E}[V_1(S+dS,t+dt)|S],
\end{aligned}
$$

and the corresponding system of PDEs is

$$
\begin{aligned}
&\frac{\partial V_0}{\partial t}(S,t) + \frac{1}{2}\sigma_S^2 S^2 \frac{\partial^2 V_0}{\partial S^2}(S,t) + \lambda(V_1(S,t) - V_0(S,t)) + \bar{K} - \delta V_0(S,t) = 0, \\
&\frac{\partial V_1}{\partial t}(S,t) + \frac{1}{2}\sigma_S^2 S^2 \frac{\partial^2 V_1}{\partial S^2}(S,t) + S + \bar{k} - \delta V_1(S,t) = 0,
\end{aligned}
$$

with boundary conditions

$$V_0(S,T) = V_1(S,T) = 0.$$

To simplify notation, we let $V_0(S) := V_0(S,0)$ and $V_1(S) := V_1(S,0)$. The value of an operating project is then

$$V_0(S) = r_0(\lambda)\bar{K} + r_1(\lambda)(S+\bar{k}), \;\; V_1(S) = r(S+\bar{k}),$$

where the annuity factors are

$$r_0(\lambda) := \frac{1-e^{-(\delta+\lambda)T}}{\delta+\lambda}, \;\; r_1(\lambda) := r - r_0(\lambda).$$

Note that $V_1$ is the value of an infinitely applied FIP, which varies with $S$. In this case, $V_0$ also varies with $S$.

By similar derivations, without retroactive termination, the value of an operating project is

$$V_0(S) = r\bar{K}, \;\; V_1(S) = r(S + \bar{k}).$$

Now $V_0$ is the value of an infinitely applied FIT, which is independent of $S$.

To focus on the effect of a sudden change in risk exposure, we assume that at the time of revision government sets the FIP such that the revenue remains the same as under the FIT, i.e.

Assumption 1. *$\bar{K} = S + \bar{k}$, where $S$ is the price at the time of revision.*

Remark 6. By Assumption 2, $V_0(S) = V_1(S) = r\bar{K}$, both with and without retroactive revision, where $S$ is the price at the time of revision. Thus, at the time of revision, a project will be worth the same under the FIT and the FIP. In fact, under Assumption 2, $V_0(S) = r\bar{K}$ for all $S$, which is independent of $S$, both with and without retroactive revision. As a result, a project will always be worth the same prior to revision. In other words, if government ensures the same revenue immediately prior to and following revision, with no trend in prices, the expected value of future revenues and thereby the project value is unaffected by revision, even in the retroactive case. This may not hold if prices have a trend or if the investor values an operating project by some other measure than expected value. As $V_1(S) = r(S + \bar{k})$ is independent of revision, it continues to vary with $S$.

The Bellman equations for the value of the investment option are

$$\begin{aligned} W_0(S) &= \max\left\{V_0(S) - I, \frac{1-\lambda dt}{1+\delta dt}\mathbb{E}[W_0(S+dS)|S] + \frac{\lambda dt}{1+\delta dt}\mathbb{E}[W_1(S+dS)|S]\right\}, \\ W_1(S) &= \max\left\{V_1(S) - I, \frac{1}{1+\delta dt}\mathbb{E}[W_1(S+dS)|S]\right\}, \end{aligned}$$

and the corresponding system of PDEs

$$\frac{1}{2}\sigma_S^2 S^2 \frac{\partial^2 W_0}{\partial S^2}(S) + \lambda(W_1(S) - W_0(S)) - \delta W_0(S) = 0, \;\; \frac{1}{2}\sigma_S^2 S^2 \frac{\partial^2 W_1}{\partial S^2}(S) - \delta W_1(S) = 0.$$

To derive a solution, we define the equations

$$\mathcal{Q}_1(\alpha) = \frac{1}{2}\sigma_S^2 \alpha(\alpha - 1) - \delta, \;\; \mathcal{Q}_0(\alpha) = \mathcal{Q}_1(\alpha) - \lambda$$

and obtain the result:

Proposition 1. *Assume $\lambda > 0$. Then, for given $S > 0$, the following holds:*

1. *It is optimal to invest in regime 1 if $\bar{k} \geq k^*(S)$, where*

$$k^*(S) := \frac{I}{r} - \frac{\alpha_1 - 1}{\alpha_1} \cdot S, \mathcal{Q}_1(\alpha_1) = 0, \;\; \alpha_1 > 1.$$

2. *It is optimal to invest in regime 0 if $\bar{K} \geq K^*(S)$, where*

$$K^*(S) = \frac{I}{r} + \frac{w_0(S,K)}{r} - \frac{1}{\alpha_0} \cdot \frac{S}{r} \cdot \frac{\partial w_0}{\partial S}(S,K), \mathcal{Q}_0(\alpha_0) = 0, \;\; \alpha_0 > 1.$$

*where $w_0(S,K)$ satisfies*

$$\frac{1}{2}\sigma_S^2 S^2 \frac{\partial^2 w_0}{\partial S^2}(S,K) + \lambda(W_1(S,K) - w_0(S,K)) - \delta w_0(S,K) = 0.$$

Under regime 1, the support scheme has been revised, and the problem has the structure of the FIP with infinite lifespan discussed in Section 3. In spite of a fixed tariff under regime 0, with the prospective of a revision of the support scheme, the future revenues and thereby the investment timing depends on the current electricity price.

Compared to the infinitely applied FIT, prior to revision we expect a risk of an unannounced change from FIT to FIP to increase the required revenue to trigger investment and thereby slow down the investment rate. Under the assumption of the a continuous revenue stream at revision, it makes no difference whether such revision is applied retroactively or not. Under the infinitely applied FIP following revision, we expect investment to further slow down. We aim to illustrate these conclusions numerically.

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