Methodological approaches to the valuation of investments in biogas production plants: incentives vs. market prices in Italy

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Abstract

In the last decade, biogas production in Italy has significantly increased. It is commonly agreed that the profitability of investing in biogas to produce electricity by cogeneration is strongly related to incentive mechanisms and State aids, which may not be implemented in the future.

Uncertainty over future incentives and feed-in tariffs (FITs) and the volatility of future payoffs make operational decisions on investment timing more crucial than ever.

Biogas production plants are characterized by high operational flexibility and this flexibility has an economic value, which is usually not captured by traditional capital budgeting techniques (discounted cash flow analyses).

The real options approach allows investors to identify the strategic dimension of investment projects and capture future investments opportunities as a sequence of cash flows and option values (Expanded Net Present Value).

In this paper, we propose a theoretical and methodological framework to determine the profitability of biogas investments in the presence of incentives and we model the optimal investment strategy in the absence of incentives according to the real option approach.

When FITs are paid, these FITs secure revenues over a long period; consequently cash flows are deterministic and the Net Present Value (NPV) is a good proxy of the investment value. In the absence of incentives, energy prices are stochastic and consequently cash flows are stochastic. In this case, NPV approaches may not capture the investment value and represent an underestimation of the investment value.

The model here provided, and developed in the real options theoretical framework, makes the value of flexibility embedded in investment projects explicit and allows for determining the investment Expanded Net Present Value.

Our findings show that a negative NPV project may turn out to be a positive NPV project in the future, and a positive NPV project may increase in value in the future.

Aim of this paper is to determine whether, in the absence of incentives, it may be profitable to invest in biogas production plant. In addition, we compare the scenario where FITs are paid with the scenario where they are not paid to verify whether FITs are overestimated with respect to current electricity market prices.

1. INTRODUCTION

In the last decade, biogas production in Italy has significantly increased due to more than 4.5 billion euro investments.

This rapid increase led to 2 billion normal cubic meters of natural gas equivalent produced (i.e. 20% of the national natural gas production), 12 thousand opportunities for job creation and about 7.4 thousand GWhs of electricity produced by cogeneration (CIB, 2016; EBA, 2016; Energy & Strategy Group, 2016; GSE 2017).

It is commonly agreed that the profitability of investments in biogas is strongly related to incentive mechanisms and State aids (Rickerson e Grace, 2007; Fouquet and Johansson, 2008; Couture and Gagnon, 2010; Chinese *et. al.*, 2014; Georgiu *et. al.*, 2015; Guerrero-Liquet *et. al.*, 2016; REN21, 2016; Banzato *et. al.*, 2017). These investments are generally considered to be costly due to high investment costs (Raven and Gregersen, 2007; Walla and Schneeberger, 2008; Carrosio, 2013; Giuliano *et. al.*, 2013; Carrosio, 2014; Banzato, 2015; Banzato, 2016; De Mare *et. al.*, 2017) and great capital outlays.

Nevertheless, incentive schemes, and specifically feed-in tariffs (FITs) payments, may not be implemented in the (near) future according to the general trend in the European Union and at national level to reduce incentive amount and limit the time-length of incentive schemes.

Uncertainty over future incentive schemes and the volatility of operating costs of biogas production plants make investment decisions more crucial than ever before.

When future payoffs are stochastic and their volatility is large, decisions on optimal investment timing are of strategic importance in determining whether investments are successful or not.

Biogas production plants are characterized by great operational flexibility in terms of selection of the digester feedstock (diet) and possibility to expand the project by sequential or modularized investments. The former allows the investor to adapt the feeding stock to input supply and input market prices (Di Corato and Moretto, 2011; Hu and Cardin, 2015), the latter allows the investor to adapt investment decisions to potential demand increase and other contingencies (Moretto and Rossini, 2012; D'Alpaos, 2012; Buratto and D'Alpaos, 2015). These technical and operational flexibilities can be interpreted dynamically and generate future investment opportunities as a collection of Real (operating) Options, among which the flexibility to decide the optimal investment timing is of paramount importance in strategic investment decisions.

Operating options may *de facto* increase investment values and make it profitable to invest in biogas production plants although FITs are no longer paid. In the absence of state incentive, the investor's ability to optimally exercise the option to invest and optimally set the size of plants make it explicit the strategic nature of investment projects and allows for valuing under the more dynamic paradigm of Real Options the initial investment opportunity as collections of options on real assets, through the option-based technique of contingent claims analysis (Trigeorgis, 1996). In other words, managerial flexibilities call for an Expanded Net Present Value (F) criterion that reflects both the traditional (static) NPV of cash flows and the option value of operating flexibility and strategic interactions.

Traditional discounted cash flow approaches to the appraisal of capital investment projects ignore the value of managerial flexibilities to adapt and revise future decisions in response to unpredictable market conditions and exogenous state variables.

The Real Options approach by taking into consideration managerial operating flexibility represents a valuable tool to address risk and uncertainties that characterize investments and specifically capital investments in biogas production plants.

The present paper provides a theoretical framework to value the opportunity to invest in a biogas plant to produce electricity by cogeneration in two reference scenarios: the former represents the case in which electricity is sold in the market and the latter illustrates the case in which incentives schemes are set (and FITs are paid).

When FITs are paid, cash flows generated by operation of the plant are deterministic and investment decisions can be properly made according to the Net Present Value (NPV) rule.

When FITs are not paid and incentive schemes are not present, cash flows are stochastic as the market price of electricity is stochastic and the investment NPV may not accurately capture the investment value (underestimated by the NPV).

In the specific, the prosed model draws valuation procedures from the body of knowledge developed for financial options and has the potential to quantify the value of options from active management and strategic interactions. This value is determined as a collection of real options (e.g. the option to defer) embedded in capital-investment opportunities whose values add to conventional NPV. Expanded Net Present Value F incorporates managerial operating flexibility and strategic adaptability to future events which turn out to be different from management's expectations at the outset (Trigeorgis, 1996).

The rest of the paper is organized as follows. Section 2 presents the theoretical framework and provides the model to value investment timing flexibility. Section 3 introduces the model parameter estimates and provides the value of investing in biogas in two reference scenarios (i.e., incentive schemes vs. market prices). Section 3 provides simulations and sensitivity analyses to illustrate theoretical results. Section 4 concludes.

2. THEORETICAL FRAMEWORK

Government Decree June 23 2016 sets incentive schemes for energy production by renewable sources, different from photovoltaic, for plants that have started operation since January 1 2013.

Current incentive schemes establishes feed-in tariffs (FITs) and premiums for renewable energy quota produced and injected in the grid for a time-period equal to the average useful life of production plants (GSE, 2017). Consequently, when FITs are paid, revenues generated by the investment are deterministic and NPV represents a good proxy of the investment value. By contrast, when FITs are not paid, the investment NPV may not represent a proper proxy of the investment value. Revenues are stochastic and uncertainty over future payoffs may generate investment opportunities and managerial flexibilities whose value is not captured by traditional discounted cash flow analysis (Amram e Kulatilaka, 1999).

NPV approaches fail to capture the strategic impact of projects and the additional value deriving for example from the opportunity to delay an investment decision. The NPV rule presumes management commitment to a certain operating strategy and measures profitability of investments according to a now-or-never proposition, that is if investors do not undertake investment now, they will lose the opportunity forever (last chance), and presumes to abandon investment when its NPV is negative (Majd and Pindyck, 1987; Triantis and Hodder, 1991; Dixit and Pindyck, 1994; Trigeorgis, 1996). NPV approaches fail to make it explicit the strategic impact of investment projects on real assets.

The actual marketplace is characterized by uncertainty and competitive interactions. In this changing scenario, future realization of cash flows may differ from management expectations at the outset.

As new information arrives and uncertainty about future cash flows is gradually resolved, management may have valuable flexibility to alter its initial operating strategy in order to capitalize on favorable future opportunities and mitigate losses (Trigerogis, 1996).

When market conditions are highly volatile and technology is flexible the NPV rule does not properly capture investment values and strategic interactions. By contrast the Real Options approach allows for taking into consideration managerial operating flexibility and thus represents a valuable tool to address risk and uncertainties that affect investments which are irreversible and deferrable. Irreversibility makes investments sensitive to both uncertainty over future payoffs of state variables (e.g. market prices, interest rates, operating costs and investment timing), and to the stability and credibility of macroeconomic policy.

Highly irreversible investments often require in-deep preliminary investigations due to the involvement of significant capital outlays and are postponed as long as uncertainty is at least partially resolved. Many strategic investments guarantees the acquisition of subsequent and future investment opportunities. Real investment opportunities can be viewed as collections of options and thus we can consider the initial investment opportunity as a sequence of discounted cash flows and option values (D'Alpaos *et. al.*, 2006; D'Alpaos *et. al.*, 2013; D'Alpaos and Marella, 2014; Antoniucci *et. al.*, 2015).

Irreversibility and deferability make the investment opportunity analogous to a financial call option on an asset which gives the right to postpone investments waiting for new information to come on future market conditions and performance and consequently mitigate potential losses.

A negative NPV project may nonetheless turn out to be a positive NPV project in the future. Analogously, a positive NPV project may have a greater NPV in the future and the project value may be therefore smaller than F. In detail, the NPV rule does not take into consideration the opportunity cost of delaying investment. By deciding to make an expenditure for an irreversible investment the investor gives up the possibility of waiting for new information that might affect the profitability or timing of the investment should market conditions change adversely.

In the following section we calculate the value of investing in biogas to produce electricity by cogeneration in two reference scenarios: when FITs are not paid (market prices) and when they are, respectively.

2.1 The investment value at market prices (no incentives)

Starting from D'Alpaos and Moretto (2005) and D'Alpaos *et al.* (2006), we develop a real option model to investment decisions in biogas production plants under uncertainty.

Specifically we introduce the following simplifying hypotheses:

1) Once installed, the plant generates in the absence of incentives the following annual net cash flow (i.e. profit flow) Π_t^{mp}:

$$\Pi_t^{mp} = \Pi_t^{mp}(X) \qquad (1)$$

where X is the plant size (KWh_e/year).

2) The plant useful life is T_u (years) and at time T_u the salvage value is null.

3) In a risk-neutral world) Π_t^{mp}evolves over time according to a Geometric Brownian Motion (Cox e Ross, 1976; Harrison e Kreps, 1979; Harrison and Pliska, 1981):

$$d\Pi_t^{mp} = (r-\delta)\Pi_t^{mp}dt + \sigma\Pi_t^{mp}dz_t \qquad \Pi_0^{mp} = \Pi^{mp} \qquad (2)$$

where dz_t is the increment of a standard Wiener process with mean zero and variance dt (i.e. $E(dz_t)=0$ e $E(dz_t^2)=dt$), σ is the instantaneous volatility, r is the risk-free discount rate, δ is analogous to a dividend yield and represents opportunity cost (in annual terms) of investing in the plant rather than in financial stocks of same riskiness (McDonald e Siegel, 1984; Cox, Ingersoll e Ross, 1985), and r-δ is the cost of carry (D'Alpaos e Moretto, 2005).

4) The investment entails a sunk capital cost I (construction costs).

5) The option-to-invest exercise time is τ.

According to the above assumptions 1)-5), the project value is:

$$V^{mp}(\Pi^{mp}) = E \int_0^{T_u} e^{-rt}\Pi_t^{mp} dt \equiv \frac{\Pi^{mp}(X^{mp})}{\delta}(1-e^{-\delta T_u}) \quad (3)$$

where E(·) is the expectation operator under the risk-neutral probability measure (Cox and Ross, 1976; Harrison and Kreps, 1979; Harrison and Pliska, 1981).

The value of the opportunity to invest in the plant (i.e. the plant ENPV) F is analogous to value of a European call option on a constant dividend-paying asset (i.e. the plant):

$$F(V_t, t) = E_t \left[e^{-r(\tau-t)} \max(V_\tau^{mp} - I, 0)\right] \quad (4)$$

where τ is the option exercise time and V is the plant's value at time τ.

By imposing a non-arbitrage condition, F can be obtained by solving the following second order differential equation (Black and Scholes, 1973; Merton, 1973):

$$\frac{1}{2}\sigma^2 (V^{mp})^2 F_{VV} + (r-\delta)(V^{mp})F_V + -rF - F_t = 0 \quad (5)$$

subject to the terminal condition:

$$F(V_\tau^{mp}, \tau) = \max[(V_\tau^{mp} - I)^+, 0] \quad (6)$$

and to the boundary conditions:

$$F(0,t) = 0 \quad \text{and} \quad \lim_{V^{mp}\to\infty} F(V_t^{mp}, t)/V_t^{mp} = 1 \quad (7)$$

The solution of (5) is given by the well-known formula by Black and Scholes (1973):

$$F(V_t^{mp}, t) = e^{-\delta(\tau-t)}\Phi(d_1)V_t^{mp} + -e^{-r(\tau-t)}\Phi(d_2)I \quad (8)$$

where:

$$d_1(V_t^{mp}) = \frac{\ln(V_t^{mp}/I) + (r-\delta+\sigma^2/2)(\tau-t)}{\sigma\sqrt{\tau-t}}$$

$$d_2(V_t^{mp}) = d_1(V_t^{mp}) - \sigma\sqrt{\tau-t} \quad ,$$

Φ(·) is the cumulative standard normal distribution function.

2.2 The investment value when incentives are paid

When incentives (FITs) are paid, constant revenues are guaranteed over time, and the investment generates a deterministic net cash flow $\Pi^i{}_t$ equal to:

$$\Pi_t{}^i = \Pi_t{}^i(X) \text{ where } \Pi_0{}^i = \Pi^i.$$

The investment present value is therefore:

$$V^i = \int_0^{T_u} \Pi^i(X)e^{-rt}dt \quad (9)$$

and the project NPV is a good proxy of the investment value.

3. THE VALUE TO INVEST IN A BIOGAS PRODUCTION PLANT

The aim of this section is to show the potential of the real option approach in the decision to invest in a biogas production plant of fixed size[1], and to compare the results with the investment decision when FITs are paid, all the costs (investment and operating costs) equal[2].

In the following economic analysis, we consider a stylized case study on the development of a biogas plant by a livestock farm in the Po Valley[3], by examining the most common plant typology currently installed in the North of Italy.

The plant produces biogas by anaerobic digestion and electricity by cogeneration process, and the digester is fed with manure and energy crops (maize silage).

The plant useful life is Tu=20 years, the installed power P is equal to 199 kW_e[4] and it is operating for 8,000 hours per year, therefore X=1,592,000 KWh_e/year.

The feedstock substrate is made by 30% energy crops and 70% manure. The anaerobic digestion process is a two-

[1] We are not examining the case in which the investor has to decide both optimal size and investment timing.

[2] The present contribution focuses on the analysis of revenues: in both the scenarios the cost structure is identical and does not affect comparative results on the investment value.

[3] The plant's layout description and related technical issues are not the main objectives of this contribution. See on this respect among others Holm-Nielsen *et al.* (2009), Karellas *et al.* (2010), Nasir *et al.* (2012), Giuliano *et al.* (2013), Rodriguez-Verde *et al.* (2014), Mata-Alvarez *et al.* (2014), Lora Grando *et al.* (2017).

[4] The plant typology here described is the most widespread in Northern Italy due to the high number of livestock farms located in the area, to simplified authorization procedures and higher FITs set for these plants, according to current legislation (Government Decree June 23 2016).

phase process and the plant consists of a pre-thank for mixing, two digestors, two storage thanks, a silos and a cogenerator.

The plant size is small and we assume that thermal energy produced during the cogeneration process is partially used for heating the plant whereas the residual quota is dispersed in atmosphere[5].

3.1 Costs

Construction costs I vary with plant size X and installed power P: $I=KP^{2/3}$ where constant K depends on the installed power and the feedstock and it ranges between 3,500 and 4,500 €/KW_e. (Castellini and Ragazzoni, 2009; Pantaleo *et al.*, 2013; Gaviglio *et. al.*, 2014; Banzato, 2016; CIB, 2016)[6]. The plant investment costs are equal to I=850,000 Euros.

Operating and management costs C^{op} vary according to the operating time, the feedstock and its harvesting. They include input costs, opportunity cost of digestate, labor costs, maintenance and insurance costs (Rehl *et. al.*, 2012; Torquati *et. al.*, 2014; Schievano *et. al.*, 2015; Abbas *et. al.*, 2017).

As far as feedstock (input) costs are concerned, we assume that manure residues are fully provided by the livestock farm owner and their (weighted) opportunity costs collapse to transport costs from the farm to the plant and are equal to 0.005 €/KWh_e (Bacenetti *et. al.*, 2013; Pirazzoli and Ragazzoni, 2013; Gaviglio *et al.* 2014; Cianci, 2015; Salerno *et. al.*, 2017).

In addition we assume that energy crops, and specifically maize silage[7], are mainly provided by the livestock farm, whereas a minor quota is provided via a short supply chain (about 15 kilometers by the plant) according to a five-year (renewable) purchase contract[8]. We assume that the weighted buying cost of maize silage is equal to 0.065 €/KWh_e (Bacenetti *et al.*, 2013; Castellini and Ragazzoni, 2013; Marangoni *et. al.*, 2013; Pirazzoli and Ragazzoni, 2013; Gaviglio *et. al.*, 2014; Bartolini *et. al.*, 2015; Bartoli *et. al.*, 2016; Salerno *et. al.*, 2017). As far as other operating costs are concerned, we assume a consistent integration between operation of the plant and livestock farming that allows to reduce labor costs to the salary of a single worker in charge of basic maintenance activities (0.012 €/KWh_e), whereas planned maintenance activities and monitoring of plant operation are performed by an Operation & Management Company via a full service contract.

In addition, assuming that digestate is used at the own farm as a bio-fertiizer and mineral fertilizer substitute (Battini *et. al.*, 2014; Fantin *et. al.*, 2015; Gregson *et. al.*, 2015; Dahlin *et. al.*, 2015; Nighiem *et. al.*, 2017), the opportunity cost of digestate is equal to 0.011 €/KWh_e (Ragazzoni and Castellini, 2012; Bacenetti *et. al.*, 2014; Bezzi and Ragazzoni 2015). The estimated operating and maintenance costs are equal to C^{op}=0.075 €/KWh_e.

REVENUES

In the first valuation scenario (i.e., when FITs are not paid) electricity produced by cogeneration can be either sold in the market to the publicly-owned company in charge of promoting, supporting and developing renewable energy sources in Italy (GSE), or it can be used for self-consumption. The opportunity cost of electricity produced by cogeneration coincides with the stochastic market price of electricity. In accordance with recent literature referring to the Italian electricity market (Biondi and Moretto, 2015; Bertolini *et. al.*, 2016), we assume that the reference price of electricity in the Italian Power Exchange (PUN) – calculated as the average of hourly prices – represents a good proxy of the price paid by end-users (i.e, the average price set by the Italian National Authority for Electricity, Gas and Water Services, AEEGSI).

It can be demonstrated that the time series of PUN follows an adjusted Geometric Brownian Motion (Adj-GBM) to take into account that the time series of PUN is too short to exploit a mean-reverting behavior, which is usual for many commodities (Biondi and Moretto, 2015; Bertolini *et. al.*, 2016)[9].

The evolution over time of the (selling) market price v is consequently:

$$dv^{mp}(t) = av^{mp}(t)dt + \sigma v^{mp}(t)dz(t) \tag{10}$$

where dz(t) is the increment of a standard Wiener process, σ is the volatility[10] and $v^{mp}(0)=v^{mp}$.

[5] In this analysis we consider as negligible the opportunity cost of thermal energy in both the scenarios.

[6] We consider as negligible the opportunity cost of land where the plant is built, as we assume that the plant is built on marginal land in order to ensure investment compatibility with different competing agricultural purposes (Bartolini and Viaggi, 2012; Bartolini *et. al.*, 2015; Bartoli *et. al.*, 2016). Obviously land market value is the same in both scenarios (Manganelli, 2017).

[7] We assume that the average energy performance (yield) is equal to 300 kWh/ton (Ragazzoni, 2011; Cintia and Frascarelli, 2011; Castellini and Ragazzoni, 2013; Gaviglio *et. al.*, 2014).

[8] Input transport costs are not linear and depend on the number of plants in the area, the size of the plant and Input typology (Gaviglio *et. al.*, 2013; Gaviglio et al. 2014; Bartoli *et. al.*, 2016; Demartini *et. al.*, 2016).

[9] Instead of estimating a mean-reverting process, we lowered the trend of the GBM by correcting the drift by a measure of the speed the process takes to converge to the mean if it had been of mean-reverting type.

[10] For convergence to be satisfied, it is necessary that a is not less than the risk-adjusted rate of return â. In other words, when markets are complete and in equilibrium, drift a cannot be greater than the risk-adjusted rate of return â required by investors from a risk-equivalent financial option. It is therefore possible to deter-

Process drift a and volatility σ were estimated in accordance to the time series of electricity zonal prices relative to Northern and Northern-Central areas, recorded in the time interval December 2004- December 2015. Drift a is equal to a=2.5%, volatility is equal to σ=32% and the starting price, calculated as the average of yearly prices recorded in the time interval 2011-2015, is equal to v^{mp}=0.068 €/KWh$_e$ (Bertolini *et al.*, 2016).

In the second scenario (i.e., when incentives are paid), revenues are deterministic and coincide with FITs set by the Government (Government Decree June 23 2016: "Incentivazione dell'energia elettrica prodotta da fonti rinnovabili diverse dal fotovoltaico"). For the plant typology under investigation, FIT v^i paid to net production injected in the national grid[11] amounts to v^i=0,233 €/KWh$_e$.

3.3 The investment value

To determine the investment value when incentives are not paid, we introduce the following simplifying hypotheses[12]:

a) instantaneous profit P_t is linear in dimension X:

$$\Pi_t^{mp} = v_t^{mp}X - C_t^{op}X \quad v^{mp}(t=0) = v^{mp}; \tag{11}$$

b) operating and management costs C^{op} are deterministic and can be discounted at the risk-free discount rate (Brennan and Schwartz, 1985);

c) the risk-free discount rate is deterministic and constant over time;

d) the present value of future cash flows is a good proxy of the asset present value, and the residual value at the end of the plant useful life is null:

$$\begin{aligned} V^{mp} &= E\int_0^{T_u}(e^{-rt}v_t^{mp} - e^{-rt}C_t^{op})Xdt \\ &= \left(\frac{v^{mp}}{\delta}\left(1-e^{\delta T_u}\right) - \frac{C^{op}}{r}(1-e^{-rT_u})\right)\quad X. \end{aligned} \tag{12}$$

mine the rate of return shortfall δ= â-a, in analogy with the rate of return shortfall between a (constant) dividend-paying asset and a non-dividend-paying asset (McDonald and Siegel, 1984; Cox, Ingersoll and Ross, 1985). In addition, since the rate of return of the risk-equivalent traded security in equilibrium is equal to â=r+RP, where RP is the risk premium, then a-RP=r-δ, and we can determine RP by implementing the Capital Asset Pricing Model. It follows that for convergence to be satisfied r-δ≥0 (Harrison and Pliska, 1981; Trigeorgis, 2005).

11 Net production injected in the national grid is the difference between gross production and energy consumption related to auxiliary services and energy line losses, according to prescriptions set by article 25 Government Decree June 23 2016 (see Annex 4, Government Decree July 6 2012).

12 We assume that the Italian electricity market is complete to implement the CAPM and assume that δ accounts for non-diversifiable risk. Nonetheless, to consider that the Italian electricity market is not perfectly complete (i.e. δ incorporate diversifiable risk as well), we perform comparative statics on the cost of carry and δ whose results are illustrated and discussed in what follows.

It is then possible to determine by (8) the value of the opportunity to invest F.

In the scenario when FITs are paid, the net cash flow is equal to:

$$\Pi_t^i = v_t^i X(1-i) - C_t^{op}X \tag{13}$$

where (1-i) is the net energy quota produced and injected in the national grid (i=11%).

In this latter case, the value of the opportunity to invest coincides with the investment NPV:

$$VAN^i(\Pi) = V_i - I = \frac{\Pi^i(X)}{r}(1-e^{-rT_u}) - I. \tag{14}$$

According to estimated cost of carry r-δ=3%[13] and input data previously determined[14] and illustrated in Table 1, the investment value when FITs are paid is NPV^i=1,429,595 €.

Table 1 - *Plant technical and economic input data*

P (KWe)	**199**
X (KWh$_e$/year)	1592000
I^A (Euros)	850000
T_u (year)	20
C^{op} (Euros/KWh$_e$)	0,075
v^i (Euros/KW$_e$)	0,233
v^{mp} (Euros/KW$_e$)	0,068
a	2.5%
r	3.5%
σ	32%
i	11%

When FITs are not paid, the investment NPV[15] is negative: NPV^{mp}=-506.979 €.

According to the NPV rule, the investment is not profitable and should not be undertaken.

The project Expanded Net Present Value F is positive for any τ≥1 and it increases for increasing τ (Table 2), *ceteris*

13 The risk-free discount rate coincides with the average rate of return of Italian Treasury Bonds (BTPs) maturing at 20 and 25 years, published by the Italian Department of the Treasury (Dipartimento del Tesoro): r=3.5% (Dipartimento del Tesoro, 2016). Since the market risk premium in Italy is about 5%, and being beta in between 0.5% and 0.6%, the risk-adjusted discount rate is â=6% (Bertolini *et. al.*, 2016). As above mentioned, in equilibrium â-a=r-δ, then â-a=3.5%, and consequently δ=0.5%.

14 Input data estimated according to literature were validated and updated by interviewing 18 industry experts.

15 When τ=0, NPV coincides with F. By investing immediately, the option to invest is killed and the option value is null.

paribus. Our results show that a negative NPV project may turn to be a positive NPV project in the future, and consequently it may be undertaken at a future date. The option value to wait for new information to come on the evolution over time of stochastic variables (i.e., electricity market prices) is positive and it increases as exercise time τ increases (Table 3).

In addition, it is possible to determine the expected time, that current electricity price takes to reach current FIT value (D'Alpaos *et. al.*, 2013; Bertolini *et. al.*, 2016):

$$E(t) = \frac{\ln\left(\frac{v^i}{v^{mp}}\right)}{a - \frac{1}{2}\sigma^2}. \quad (15)$$

This expected time is about 47 years.

Tables 4 and 5 show some comparative statics with respect to different levels of σ and δ respectively.

Table 2 - *Expanded Net Present Value F (€) for σ=32%, r-δ=3% and different values of τ*

τ					
0	1	2	3	4	5
-506979	155	2731	8507	16237	24969

Table 3 - *Option Value to Wait (€) for σ=32%, r-δ=3% and different values of τ*

F-NPV				
τ				
1	2	3	4	5
507134	509710	515486	523216	531948

Table 4 - *Expanded Net Present Value F (€) for r-δ=3%, and different values of exercise time τ and volatility σ*

		F					
		τ					
		0	1	2	3	4	5
σ	30%	-506979	78	1849	6381	12854	20452
	35%	-506979	359	4456	12251	21886	32274
	40%	-506979	1037	8392	19785	32547	45524

Table 5 - *Expanded Net Present Value F (€) for σ=32%, and different values of exercise time τ and opportunity cost δ*

		F					
		τ					
		0	1	2	3	4	5
δ	0,5%	-423751	1387	9999	22829	37137	51789
	1%	-605015	2	250	1446	3781	7043
	2%	-782872	1,41E-11	2.52E-04	8,21E-02	2	10

Our results show that, *ceteris paribus*, for increasing σ, the option value to wait increases (Table 4). The optimal investment strategy is to wait as long as possible to undertake investment. When constraints on the duration of the opportunity to invest to expire, once administrative papers and authorizations have been obtained, investment may be deferred indefinitely. Nonetheless, it is rationale to assume that 5 years is the reasonable time a private investor (with a short-medium agenda) takes to make the decision whether to invest or abandon the project. In this latter case, the optimal exercise time of the option that, in turn, maximizes the investment value is equal to 5 years.

Vice versa, according to the results displayed in Table 5, *ceteris paribus*, for increasing δ (and consequently for decreasing cost of carry), the option value of waiting to invest decreases. When δ=2% it is never profitable to invest.

Expanded Net Present Value F is negligible also for exercise times of the option equal to τ=4, 5 years respectively. Whenever δ is large, that is, when the opportunity cost of waiting is large, the optimal investment strategy is to accelerate investment.

If there exist time constraints on the duration of the opportunity to invest (e.g. validity of authorizations expires), these constraints affect the optimal investment strategy. In this latter case, there exists a tradeoff between the value of waiting for new information to come on electricity price evolution (that in turn reduces potential value losses), and the opportunity cost of deferring investment. Due to this tradeoff, F may have a maximum and be concave.

By comparison of the two scenarios, we show that incentives make investing in biogas extremely profitable. When FITs are paid, the investor will never find it optimal to sell electricity produced by cogeneration in the market. In this latter case the optimal investment strategy is to invest immediately to benefit from current generous FITs.

In the event that the Italian Government abolishes incentive mechanisms to biogas production, the investor's ability to exercise operating options embedded in the project, may increase the investment value and make it profitable as well to undertake investment at market prices.

4. CONCLUSIONS

The present paper provides a dynamic tool to model investment decision in biogas production plants and make it explicit their strategic dimension. The opportunity to defer investment until uncertainty is at least partially resolved, has an opportunity cost that is not captured by traditional discounted cash flow analysis.

According to the Real Option Theory, our results show that the greater the volatility of electricity market prices, the greater the option value to defer, and consequently the greater the investment value. *Vice versa*, the greater the opportunity cost of waiting to invest δ, the smaller the option value to wait, and consequently the smaller the investment value.

There exists clearly a tradeoff between the value of new information to come and the opportunity cost of waiting to invest.

Our results show that the lack of incentives does not necessarily reduces investments in biogas. The value of managerial flexibilities, such as investment timing flexibility, whenever they are optimally exercised, may nonetheless favor investments in biogas production plant, and increase electricity production by cogeneration. The greater the flexibility, the greater the investment value in conformity with the basic principle of the Real Options approach according to which "uncertainty generates value".

In addition, from our results we derive some policy implications. Current FITs paid to biogas production plant are largely greater than current electricity market prices. Current electricity market price would take about 47 years to reach the FIT value.

In order to be cost-effective, the policy maker should set incentives contingent to the actual electricity market price. The decision to pay current FITs for the entire useful life of biogas production plant turns out to be inefficient in resource allocation and excessively costly for the society.

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