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Temporal Cross-Over Points for Renewable Energy Technology Project Investment With Consideration for Energy Pricing, Carbon Tax Credits, and Implied Socio-Political Value

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12R0321 - Temporal Cross-Over Points for Renewable Energy Technology Project Investment With Consideration for Energy Pricing, Carbon Tax Credits, and Implied Socio-Political Value

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Abstract

This study explores the technological, economic and socio-political conditions surrounding the world's first installation of a wind-hydro-diesel hybrid electrical generating system on the Island of el Hierro, Spain. A modified levelized cost of energy (LCOE) model is presented for both existing diesel energy systems and the renewable energy hybrid closed-loop system to determine the economic crossover point of project selection. By comparing the projected economic cross over point against the oil price at which the decision to build the hybrid system was made, the socio-economic value of risk avoidance can be quantified. It can also be used to represent the system's ability to hedge against future petroleum price rises and mitigate the effects of climate change. This inference has the unique advantage that it can be used to illustrate an inherent value of the system that can be difficult to quantify otherwise. The economic cross-over analysis also represents a method for comparing multiple energy options in discounted and non-discounted cash flow scenarios that indicate potential socio-political value applied to projects that are initiated at an input energy cost point well below their equilibrium economic cross-over point. A graduate student spent time on site to collect data for the cost build up models presented in this paper.

Introduction

The island of el Hierro, part of the Spanish Archapelago of the Canary Islands, has been implementing a Sustainable Development Plan since 1997. The energy portion of this plan has focused on the implementation of renewable energy systems for electrical power supply, in anticipation of replacing the island's current diesel power generating facilities. As of January

2012, the hybrid closed-loop energy system consisting of a coupled wind farm and hydroelectric facility that stored excess energy by pumping water from a lower reservoir to an upper reservoir was in process of final installation with an activation date planed in 2012. The plan and subsequent implementation of the project has been borne out through sponsorship of the project by the Industry and Trade Ministry of the Canary Islands, with the intention that the results should be disseminated to other islands and remote regions first in Europe, then Africa and Latin America if possible [51]. Preliminary planning has already been conducted for the Portuguese Island of Madeira and the Greek Island of Crete, and the African nation of Cabo Verde, with the Spanish construction and engineering companies involved in the development of the el Hierro project anticipating involvement in the export of this type of system design.

As an example of how this hybrid technology is being considered for export to other areas of Europe, the Instituto Tecnológico de Canarias (ITC) is currently working with funds from the European Commission, under the Proyecto Tres initiative, to identify the potential for deployment of energy storage technologies in the Macronesian Islands (Canary Islands, Azores and Cabo Verde) that will help offset the variability and intermittency of energy produced from renewable sources. Specifically, the studies underway at the ITC are concerned with the use of pumped hydro storage systems to regulate and store the energy generated by a proposed large-scale expansion of wind power on the Island of Gran Canaria, Spain. Preliminary investigations of the wind and hydro pumped resources on the Island show that it is possible to provide in excess of 40% of the Island's yearly electrical demand utilizing the combined system, with an estimated 2011 capital cost of €1.2 Billion. Further studies are being carried out by engineers at the ITC in order to optimize the system, at which time it should be possible to determine the fuel and emissions savings, as well as the economic savings in terms € per kWh resulting from utilizing the abundant wind resources available on the Island.

There are three primary reasons driving the use of a hybrid closed-loop energy system in the Canary Islands, namely the desire to pursue renewable energies as a major component of the island's development (socio-political reason), reduce risk sensitivity to increasing oil pricing and thus the input energy cost for diesel fuel (economic reason), and to grow the region's engineering prowess in designing and building (technological reason). Supporting circumstance include the availability of EU subsidies to build the energy facility, the availability of great wind resources, and a topography that is ideal for the use of hydroelectric potential storage. Figure 1 provides an overview of the system

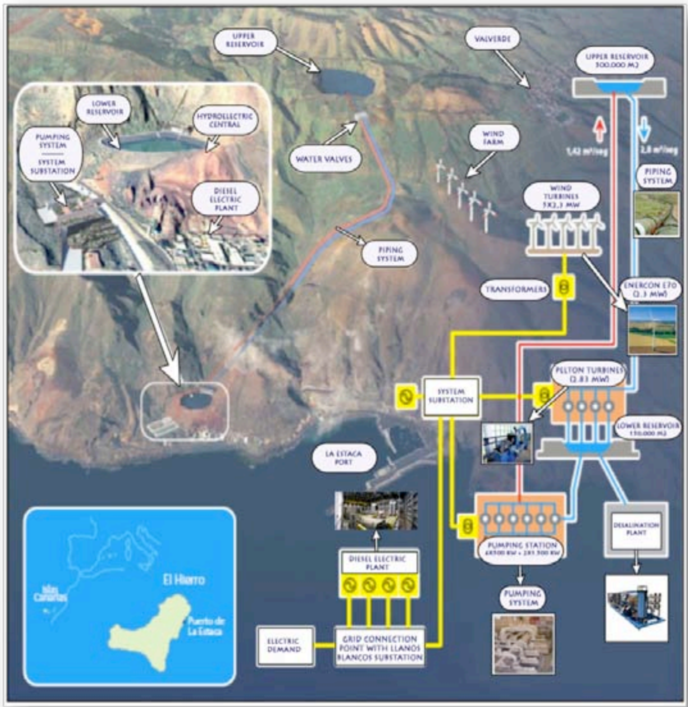

Figure 1 - el Hierro Hybrid Closed Loop Energy System Schematic

As energy demand increases globally, upward price pressure is making some renewable energy sources more attractive for long-term investment. Non oil based energy sources remove the price and supply risk associated with oil and diesel fuel supplies. They also operate with little or no emissions, thus causing minimal environmental impact while creating a cost savings in markets where emissions are priced or taxed. Traditionally these systems have been far more expensive to install than oil-based systems, and operating as independent systems, such as wind or solar supplied directly to the grid, can have difficulty in load balancing. The economic impetus for renewables is being driven by increasing energy costs, while the technological issues are being resolved by the ingenious combination of technologies. With the el Hierro hybrid closed-loop system as an example of one of these combinations, public and provate organizations are looking to the future for further opportunities to change their power generating landscape. From an economic standpoint, the use of diesel generating systems will be exposed to input fuel price risk, while the hybrid systems will have much larger installation costs with little or no input fuel price risk. This paper provides an analytical model for determining where the two systems have economic equivalency based on the price of oil as the independent variable. The model also serves as a policy making tool for determining the effects of emissions pricing, political project value, and net present value analysis on comparing the two types of systems.

Theoretical Framework

Building the comparative framework for this study requires the use of a basis of analysis. The independent variable of interest in oil pricing (in dollars or Euros) and its relative affect on the cost of the two systems in question. The dependent variable will be the levalized cost of energy (LCOE), which defined as the total cost of the system over its life divided by the total energy output expected, resulting in an LCOE metric of dollars per kilowatt-hour. The existing diesel systems will be much more sensitive to the price of oil on their operating costs, as they require diesel fuel as an input for every unit of energy produced. Conversely the renewable systems have essentially no dependence on diesel for operations, however their initial start-up costs are high. As a result, some form of relationship is expected as seen in Figure 2, where the varying dependency on diesel for operating costs will result in different slopes for the two systems, with the slope of the diesel system being steeper, and thus crossing over the cost curve associated with the hybrid closed-loop system. This cross-over point would then identify the effective oil price at which the two systems are equivalent (C_1). The model can be modified to include carbon-credit or other emissions pricing scenarios, serve to lower the hybrid curve for the former, or raise the diesel curve for the latter, both of which result in a cross-over point of C_2, which is below C_1. An analysis of the existing project will also determine if a third point C_3 was chosen for the el Hierro project, which would imply a perceived socio-economic value being applied to the hybrid closed-loop energy system, again shifting its cost curve down, and pushing the crossover point further to the left. Finally, net present value analysis (NPV) applied to these models will flatten the cost curves and place a large value on the initial costs associated with the system, devaluing some of the input energy price risk associated with diesel fuel.

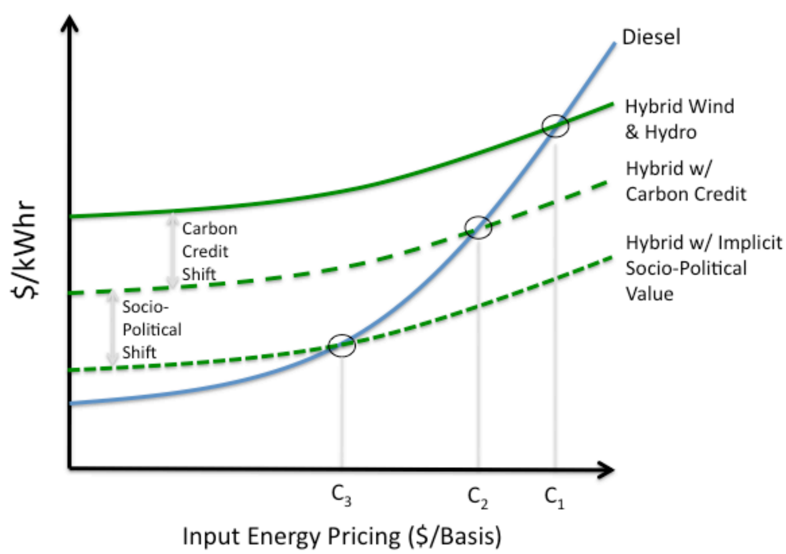

Figure 2 - Theoretical LCOE Model for comparing energy systems

Building the Economic Model

The LCOE is defined as the sum of all costs incurred over the lifetime of a given generating technology, divided by the energy produced [39]. This study utilizes the Levelized Cost of Energy approach outlined by the IEA as this method is universally agreed by all OECD members to be the most transparent mode for measuring the costs of electricity generation in modeling and international policy planning discussions [40]. The specific advantage of the LCOE method is that it computes the present day cost per kWh produced by a given generating technology over its life cycle [41], which can then be compared side by side with other electricity generating technologies. As such, it is widely seen as the best summary measure for evaluating the overall competitiveness of different electricity generation technologies [42].

The costs present in LCOE calculations include the investment costs, often known as the overnight capital costs, fixed and variable operating and maintenance (O&M) costs, fuel costs, carbon costs, decommissioning costs, the annual electrical output of the plant, and the financial cost, or the discount rate involved in building a new power plant [43].

The formula is expressed as follows:

$$LCOE = \frac{\sum_t \left(Investment\ Cost_t + O\&M_t \right) * \left(1 + Discount\ Rate \right)^{-t}}{\sum_t \left(Electric\ Output_t \right)} \quad (1)$$

Where ‘t’ is the year in which the costs are incurred and electricity is generated.

An alternative way of understanding the LCOE is that if the sale price for electricity generated by the plant were to be exactly equal to the levelized lifetime cost of energy produced, an investor would exactly break even on the project [45]. As such, this method is utilized by national utility regulation boards to determine the minimum price for electricity in situations with either monopolistic competition or where electricity prices are highly regulated, as is the case in Spain. The Cost model can be expanded as follows

$$\sum_t \left(Investment_t \right) = \sum_t \left(EPC + Decommissioning \right) \quad (2)$$

and

$$\sum_t \left(O\&M_t\right) = \sum_t \left(Fixed\,Cost_t + Variable\,Cost_t\right) \tag{3}$$

$$\sum_t \left(O\&M_t\right) = \sum_t \left(Scheduled\,Maintenance_t + Administration\,Cost_t\right) + \sum_t \left(Unscheduled\,Maintenance_t + Fuel_t + Emmission\,Cost_t\right) \tag{4}$$

The emissions cost can be modeled based on the major categories of emissions, as shown below

$$\sum_t \left(Emission\,Cost_t\right) = \sum_t \left(CO_2 * \text{Price} + NO_x * \text{Price}\right) \tag{5}$$

With the electrical output being modeled as a product of the rated power output and the capacity factor, which represents an average availability of the system to account for loss of wind or downtown for maintenance and operations as follows

$$\sum_t \left(Electrical\,Output_t\right) = \sum_t \left(Rated\,Power\,Output\right) * \left(hours\right) * Capacity\,Factor \tag{6}$$

Combining all equations 1 through 6 yields:

$$LCOE = \sum_t \Big[\left(EPC + Decommissioning\right) + \left(Scheduled\,Maintenance + Administration\,Cost_t\right) + \left(Unscheduled\,Maintenance + Fuel + Emissions + Waste\,Treatment\right) + \left(CO_2 * Cost + NO_x * Cost\right)\Big] * \left(1 + Discount\,Rate\right)^{-t} / \sum_t \left(Rated\,Power\,Output\right) * \left(hours\right) * \left(Capaity\,Factor\right) \tag{7}$$

From a research perspective, the equation is sensitive to changes in oil price as it is a basis for input costs into the system. Factoring the effects of oil price changes into each of these variables can be accomplished with the inclusion of variable specific differentials as follows:

$$LCOE = \sum_t \Big[(EPC + Decommissioning)_t * (1 + \Delta IPI / \Delta Oil)_t + (Scheduled\ Maintenance + Administration)_t * (1 + \Delta CPI / \Delta Oil)_t + (Unscheduled\ Maintenance)_t * (1 + \Delta IPI / \Delta Oil)_t + (Fuel)_t * (1 + \Delta Diesel / \Delta Oil)_t + (CO_2 * \text{Price} + NO_x * \text{Price})_t * (1 + \Delta Emissions / \Delta Oil)_t \Big] * (1 + Discount\ Rate)^{-t} / \sum_t (Rated\ Power\ Output) * (hours) * (Capacity\ Factor) \Big] \tag{8}$$

Rewritten to highlight the differentials the formula reads as:

$$LCOE = \sum_t \Big[(Investment_t) * (1 + \Delta IPI / \Delta Oil)_t + (Fixed\ O\&M_t) * (1 + \Delta CPI / \Delta Oil)_t + (Variable\ O\&M_t) * (1 + \Delta IPI / \Delta Oil)_t + (Fuel)_t * (1 + \Delta Diesel / \Delta Oil)_t + (CO_2 * \text{Price} + NO_x * \text{Price})_t * (1 + \Delta Emissions / \Delta Oil)_t \Big] * (1 + Discount\ Rate)^{-t} / \sum_t (Electrical\ Output) \tag{9}$$

Where ∆IPI/∆Oil, ∆CPI/∆Oil, ∆Diesel/∆Oil, ∆Emissions/∆Oil refer to the incremental change, in percentage terms, that a change in oil prices has on each of the cost variables. In order to determine what effect an oil price change would have on each of the cost variables, regression analyses were run to compare oil prices with the statistical indices that most closely represent the prices of the cost components. For instance, diesel fuel price statistics in Spain made available by the European Commission were regressed against oil prices to uncover a linear relation between oil prices and diesel fuel prices since the 2002 advent of the Euro in Spain.

Similarly, for fixed O&M costs such as administration and scheduled maintenance, the Spanish Consumer Price Index (CPI) [44] index was regressed against oil price movements to determine the incremental effect of oil price changes; for variable O&M costs, which include a high proportion of replacement part charges, the Spanish Industrial Price Index (IPI) [45] for Electrical equipment was regressed against oil prices. The same index was used to estimate the incremental effects of oil on capital investment costs.

At a 95% confidence level, the results generally showed a high adjusted R-squared result, which permits a good level of confidence in the use of these coefficients. The results are summarized as follows:

CPI / OIL INDEX: To be applied to changes in fixed operating expenses of all systems. Therefore, a 10% change in the value of oil will yield a 2.57% change in the CPI.

Co-efficient	**0.257**
Multiple R	0.911
R Square	0.829
Adjusted R Square	0.826

ELECTRICAL EQUIPMENT (IPI) / OIL INDEX: To be applied to variable operating costs of wind, unscheduled maintenance of diesel equipment and capital investment. Therefore, a 10% change in the value of oil yields a 2.36% change in the price of electrical equipment.

Co-efficient	**0.236**
Multiple R	0.860
R Square	0.740
Adjusted R Square	0.736

SPANISH DIESEL PRICES / OIL PRICE INDEX: To be applied to future oil price rises. Therefore, a 10% change in oil price per barrel yields a .0104 % change in the diesel price per liter.

Co-efficient	**0.0104**
Multiple R	0.985683267
R Square	0.971571502
Adjusted R Square	0.971447631

CO_2 / NO_x PRICE INDEX: Due to a lack of historical data, no regressions could be run to approximate the effects of oil price changes on CO_2 or NOx emission prices. Consequently, the study will take these as fixed coefficients for all future calculations.

LCOE - Diesel Power Plant

For this example, investment costs were calculated as the sum of the EPC turnkey price. Normally the Investment cost for a diesel power plant worldwide is approximately 300 to 900 $/KW turnkey installed [22]. However that's not a rule for remote and isolated places where price could be dramatically higher, such as in the case of the Island of el Hierro. The following cost categories released by "Unelco Endesa" for the investment costs of the diesel plant are as follows

1. General Works
2. Civil Work
    - Diesel Generators
    - Transformer and Delivery station.
3. Mechanical & Equipment
    - Diesel Units (Caterpillar 3516 series) compose by; Inlet Air, Cooling system, Exhaust system, Lube system, alternator and Engine Control Module,
    - Fuel Storage System
4. Electrical Equipment
    - Transformers
    - Electric Protections and cables.
    - Fire Protection System
5. Engineering, procurement and permitting
6. Installation Cost
7. Contingencies- Extras
8. Decommissioning
9. Insurance and Health and Safety

The Diesel Power plant of the Hierro has a power installed of 13.300 KW and has a investment cost approximately of $21,707,343 turnkey or 1,632 $/KW installed[1]. The installed cost is 2 to 4 times more than the average cost to install a diesel power plant on the mainland due to a higher cost of material transportation and construction. Although, construction phases of el Hierro diesel plant were clearly correlated with the increase of the electric demand in the island,

[1] To calculate the investment cost of the Diesel plant the study source comes from Endesa Generacion (UNELCO) and Boletin Oficial de Canarias (BOC).

having to upgrade the system systematically during the last years, which makes the system increasingly more expensive than doing the construction and commissioning at once time. The investment cost percentages are as follows for the system.

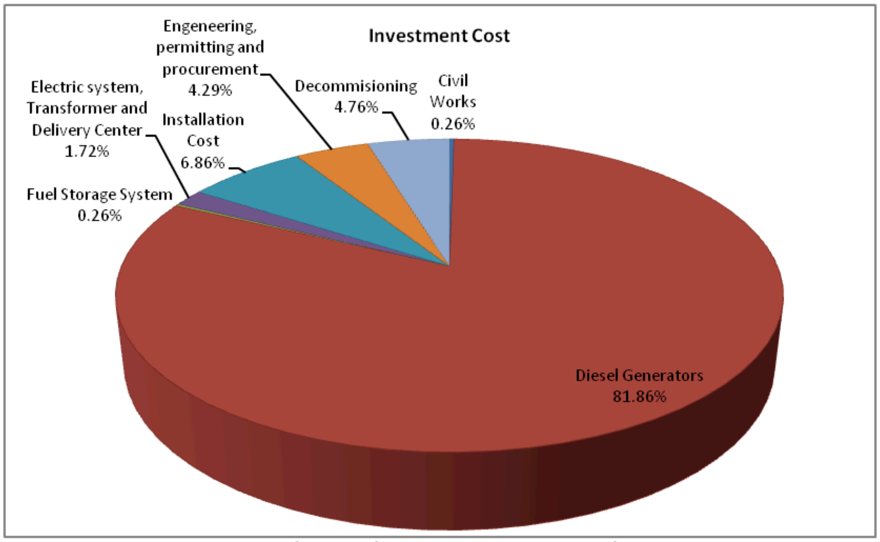

Figure 3 - Investment Cost of the Diesel Plant of El Hierro Island.

Engine based power plants can have comparatively low construction time which generally does not exceed one to one and a half years, depending on the size of the plant [22]. This study established a schedule of 2 years for EPC activities, 1 year for Engineering, procurement and permitting and 1 year for construction and plant commissioning.

When looking at the fixed and variable O&M costs, the results of the listed plant types are not as easy to determine. For the economic this study establishes technical assumptions about the operation of the plant during the lifecycle as follows

1. The production of the diesel units was calculated at ISO ambient reference conditions.
2. The Diesel Catepillar 3516 "Prime Power" is assumed to operate for 4192 hours per unit annually with a load factor of 80%.
3. The Diesel used is Ultra Low-Sulfur Diesel, or ULSD, may not exceed 15 parts per million (ppm). This type of diesel distillate
4. Fuel consumption to a load factor of 100 % is 422.3 Litres /hr (Caterpillar Model 3516)
5. Efficiency 4 Engine Stroke it's approximately 47%
6. Production =Demand = 44, 604 MWh/year

7. Life expectancy without major overhauls is 40 000 hours

8. Lifecycle of the units 10 years

In the cost build up, fixed costs include Scheduled Maintenance, Administrative cost, and insurance, but does not include land lease, as the comparison for this analysis is between technologies. Scheduled maintenance consists of general inspection, lubrication service, cooling system service, fuel system service, servicing and testing starting batteries, and regular engine exercise.

Variable Costs include unscheduled maintenance, major overhaul and repair, ignition cost, fuel cost, and emissions as a variable that can be set to zero depending on the economic model run under consideration. Unscheduled Maintenance includes all maintenance during the operation of the plant that is not included in scheduled maintenance. This study assumes 40 000 hours of operation per diesel unit to limit the scope of unscheduled maintenance charges. Once the different units of the system overhead the 40 000 hours of operation some major overhauling must be done to the units, including cylinder heads, cylinders, piston bearings, grinding valves, injectors, turbo chargers and auxiliary services. Major overhauling is a variable cost, however the study established a rate of 25% of investment cost for overhauling during the 25 years of operation [24]. There is a cost associated when engines are disconnected and connected again. The power installed in the el Hierro Island 13.3 MW nearly covers two times, the average of peak demand of the island 7.8 MW, meaning that part of the diesel units are connected or disconnected in function of the daily electricity demand during a year period. The study established 1200 hours of ignition engine cost at an average price of 65.22 €/hour [42].In engine-based power solution this is the most volatile and significant cost parameter of the LCOE for Diesel plants. In remote places like El Hierro the price of diesel will easily rise more than 10% above mainland locations due to added transport costs. Often, fuel costs represent more than 80% of total O&M costs [42] [43]. Even though the emission cost associated with the operation of a diesel plant in el Hierro is not a known cost, in the near future pollutants will play a more significant role as an economic or financial variable for electricity production. This study values the external cost of the exhaust gases that the Diesel plant generates during the lifecycle of the plant, taking the indexes of 20 €/ton CO_2 and 2980 €/ton NO_x reflected in the study [30].

LCOE – Hybrid Wind Hydro System

For the Hybrid Wind Hydro energy system, the components of the investment costs of both technologies include the following categories:

Wind Generators	Hydro Storage/Generators
1. General Works **2.** Civil Work • Turbines Generators. • Transformer and Delivery station. **3.** Mechanical & Equipment • Turbine Generators. Enercon E-70 **4.** Electrical Equipment • Transformers • Electric Protections and cables. • Fire Protection System **5.** Engineering, procurement and permitting **6.** Installation Cost **7.** Contingencies- Extras **8.** Decommissioning **9.** Insurance and Health and Safety	**10.** General Work **11.** Civil Work • Upper Reservoir • Lower Reservoir • Hydroelectric Pumping Plant • Hydroelectric Turbine Plant **12.** Mechanical & Equipment • Penstocks • Turbines • Pumps **13.** Electrical Equipment • Transformers • Supply and Control System I • Supply and Control System I • Fire Protection System • Ventilation **14.** Engineering, procurement and permitting **15.** Contingencies - Extras **16.** Decommissioning **17.** Insurance and Health and Safety

When considering the relationships of these variables to oil prices, each category can be decomposed into its respective cost components as primarily materials, labor and transportation. For example, the costs of materials in the turbine costs are the sum of all the materials such as steel, copper, fiberglass, etc. that go into fabricating the body of the turbines [39]. The prices of these materials are determined by international commodity markets and can be said to directly reflect the industrial price index. Hence for all capital costs, the Spanish

Industrial Price Index (IPI) for Electrical Generating Equipment was utilized to approximate price sensitivity to oil price changes.

Second, each cost component includes the labor cost involved in producing it. This is the number of labor hours required to produce the good multiplied by the hourly wage. In labor markets where wage rates are flexible, labor costs typically rise and fall in unison with the consumer price index; however in labor markets such as Spain, where labor contracts are considered to be rather rigid, labor prices tend to rise with inflation, however they do not fall [46]. Consequently, labor prices must be considered specific to the location in which the work is being performed, and they cannot necessarily be said to respond to changes oil prices. However, due to lack of a better index, the Spanish consumer price index (CPI) was utilized to approximate price sensitivity of labor costs to oil price changes.

Finally, the transport portion of each input may be considered to vary directly with the price of fuel, however with a certain time delay. Transport operators are often reluctant to immediately pass on increases in fuel prices to their customers for fear of relinquishing competitive advantage to other market participants. Consequently, transport costs, while they do reflect changes in oil prices, do not do so immediately, and care must be taken when ascribing price changes to the effects of oil on transport costs. With this caution in mind, diesel fuel prices per liter were used to estimate the sensitivity of transport prices to changes in oil price changes.

In the case of the hybrid-hydro electric plant at el Hierro, the wind park was provided a on a turnkey basis by Enercon systems of Germany, with the remaining contracts offered on a tenure basis. The entire project has and investment cost of 64.7 Million Euros, with the following percentage cost breakdown:

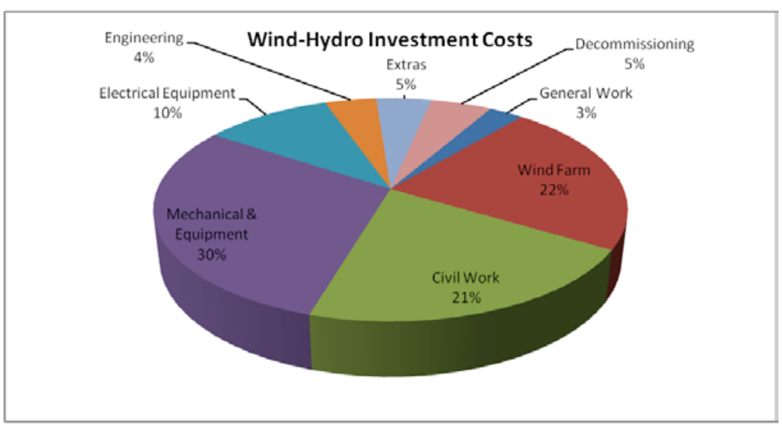

Figure 4 - Investment Cost of the Wind Hydro System of El Hierro Island

Additionally, as the wind-hydro installation can only be expected to provide 77% percent of the energy demanded yearly on the Island due to the seasonal variation in the wind resource, the entire capital costs of building the diesel plant were calculated the LCOE costs of the wind hydro hybrid. The rationale behind this is that in the winter months, there is so little wind resource on the Island that the wind-hydro system cannot be expected to produce enough power to meet even a portion of the peak electrical demand [48]. Consequently, the electrical system of the Island cannot function without the diesel plant, and to make a realistic estimate of the cost of building such a system elsewhere in the world, the capital costs of the diesel system must be included in the LCOE equation. Fixed and variable cost categories were established in a similar manner to the diesel system described previously. With respect to the operation and maintenance costs of the wind-hydro installations, a lifetime maintenance contract with Enercon systems was signed that covered both fixed and variable operating costs, and these cost data have been input into the model. Further, cost estimates given by Gorona del Viento have been followed with respect to the O&M costs of the hydro pumping installations.

Results

The study shows a comparison of two electric systems that are able to cover the power demand of the el Hierro Island. However, both systems are totally different from a construction and operation perspective, having some attributes and cost inherent from the technology application. The study produced a model that allows those differences to be explored from an economic point of view.

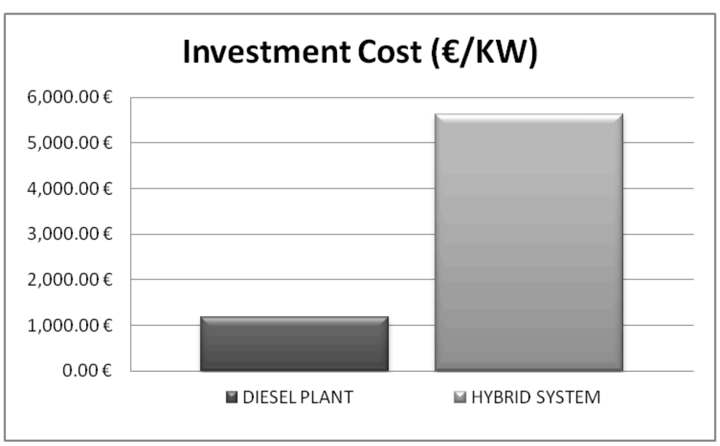

Figure 5 - Comparison of the electric systems in €/KWh

Figure 5 shows that the hybrid system is a highly capital intensive technology compared to a diesel plant, being approximately 5 times more expensive an investment cost. The high cost of the plant comes from the civil works that must be undertaken and the equipment (wind turbines, hydro-electric turbines, and the associated electro-mechanical equipment) which represent 77% of the total cost of the plant. However, when it comes to operations and maintenance, Figure 6 shows that the cost are reversed, with the diesel plant being approximately four times more expensive to run than the hybrid system [2]. The high cost of O&M is of the diesel plant is greatly influenced by the diesel fuel needed to operate the diesel units, which are in excess of 70% of the total operating costs. As such, the diesel plants are risk sensitive to fuel supply and fuel pricing.

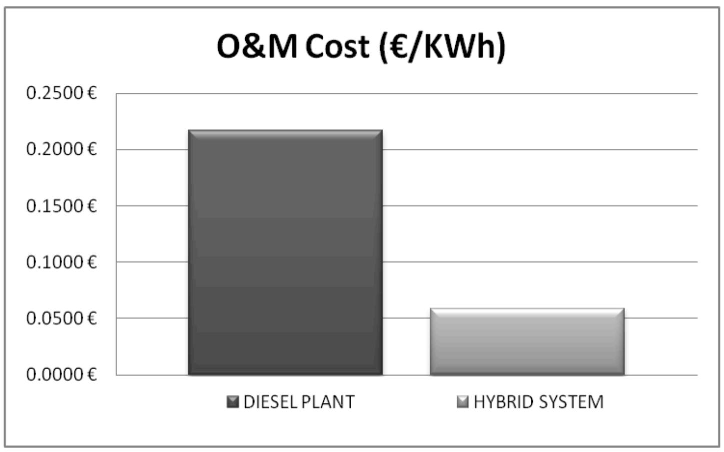

Figure 6 - Comparison of the electric systems in €/KWh

For the initial LCEO analysis, plots of system LCEO versus the price per barrel of oil were generated, as seen in Figure 7. The orange line shows the hybrid energy system with a relatively high installed cost basis, and a fairly flat oil price sensitivity slope on the order of 2.5%. Conversely, the diesel system has relatively low start up costs, but a slope approximately four times that of the hybrid system, highlighting the sensitivity to input oil prices. In the first case, the LCEO cross-over point for the two systems is at € 30.00 / barrel when emissions are not factored in equation. When emissions are factored in as a cost the LCOE curve for the diesel system shifts upward causing the cross-over point to move left to € 15.20 / barrel. This result demonstrates the high sensitivity of the analysis and the projects to emissions markets and

[2] The cost of O&M includes the damage factors per ton established by the European Environment Agency.

regulatory requirements for valuing emissions. The alternate for of this analysis would value the avoidance of the emissions as a credit for the hybrid system, shifting its LCOE curve downward, resulting in the same economic cross-over point. The emissions costs associated with the diesel system were € 20 / metric ton for CO_2 and €2980 / metric ton for nitrous oxide. It can be seen by the graphs that the LCOE of the diesel system moves in a constant line as oil prices increase, with the LOCE of the hybrid system is rising at ¼ the rate, reflecting the fact that 25% of the energy generated in this system is generated by diesel.

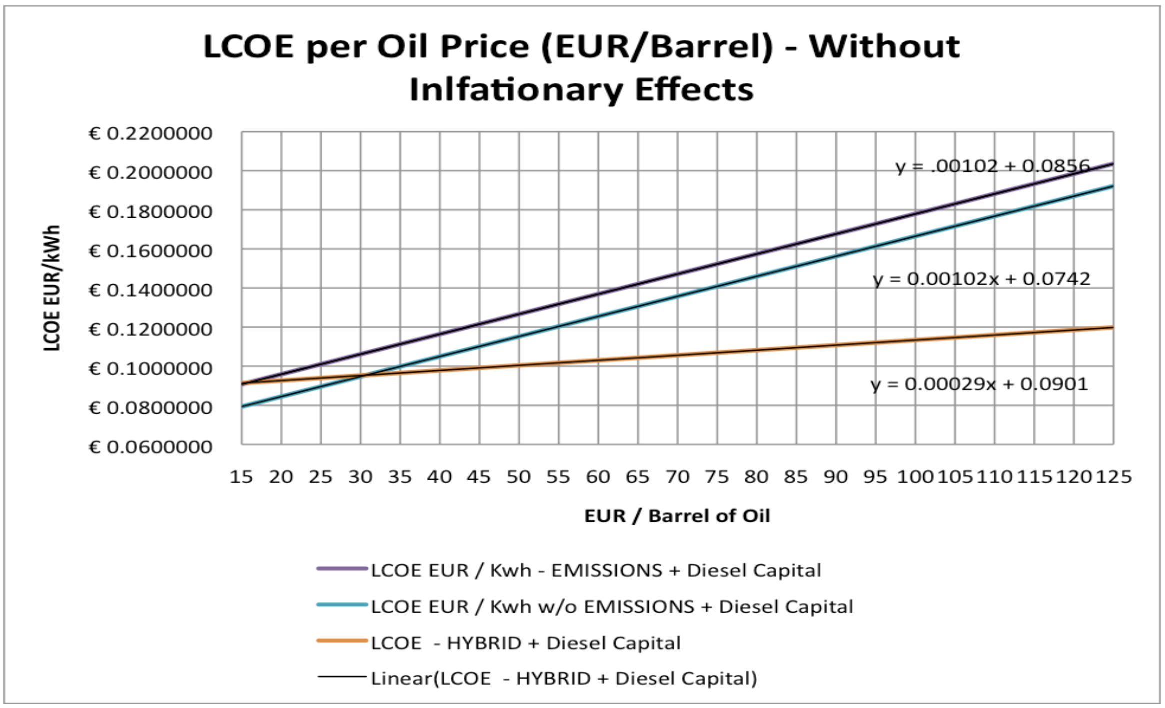

Figure 7 - LCOE comparisons

The historical data for oil prices in the past decade (Figure 8) show that oil has not been below € 30.00 / barrel since the first quarter of 2005, except for a brief period in 2009 at the depths of the European economic crisis. The idea for the project began back in the 1980's, but saw little traction for many years. The increase in oil prices in the past decade serve as validation for the advocates of the project who have argued the advantages of reducing the exposure to oil price risk with a purely diesel based system. Given the trends in oil prices, and barring major financial collapses, electricity produced by the wind-hydro-diesel hybrid appears as if it will have a lower LCOE than electricity produced by a similarly sized diesel system.

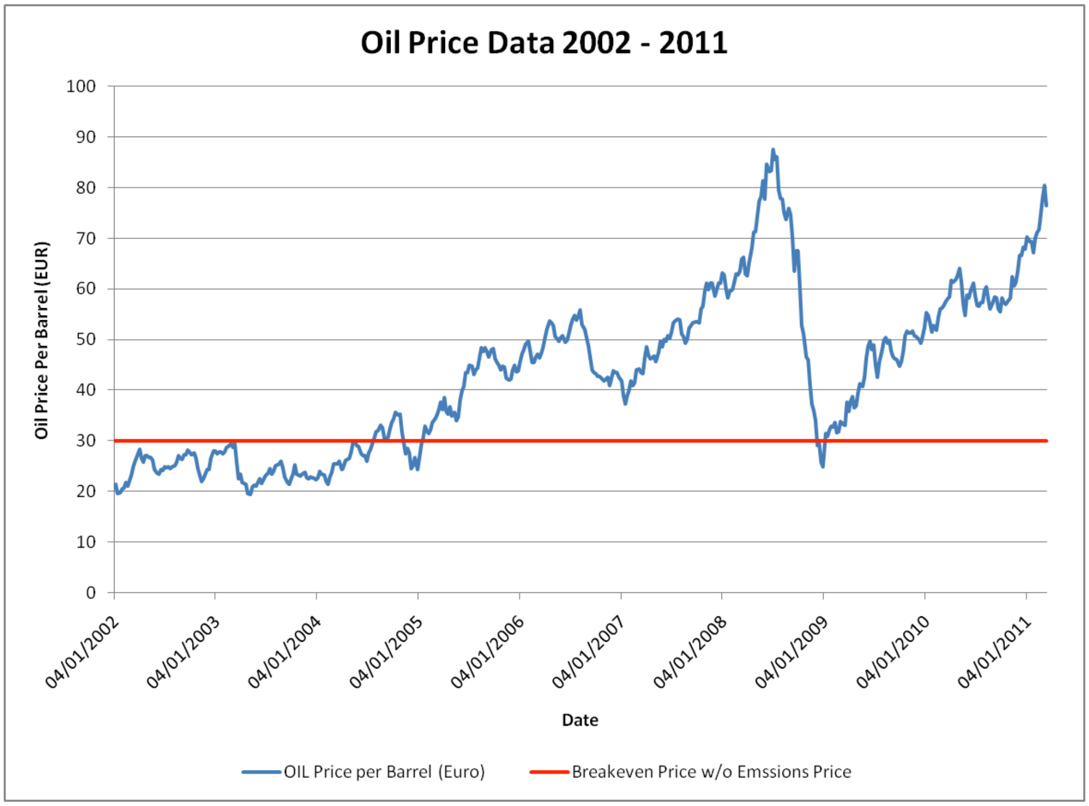

Figure 8 - Historical Oil Prices

In a second LCEO analysis of the two systems (Figure 9), the model was run with no input cost for the diesel system, assuming the existing one on the island would be left running. As such, there is an equivalent cost reduction to both the diesel model and the hybrid model, resulting in all curves shifting down equivalently. This results in the same economic cross-over points and same slopes for the two systems.

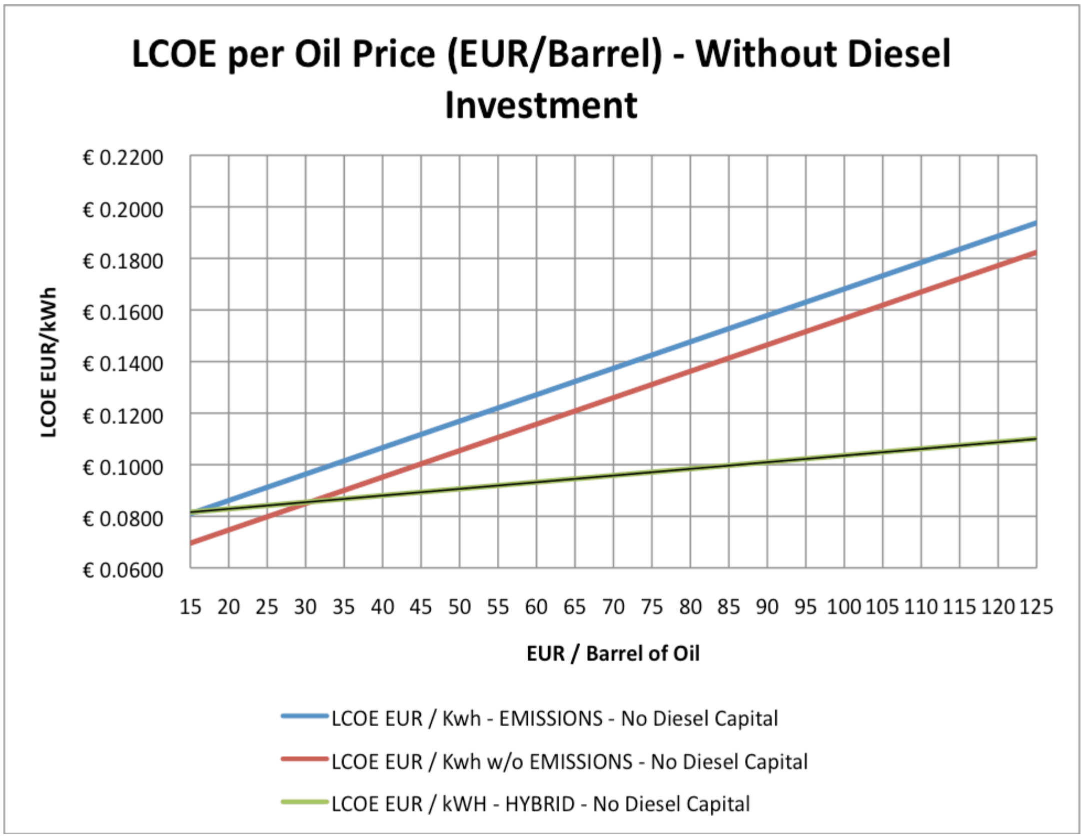

Figure 9 - LCOE without diesel capital investment

Conclusions

This study involved 2 months of field work in the Canary Islands working with agencies and organizations involved in the creation of the Hybrid closed-loop energy system on el Hierro. The data was not available from a single source and was collected via many channels. There were two surprising elements found in this study. First is the fact that this type of economic cross-over analysis had not been used in the initial project choice. The genesis of the project was more of a socio-political effort aimed at reinvigorating the island's tourist economy by creating a one-of-a kind system in the world.

The second surprise was the fact that through an exhaustive cost build up, the economic cross-over points for investing in the hybrid closed-loop energy system are below the current oil prices in the world. This cross-over point can be pushed even lower with emissions markets and/or regulations that place an economic consideration on emissions. In the appropriate locations, the need for diesel backup could be significantly reduced, thus driving the system cost down even lower, and thus a lower cross over point.

However, the caveat to these low oil price cross-over points is that the land lease costs are not factored into the equation at this point in time. The footprint for a diesel generator is easily two to three orders of magnitude smaller than that required for installing the wind farms, reservoirs, and hydroelectric facilities. In a commercial project where these are not state-owned lands, the cost of land use could significantly increase the LCOE of the hybrid closed-loop energy system, shifting its curve upwards, hence shifting the economic cross-over point much farther to the right.

The use of hybrid wind-hydro technology is not limited to island regions however, as the global wind industry is experiencing greater than 20% annual growth. This growth is expected to be complimented by the growth of pumped hydro storage systems. The Spanish multinational energy company, Iberdrola sees pumped hydro storage (PHS) as the best option for regulating and storing the output of wind parks, and as of 2009 had an 852 MW pumped storage plant at La Muela in Valencia, Spain under construction, with three other plants under investigation for a total capacity of 1640 MW [52]. In Austria, Vorarlberger Illwerke AG is building the 450 MW Kopswerk 2 project to provide for better network regulation, owing to the more than 23,000 MW of wind being installed in neighboring Germany [53]. With the recent announcement of Germany's plan to close down its nuclear reactor facilities by 2022, it is expectedthat pumped hydro storage projects will figure more prominently in their drive to replace as much as 25% of the base load generation capacity with renewable sources.

In North America, GridFlex Storage Technologies (ww.gridflex.com) has proposed in excess of 15 000 MW of storage capacity in the western states of Arizona, Nevada, Colorado, Wyoming and Hawaii, where high wind potentials are matched with by equally steep terrain [54]; and in the state of California, where the renewable energy share of energy production is slated to increase from 20 to 33% in the coming years, PHS systems are being seriously considered as the only way in which to help regulate such a large increase of solar and wind power on the grid [55].

With over 12,000 MW of new PHS capacity under construction, representing an investment of US$11 billion [56], and worldwide wind power capacity increasing by 22% (42 789 MW) in 2010, representing an investment of more than US $65 billion [57], the future looks promising for companies with an understanding of this hybrid technology.

Implications for Further Research

The economic model developed in this study can be expanded to include additional elements. The use of net present value techniques will act do devalue out-year expenditures, which are the main costs in the diesel model due to the fuel input to the system. Thus any NPV analysis will shift the diesel LCOE curve downwards. This will have the effect of moving the crossover point to the right. In a world in which firms raise capital from debt and equity markets, the discount rate is known as the financial cost of capital, or alternatively, the Weighted Average Cost of Capital (WACC), defined as

$$WACC = \left[\left(\frac{Debt}{V} \right) * (1 - T) Rd \right] + \left[\left(\frac{Equity}{V} \right) * \mathrm{Re} \right] \tag{10}$$

Where

Debt / V = percentage of financing that is debt

T = Corporate tax rate

Rd = cost of debt

Equity / V = percentage of financing that is equity

Re = cost of equity

V = Total value of the investment = Debt + Equity

As the WACC formula shows, proportional weights are assigned to the amounts of debt and equity relative to the overall level of financing involved in a project, recognizing that debt and equity markets charge different rates of return on a project, and that tax rates play an important effect on determining the ultimate costs of debt financing, as in most countries interest payments are tax deductable, whereas equity payments made to shareholders are not. How the differences in the amounts of debt and equity financing and the rates applied to each affects LCOE calculations is clearly illustrated by an example from an IEA task force investigation entitled the "*Multi-national Case Study of the Financial Costs of Wind Energy*". The task force compared the financial costs of installing wind power in seven OECD countries, utilizing the

WACC implied by each country's financial markets as the discount rate to compute the NPV LCOE, and not surprisingly, they arrived at very different cost conclusions.

Table 1 - Onshore financial parameters by country and the Reference Case in 2008

	Denmark	Germany	Netherlands	Spain	Sweden	Switzerland	United States	Reference Case
Return on debt (%)	5.0	5.5	5.0	7.0	5.0	5.0	6.0	5.0
Return on equity (%)	11.0	9.5	15.0	10.0	12.0	7.0	7.5	10.0
Debt Share (%)	80.0	70.0	80.0	80.0	87.0	70.0	0.0	80.0
Equity share (%)	20.0	30.0	20.0	20.0	13.0	30.0	100.0	20.0
Loan duration (yrs)	13.0	13.0	15.0	15.0	20.0	20.0	15.0	15.0
National tax rate (%)	25.0	29.8	25.5	30.0	28.0	21.0	38.9	28.0
WACC (%)	5.2	5.6	6.0	5.9	4.7	4.9	7.5	4.9

The results of the report attribute the variations in the LCOEs among the countries to different O&M expenditures, investment and financing costs, provides a window into why the IEA ascribes all equity financing to projects instead of using the WACC. In doing so, they are able to remove a source of local variation that otherwise complicates side-by-side comparisons. The reasons for doing this are simple: tax rates, subsidies, and financing costs are regionally specific in the very political world of infrastructure projects [41]. Therefore, when attempting to compare radically different electricity generating technologies such as renewable and conventional power solutions in which political and regulatory favor can play a large part in determining the average price per kWh generated by one system versus another, the IEA opts to remove these distorting effects. In this sense, the IEA's method can be described as working to 'flatten', or 'smooth' out any of the irregularities created by the political preferences of the respective governments of the regions in which the installations are to be placed, thereby permitting a more equitable cost comparison of the technologies.

Inflation has also not been factored into the model. The diesel model will be much more sensitive to inflation as out-year expenses will tend to rise compared to current prices, and as such, the diesel models would have a higher LCOE. This would shift their curves upwards and result the in the economic cross-over point moving leftwards.

This economic model can also be normalized and incorporated into an option modeling technique to look at balancing pricing oil price risk and environmental emissions cost risk as part of the decision model for the comparing systems. This could provide a valuable tool for policy decisions and regulatory decisions for local and regional governments and power production entities.

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