Techno-economic Optimization of Sustainable Power for Telecommunications Facilities using a Systems Approach

David Picklesimer Paul Rowley David Parish Stephen Carroll Harsha Bojja John N. Whitley

***Abstract*—Telecommunications network operators face the dual challenges of powering remote equipment while controlling both operating costs and energy consumption. As a means to help meet these challenges, this paper describes the functionality and performance of an Alternative Power Analyzer tool specially made for remote base station applications which models the outputs of renewably generated power based on location and user inputs. It combines these results with economic inputs to produce a business plan for the implementation of the preferred system. An important factor affecting economic viability is the various incentives for sustainable power generation. These can vary greatly by value, duration, equipment eligibility, location, and other constraints. To manage these complex datasets, a dynamic ontological information framework has been developed which is designed to iteratively interface with the APA tool. The outputs of the work indicate that a techno-economic systems approach can be applied both to assess the viability of location-specific system configurations under current incentives frameworks and to inform policy makers in terms of future incentives optimization.**

***Index Terms*—Radio Base Station, Renewable Energy Model, Hybrid Wind/Solar, Incentive, Ontology**

I. INTRODUCTION

Remote Radio Base Stations (RBS) for cellular mobile communications often warrant the use of diesel generators on a permanent or temporary basis to provide power. Financial and environmental factors increasingly result in consideration of renewable power generation from wind and solar sources for this application.

Earlier studies have considered renewable supply of RBS equipment primarily in situations where the grid was unavailable and where an optimal renewable resource was present [1] or where generator refueling was impractical [2]. Particular attention has been paid to RBS cooling load management, reliability of the renewable resource and the energy storage requirements [3].

Innovative solutions for energy supply, storage and cooling have been considered specifically for remote RBS systems [4]. Additionally, analysis of battery storage systems for GSM RBS [5] has been done based on the principle of energy balance.

Building on this work, the Alternative Power Analyzer (APA) tool has been developed to determine the wind, solar and battery capacity required for a particular site, along with the generator fuel consumption. When combined with the financial inputs on forecasted discounted costs, the tool produces various business case scenarios.

Location-based incentives to promote the use of low carbon power sources are growing and may be set to increase considerably in the future [6]. Variations in incentives can determine the economic viability of a specific sustainably powered solution and case studies on renewable generation in specific locations have shown that viability is defined not only by technical constraints, but also by socio-economic factors [7]. This paper shows that power generation is not characterized by a linear value chain and that a generic conceptual model (known as an ontology) is the most suitable method to manage such dynamic data rather than traditional databases [8]. Therefore, a dedicated incentives ontology has been developed to input and manage such data, which in turn integrates with the APA tool to optimize the business cases presented.

II. METHODOLOGY

A. APA Tool Capabilities

The APA tool models scenarios for both off-grid and on-grid power solutions for various RBS configurations. These include a combination of generator sets, energy storage (deep cycle batteries) and renewable technologies, i.e. solar photovoltaic (PV) and small scale wind turbines (<50kW).

For off-grid cases, the variability of these sources necessitates some form of energy storage and a control system, potentially with a dump load. A typical DC-coupled configuration is represented in Fig. 1. The APA tool offers the ability to specify a site location from which hourly values for the solar and wind resource are generated based on average monthly values. The specific power system components: wind turbine, solar module, batteries, and generator set are also input by the user based on a defined set of commercially available products.

The main output of the tool is a business case report with details for the PMO/FMO equipment combinations during each year for the analysis duration. In particular, the Discounted Cumulative Cost Estimate (DCCE) is calculated arising from the projected diesel consumption, estimated OPEX and CAPEX, energy credits gained due to the reduction of diesel use, and renewable power generation along with savings applying to present and future modes of operation respectively (PMO

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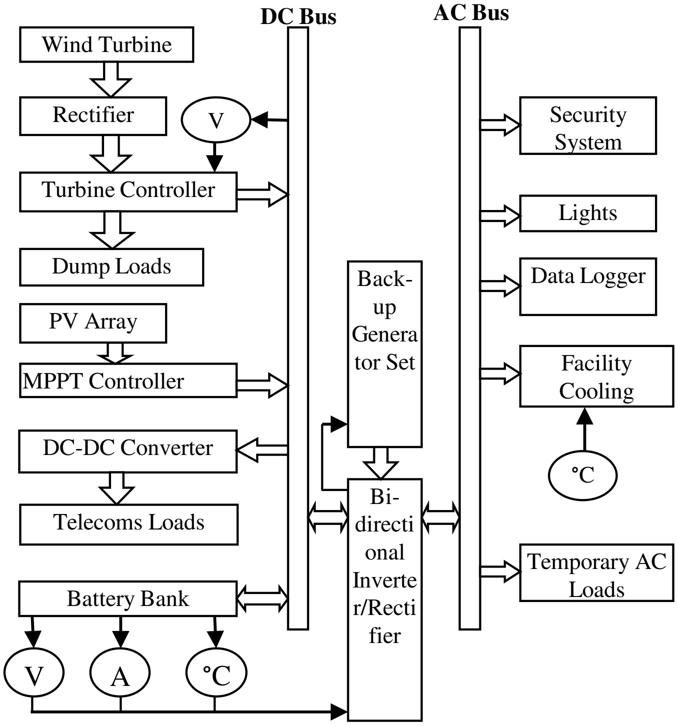

Fig. 1. Off-grid Renewable powered RBS layout

and FMO). Fig. 2 details the APA structure with inputs and outputs.

B. Wind Model

The APA wind model is based on a probabilistic approach using wind turbine and wind resource data, along with site and location parameters. The wind model outputs include monthly and yearly totals for the MWhs generated.

C. Solar PV Model

The solar model is based on parameters relating to the power output of the PV array, its operating temperature and the ambient temperature. Calculated results include the daily output in kWh for a module for each particular month along with adjusted daily output, and then taking the inverter efficiency into account to provide estimated monthly and annual outputs in kWh.

D. Battery Model

The Kinetic Battery Model (KiBaM) [9] is used as the basis for analyzing the storage component of the solution. This is a quasi-steady time series simulation which combines phenomenological and physical effects, along with the outputs of the wind and solar models and a calculation of the average daily RBS load. The required battery capacity is calculated from these parameters. Next, the load profile (arising from variations in telecommunications traffic and facility cooling requirements) is calculated. Diesel usage and the percentage of the load satisfied by the PV and wind resources are also calculated. Subsequently, starting with the initial battery charge (full capacity for all batteries) the amount of energy available from the battery during charging or discharging for each hour over time is derived.

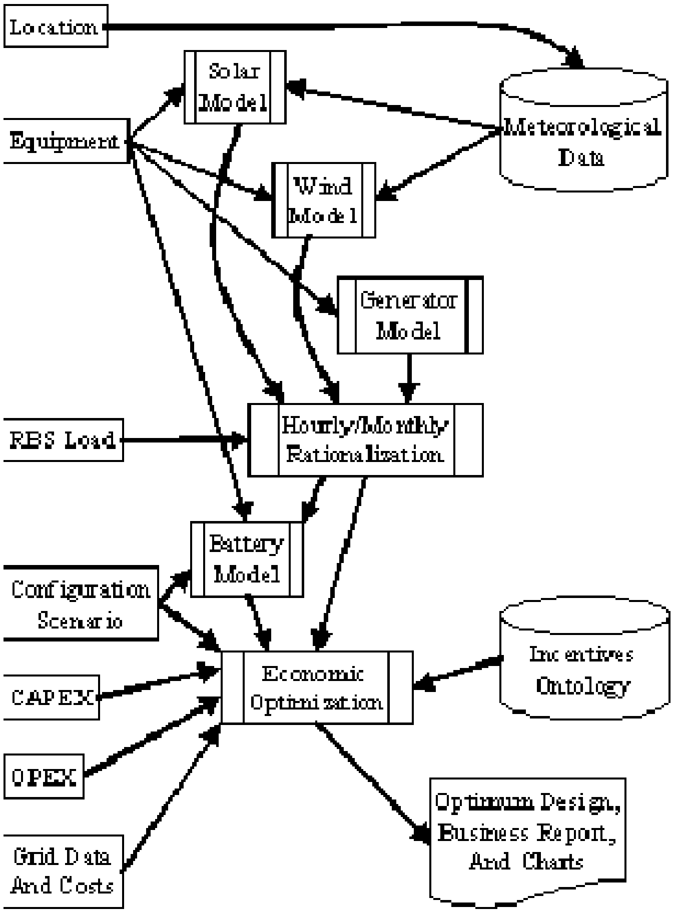

Fig. 2. APA Structure

E. Incentives Ontology

Incentives may include a range of support mechanisms, including tax breaks, grants, favorable loan rates, and other financial benefits available for particular applications. This project limits the scope of incentive to be financial or fiscal, although the potential exists for this to be extendible. Incentives are available from various sources, each of which have their own naming conventions which may change over time. To be able to search all incentives that could apply to a system, it is necessary to search all institutions that have applicable incentives.

A standard approach to maintaining and searching data would be to use a database. However, this does not easily support new forms of data. An alternative is to apply an ontological approach. An ontology is a collection of predicate-logic statements made of three constituents: a subject; a predicate; and an object. The equivalent of the database table fields and rows are constructed using statements. Each institution can create their own structure, and using further statements, these unlike structures can be linked with equivalence. It is also possible to use a reasoning engine to determine missing statements and apply them to the ontology. By using an ontology, it is possible to create a central data source that contains links to other sources, allowing the data to be maintained with trivial reworking of the ontology [10].

In practice, ontologies are written using a suite of languages, the base language being Resource Description Framework (RDF) [11]. Three important extensions, in the context of this research are RDF Schema (RDFS) [12], Web Ontology Language (OWL) [13] and Semantic Web Rule Language (SWRL) [14]. Each of these languages have their own roles: RDF provides a framework to write statements; RDFS and OWL together allow data structure to be written as statements, and so are equivalent to database tables; and SWRL provides the framework language to write rules that a reasoner (an external library or application that uses statements to infer correctness of, and missing statements within, the ontology) can use. If the incentive provider publishes their incentive data in ontological form, it is trivial to link it with other ontologies. If they do not, it is necessary to extract the data and construct an ontology to represent this data. Once this extraction and construction has been performed, it is then trivial to link with other ontologies.

The first step in defining the ontology is to define the expected shape of the data. This does not create a limitation, instead it adds meaning to the data. For example, it is likely that an incentive will apply in a specific location. Stating this within the ontology means that: it is known how the incentive applies in a specific location; how this could translate to another ontology; and how this knowledge may be used to infer other information where appropriate.

For example, some statements that have been defined in the ontology are:

- location isIn location
- location contains location

It is clear from these statements that a location may contain or be in another location. At this point, the ontology is similar to a database table with no data in it.

To make the ontology more powerful a SWRL rule is now added to allow the reasoner to further assess the statements:

- isIn inverseOf contains

The reasoner is now able to infer missing data. For example, if the following statements are added to the ontology:

- usa isA location
- washingtonDC isA location
- washingtonDC isIn usa

The reasoner will infer:

- contains inverseOf isIn
- usa contains washingtonDC

It makes data maintenance easier and more robust. An incentive was given the generic properties as outlined in table I.

TABLE I
GENERIC PROPERTIES OF AN INCENTIVE

appliesIn	the geographical location that the incentives applies in
eligibleSector	the business sector eligible for the incentive
eligibleTechnology	the technology that must be used for the incentive to apply
isWorth	the value that the incentive provides
type	of incentive (tax break, grant, etc.)
name	of the incentive, as given by the incentive provider
provider	of the incentive
startDate	of the incentive
endDate	of the incentive

This provides a basic, generic conversion between different incentive providers. Each provider is likely to name each of these differently, but for every new provider, a set of SWRL rules may be added to create equivalence. The reasoner would then be able to translate the provider's incentives into generic incentives. In order to define the initial structure of the ontology, test case analyses were carried out using data on incentives available at various locations in the USA and EU. When implemented and populated with the test case information, the ontology outputs data in a format that can then be input to the APA via a customized interface. The automation of data-sharing via this interface is currently under development.

TABLE II
TYPICAL GSM RBS LOAD PROFILE-AC BUS

Typical GSM RBS site loads	Max (W)
RBS Baseline Equipment (3x4 TRX)	2,077
RBS Baseline Transport (Backhaul)	250
RBS Baseline Facility (lights etc.)	60
RBS Baseline Cooling (AC or Fan)	450
Total	2,837

III. RBS SITE LOAD PROFILE

The maximum power consumption of a typical GSM RBS configuration in use today is detailed in table II. The load is primarily determined by the number of transmitter-receiver units (TRX) and how they are configured per antenna sector.

In addition to the RBS equipment, power is required for backhaul communications equipment (normally consisting of a microwave link consuming 200-300W), site facility loads (e.g. security systems) and temporary loads (e.g. lights, tools etc.), and cooling loads which depend on the number and type of TRXs, ventilation, insulation, and the climate at the site location.

A maximum value for these loads can be input into the APA tool. The percentage variation expected in RBS equipment and the load factor for cooling is calculated on an hourly basis during analysis. The user is required to know the specific RBS equipment and configuration.

IV. Results and Analysis

A. *APA Tool Validation*

A validation analysis of the APA solar model has been performed for locations at various latitudes north and south of the equator and compared with the results from two similar validated tools commonly used in both commercial and academic applications PVsyst and HOMER. The comparison in Fig. 3 shows close correlation between each models outputs in terms of energy generated by the specified PV system in kWh/m at each site. Ongoing validation includes comparison of APA outputs with actual performance data for real installations at a range of locations.

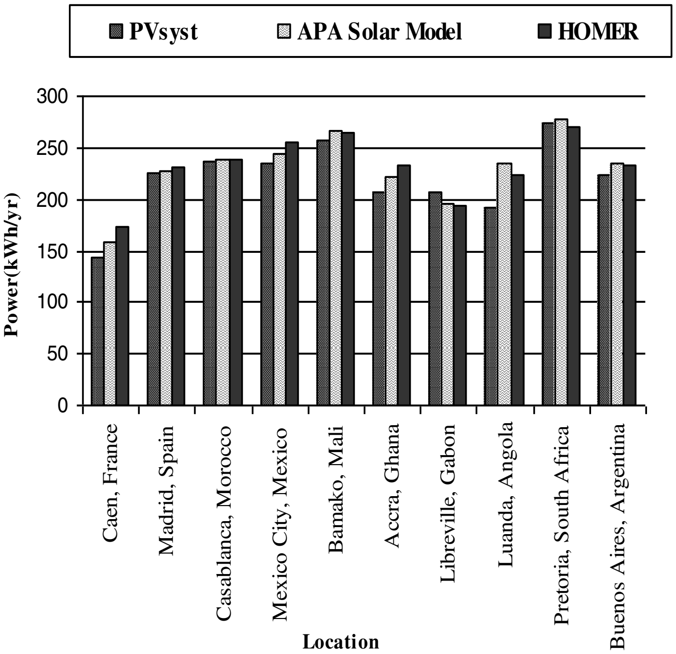

Fig. 3. APA Solar Model v PVsyst and HOMER

B. *Impact of Incentives*

Studies at two locations (Italy and USA) have been performed to examine how available incentives can influence the economic feasibility of a sustainable solution obtained with the APA tool over a 10 year period. Both grid assist and off-grid scenarios are considered. The locations have been selected as having similar solar and wind resources. The APA tool sizes the systems similarly at each site, and sizing is initially optimized to meet the system load using the maximum renewable generation while keeping the CAPEX investment and grid consumption to a minimum. To investigate the economic impact of exporting a larger surplus of power to the grid, the system was subsequently oversized for the grid-assist scenarios.

1) *CASE 1: Italy - Sicily, 38.07N, 12.71E:*

a) Grid Assist Scenarios: Incentives available in Italy (IT) in 2010 include:

1) A Feed-In Tariff (FIT) of EUR 0.3/kWh for wind ($<$ 200kW installed) and EUR 0.36-0.49/kWh for solar PV ($<$ 1MW installed).
2) Grid Net Metering with a 3 year positive credit for systems with $<$ 20kW installed.
3) 10-20% reduction in purchase tax on renewable generation equipment.
4) Green Certificates for systems $>$ 1MW.
5) The installed capacities proposed by the APA tool for both this location and the U.S. location are:

Optimal

- 10 x 170W PV modules = 1.7 kW
- 1 x 6000W Wind Turbine = 6 kW

Oversized

- 30 x 170W PV modules = 5.1 kW
- 2 x 6000W Wind Turbine = 12 kW

Therefore, incentives 1 and 2 may be applied, but option 3 is not applicable with other incentives. Inputting these financial inputs in the APA tool gives the results shown in Figs. 4, 5 and 6.

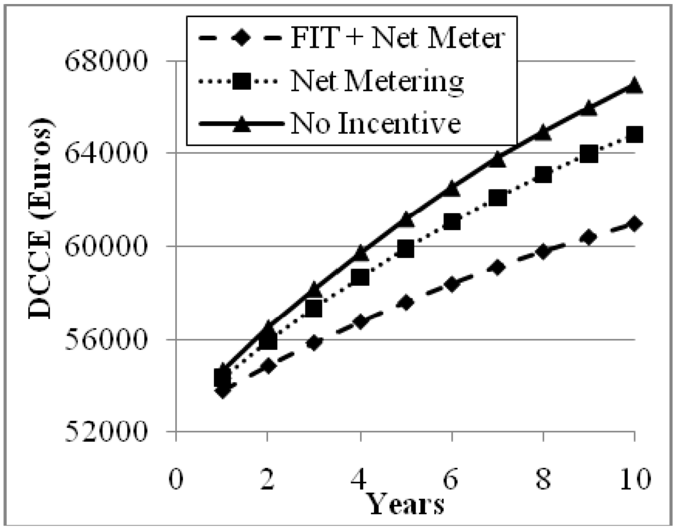

Fig. 4. DCCE for Optimal Grid Assist, Italy

b) Grid Assist Scenarios: There are currently no incentives offered for an off-grid Renewable Energy (RE) installation in the Italy location, but the option can result in long term savings as indicated in Fig. 7. The initial CAPEX for a sustainable solution may be higher than a diesel generator set by as much as a factor of 3, but the DCCE OPEX is lower after an 8 year period due to savings on diesel consumption. This solution only requires on average 1.61 hours/day diesel usage and an estimated battery replacement of 7.1 years. The effect of possible grant incentives of 30% or 50% in the future have also been calculated and serve to reduce the high CAPEX investment and the time period for OPEX savings. Fig. 7 shows DCCE reductions of up to about 70%.

2) *CASE 2: U.S.A., California, 33.95N, 117.45W:*

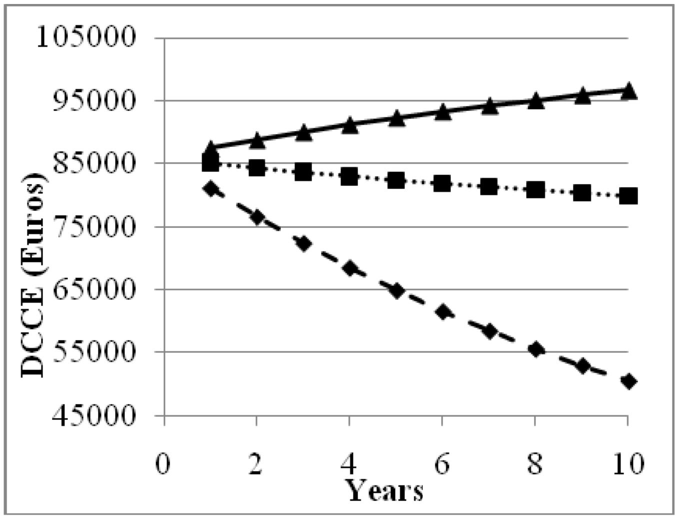

Fig. 5. DCCE for Oversized Grid Assist, Italy

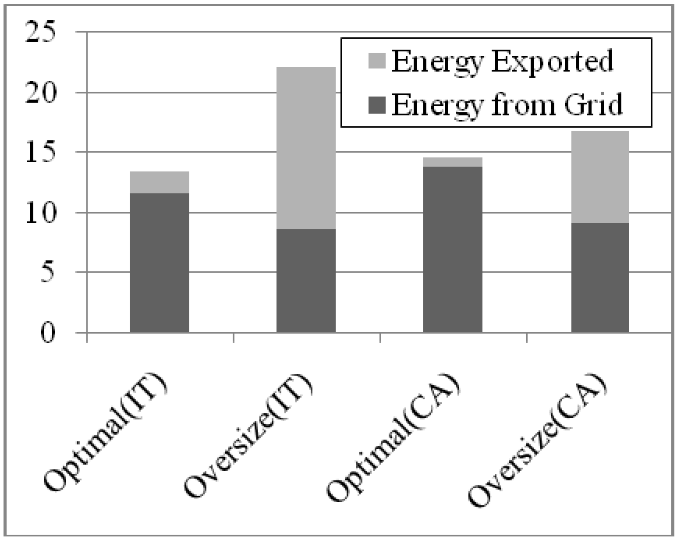

Fig. 6. Energy (MWh) supplied/exported to grid

a) Grid Assist Scenarios: Incentives available in California (CA) in 2010 are:

1) A federal grant of up to 30% of CAPEX for systems less than 100 kW installed.
2) Net Metering with any utility (except Los Angeles Dept. of Water and Power) for systems less than 1MW installed.
3) 1.A variable FIT based on current market price. The current value is USD 0.115/kWh for systems less than 1.5 MW installed.

Both the scenarios considered qualify for all schemes, but option 3 can only be used exclusively. Applying the various incentives to the systems in the APA tool gives the results in Fig. 8 and 9.

The results for the optimal sized system with the California incentives indicate that a grant helps to reduce the nominal DCCE of the system (22%) but that Net Metering and FIT

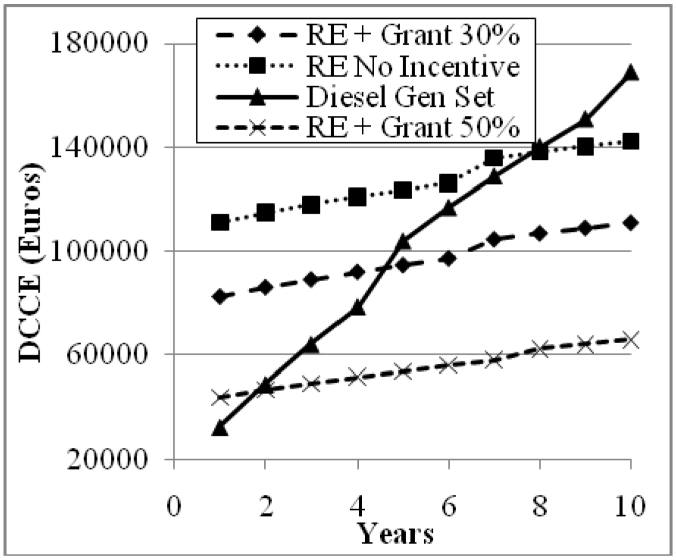

Fig. 7. DCCE for off-grid options, Italy

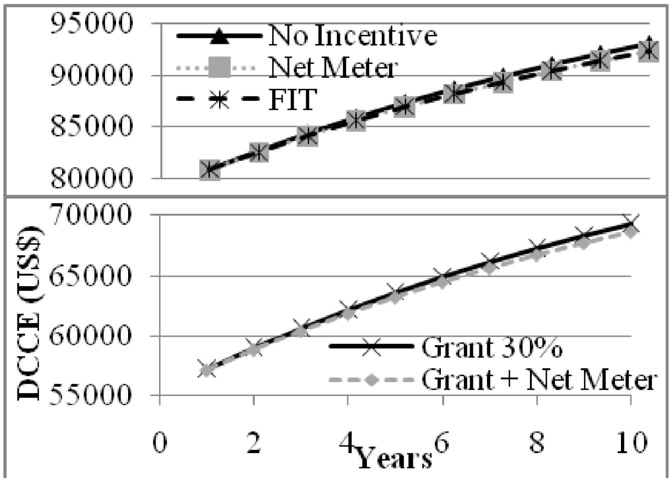

Fig. 8. DCCE for optimal grid assist, California

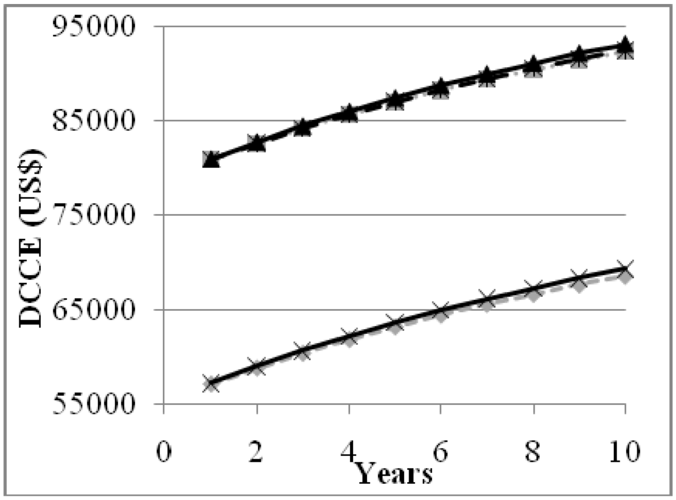

Fig. 9. DCCE for oversize grid assist, California

has no influence as there is very little energy exported and the renewables are a small contributor to the system power needs. On the other hand, for the oversized system the grants provide a significant DCCE reduction (36%) and Net Metering contributes as well as evidenced by the large amount of exported energy and increased use of renewables to satisfy the system power needs.

b) Off-Grid Scenario: Here again there are currently no incentives offered for an off-grid RE installation, but with a higher initial CAPEX the RE solution results in lower DCCE OPEX again after an 8 year period (Fig. 10). The diesel consumption is an average of 2.29 hours/day and has an estimated time for battery replacement of 6.4 years. Even predicting a future CAPEX grant of 50% means that an RE solution would require twice the investment to implement, but could be justified with OPEX reductions after 3 years in operation. Fig. 10 shows the resultant DCCE reductions of up to 50%.

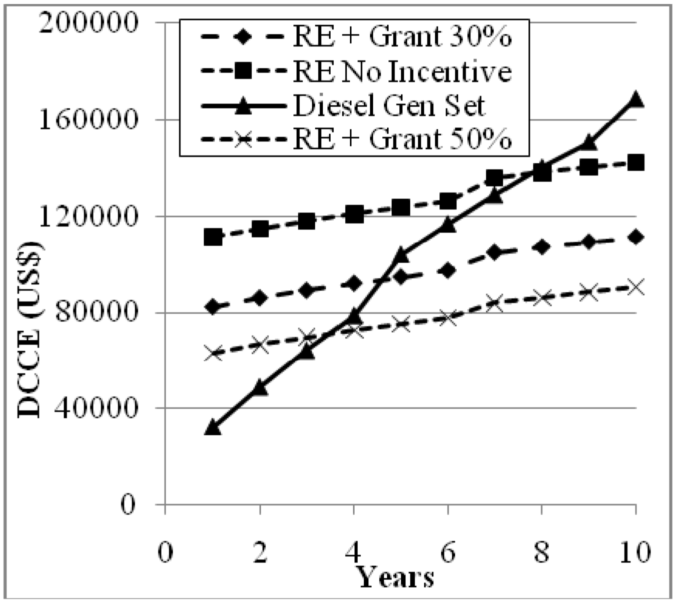

Fig. 10. DCCE for off-grid options, California

V. CONCLUSIONS

For telecommunications service providers and policy makers alike, the application of an appropriate modelling environment can help clarify feasible options for sustainable power installations.

For the two test cases in this work, currently available incentives can lead to reductions in cumulative RE costs of up to 50% over 10 years.

For off-grid scenarios, the impact of capital grants can be significant. A 50% capital grant can lead to reductions in cumulative costs in excess of 50% over 10 years if compared to diesel RBS operation.

An ontological approach can help address issues related to managing disparate datasets such as those for worldwide sustainable power incentives.

The integration of incentives data with techno-economic analyses helps identify the most viable site-specific RBS sustainable power solutions.

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