Economic Impact on Hybrid Systems on Islands

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Abstract **— This paper analyses the economic impact of various electrification options for islands, using a framework of evaluating such options proposed by the Greek Regulatory Authority for Electricity (RAE) as the foundation. It discusses additional factors apart from the pure financial evaluation in terms of the ENPV and illustrates potential effects of employment, the trade deficit and building expertise in the special domain of installing and operating larger renewable energy (RE) systems on islands.**

Keywords - renewable power generation on islands, hybrid power systems, diesel power generation, economic impact, island interconnection (key words)

I. INTRODUCTION

Hybrid electricity generation systems, integrating a higher share of renewable energy (RE) power generation into existing diesel or heavy fuel oil (HFO) based systems are becoming more widespread. With the recent completion of a 15 MW hybrid power station at Essakane gold mine in Burkina Faso, it has been demonstrated that such systems can provide electricity for large power use, critical operation and are competitive from a cost perspective.

However, cost is not the only factor, which should be taken into consideration. The analysis of the economic impact of different electrification options for isolated grids or on islands is quite complex. Particularly for nation states with a large number of islands or isolated grids, such as Greece, Indonesia, the Philippines, Australia, Malaysia, the Kingdom of Saudi Arabia or Brazil, additional factors should be taken into account, since the selected option can have a wider economic impact on the local communities.

With this paper, we want to provide a framework for the analysis of the economic impact of hybrid electricity generation systems, as well as competing scenarios, such as the current means of power generation (diesel or HFO based) and a potential interconnection of the island or isolated-grid to the main grid.

The Greek Regulatory Authority for Energy (RAE) has recently published its suggestion on the criteria and methodology for the techno-economic evaluation of the electrification of Non-Interconnected Islands (NII). The analysis is centered on comparing the interconnection of an island to the mainland Hellenic Electricity Transmission System (HETS) with other scenarios and, hence, provides a benchmark for hybrid systems on Greek islands going forward. Its suggestion provides an excellent framework for starting the discussion on economic impact and it will serve as a reference for this analysis.

In this paper, we will provide background and context on the Greek market for hybrids in section II, introduce the criteria and methodology for the techno-economic evaluation of the electrification of Non-Interconnected Islands (NII) by RAE in section III, provide an initial evaluation on the proposed concept and options for expanding it further in section IV and conclude with a summary and outlook in section V.

II. GREEK BACKGROUND AND CONTEXT

A. Electricity Generation and Cost on Greek Islands

Greece is the European country with the highest number of inhabited islands with estimates ranging between 124 [1] and 227 [2], with 32 electrical island complexes comprising of 60 islands [3]. The large islands, such as Crete or Rhodes and many of the island complexes have not been connected to the mainland as of yet. Electricity on the non-interconnected islands (NIIs) is generated by either diesel or HFO powered generation systems. With a cost of between € 70 / MWh for islands such as Chios and Samos and € 340 / MWh for smaller more remote islands such as Antikithira and Othoni in 2016 the generation is substantially more expensive than on the mainland, where it averaged € 43 / MWh [4]. Since all Greek citizens pay the same electricity price, electricity generation on the islands has to be substantially subsidised. The subsidy, which is called "public service obligation" amounted to € 720 mill. in 2016 [5], has strong correlation to the price of oil and the US$ - EUR exchange rate and ranged up to almost € 800 mill. in 2013 [4].

B. Gross Domestic Product and Unemployment

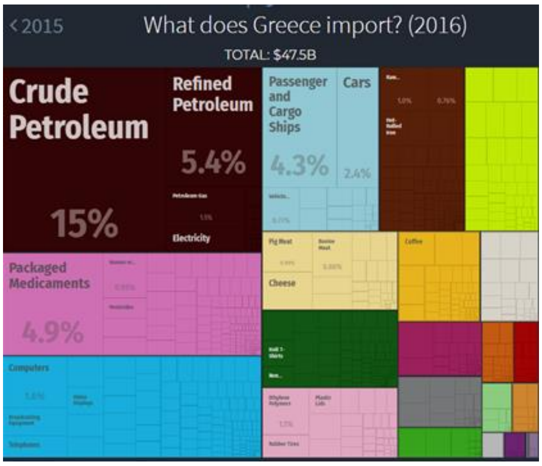
Over the past years, the country has experienced the deepest economic crises that any European country has undergone since World War II. Between 2008 and 2016 the Greek Gross Domestic Product (GDP) contracted by 45% from U$ 354.46 bn. to U$ 194.56 bn. [6]. In 2017 unemployment stood above 20% with youth unemployment standing at 48% [7].

C. International Trade and Trade Deficit

In terms of international trade, Greece exports goods valued at US$ 27.8 bn. and imports goods valued at

US$ 47.5 bn. in 2015 [8]. This results in a trade deficit of U$ 19.7 bn. Of all imported goods, crude petroleum, as well as, refined petroleum account for a total of 20.4% of total imports and a value of U$ 9.5 bn. (see table I below) [8].

TABLE I. GREEK IMPORTS IN 2015



This implies that more than 7% of Greek petroleum imports are related to petroleum products which are used for electricity generation on islands. Reducing imports has the same effect as increasing exports and would have a positive impact on the development of Greek GDP [9], the economy as a whole and job creation in the long-term.

D. Expertise and First Mover Advantage in Hybrid Power Generation Systems

As described by N. Chatziargyriou, I. Margaris, A. Dimeas, Greece is a first mover in the development of hybrid power plants utilizing RE and diesel generators on islands: "The first wind farm in Europe, with an installed capacity of 100 kW was realized in Kythnos. The project was developed within the Greek-German bilateral cooperation in scientific research and technology by a Consortium of PPC and MAN/Neue Technologie in collaboration with the University of Kassel and SMA. The official starting date of its operation was 15 April 1982 and the ultimate objective was the integration of the wind farm into the operation scheme of the diesel station and not just a simple connection to the grid. Main target was to achieve high wind energy penetration close to 25% and stable power supply system, an extremely ambitious target at that time. Soon after, the Kythnos Solar Photovoltaic Plant of 100kWp with batteries was realized within the frame of the EC/DG XII Research Program 1980-83 by a Consortium of Siemens AG, the Public Power Corporation and Varta. Within this R&D project the design, development, manufacture of the equipment and installation were carried out. The official operation of the plant started the 1st of July 1983 after the successful erection and commissioning. The PV plant with the storage was designed to operate in parallel with the Diesel power plant and the Windpark" [1].

Based on these initial experiences key expertise was generated and developed significantly further, particularly within the National Technical University of Athens (NTUA). A close collaboration between some of its engineering departments, other higher education institutions and a number of the key organisations in the Greek utility market has been established centered around the integration of a higher share of RE into fuel powered isolated grids and the forecasting of renewable power generation. These include the power system, market and grid operator of the NIIs, the Hellenic Electricity Distribution Network Operator S.A. (HEDNO S.A), RAE, the Public Power Corporation S.A. (PPC S.A.) and private players. Many of NTUA's alumni are now working at some of the most renown companies in Europe working on hybrids and increasing RE through the use of energy storage systems.

III. TECHNO-ECONOMIC EVALUATION OF THE ELECTRIFICATION OF NON-INTERCONNECTED ISLANDS

A. The Greek Regulatory Authority for Energy's Proposed Framework

The Greek Regulatory Authority for Energy has recently published its suggestion on the criteria and methodology for the techno-economic evaluation of the electrification of NIIs [10]. The analysis is centered on the interconnection of an island to the mainland Hellenic Electricity Transmission System (HETS) and, hence, provides a benchmark for hybrid systems on Greek islands going forward. The evaluation of their financial and technical viability is based on several criteria. The electricity production cost is the key evaluation factor, which itself depends on several financial and technical parameters, such as the energy demand, fuel prices, regulatory framework, national targets for Renewable Energy Sources (RES).

B. Objectives: Quantitative Factors

Aiming at securing power supply, minimizing production cost while maximizing RES penetration and reducing CO_2 emissions, the NII energy system interconnection viability is evaluated by comparing the production cost before and after the project, taking into account several indicators. The quantitative factors which are used for the final evaluation of the project include: Security of supply, socio-economic welfare, RES integration, power losses, and CO_2 emissions.

Security of supply expresses if the demand can be covered by the power supply and can be quantified with the expected energy not supplied in MWh or the loss of load expectancy in hours. Socio-economic welfare increases when the energy cost decreases and can be quantified with the energy redispatch cost in €, which includes the RES integration, the CO_2 emissions difference and the power losses difference before and after the project. RES integration expresses the new RE projects connected to the energy system as well as the curtailment that is avoided after the project, quantified in MWh. Power losses express mainly transmission losses over long distances but also in system components, quantified in MWh. CO_2 emissions reduction is achieved by operating conventional units with lower emissions, quantified in CO_2 tonnes.

C. Objectives: Qualitative Factors

In addition to these quantitative factors, qualitative indicators are also examined, even though they can only be used for comparing projects with similar quantitative results. These include: Technical resilience, flexibility, and environmental and social impact.

Technical resilience expresses how the system conforms to the operational constraints under extreme conditions, such as a cable loss during maintenance. Flexibility refers to the adaptability of the system to be modified and developed differently, for example due to changes in the design. Environmental and social impact expresses the negative effects of the project as perceived by the environment and the local community.

D. Project Evaluation

Project evaluation is based on the estimated total cost, which consists of the capital costs for engineering, procurement, installation and commissioning, financing costs, costs for temporary solutions, environmental costs, equipment replacement costs, operation and maintenance, decommissioning costs etc. The economic analysis suggests several Economic Performance Indicators: Economic Net Present Value (ENPV) expresses the socio-economic viability and should be positive, Economic Internal Rate of Return (EIRR) expresses the socio-economic attractiveness and should be greater than the social discount rate, and Economic Benefit / Cost ratio (EB/C) expresses the socio-economic efficiency and should be greater than one.

ENPV is the main deciding indicator, while the two complementary indicators serve for comparative analysis. The benefits are calculated as the sum of the five described quantitative factors in economic terms, while the costs are the sum of CAPEX and OPEX. These indicators and factors provide a common base for comparison between projects and their socio-economic impact.

IV. Evaluation and Options for Expanding the Techno-Economic Evaluation of the Electrification of NIIs

While the proposed mechanism provides an excellent framework to evaluate the financial impact of new electricity supply scenarios, this paper aims at directing the attention to additional factors, particularly employment, which also play a role for the economic development, especially in the special situation of islands.

A. Island Economic Situation

Islands, particularly, when smaller in size, are fragile economic ecosystems. Greek islands, like many others globally, have experienced a reduction in the population which permanently lives on the islands. Especially, young adults are not finding sustainable labor options on islands and are, hence, moving to the mainland or larger islands. This can be observed by the example of the islands of Kythnos, Cyclades. The population decreased from 704 in the 1991 census, to 695 in the 2001 census to 561 in the 2011 census [11] a reduction of 20%. On many islands tourism is one of the main sources of income. However, tourism often only provides a very seasonal income during the months of May through October.

B. Local Employment

When local employment around power generation on islands is analysed, there are mainly three types of activities which result in employment: (a) operation and maintenance of the power plant, (b) transport of fuel to the island, and, (c) construction, installation of or upgrades to the power plant or interconnection. A detailed quantitative analysis comparing the status quo of a fuel-based power generation system with the alternative scenarios of adding a significantly higher capacity of renewable energy generation, energy storage and a control system which balances fuel and RE power generation and the interconnection of the island to the mainland goes beyond the scope of this paper. However, in the following paragraphs we provide indicative effects of each scenario for large and small islands.

In the current situation, most islands are powered by a generation system consisting of various diesel and/or HFO engines. Regarding activity (a), the operation and maintenance of the power plant, these stations are operated 24/7 and require a number of workers to constantly control it, typically working in three shifts. Maintenance is another task which is carried out by the local teams, often involving employees with a higher education, e.g. electrical and mechanical engineering. For the scenario of adding higher shares of RE, the employment would slightly increase for large and small islands. At the current cost levels of RE generation with storage, RE penetration could reach levels of 30-50% and, hence, the fuel-based power system and its operation and maintenance staff are still required. On larger islands, there may be the opportunity to switch off some of the generators for a number of hours daily, which might result in a slight decrease of maintenance activity of the related generators. However, RE power systems, particularly wind and solar, will also require maintenance which should more than compensate the slight reduction in generator maintenance. In the scenario of interconnecting the island, the operation and maintenance staff will, possibly after an initial test phase, be lost. The additional workers for the operation and maintenance of the incoming interconnection will be marginal and mean a significant reduction of staff compared to the status quo. Of course, the potential to install an even higher capacity of RE after the interconnection with the mainland may result in additional jobs on the operation and maintenance side of the RE systems, which might, at least partly, balance these losses.

Regarding activity (b), the transport of fuel to the island, it has to be noted that the mode of transporting the fuel to the island depends on the size of the island. For larger islands and power plants, e.g. Atherinolakos on the island of Crete, a special port has been constructed and fuel is delivered particularly for the power plant. This requires a whole logistics chain which is operated exclusively for power generation. For smaller islands, fuel is typically transported together with other goods on commercial vessels. In both alternative scenarios the requirement of fuel transport and, hence, related employment will decrease. In the scenario of increasing the capacity of RE on the islands, fuel consumption will be reduced by 30-50% which still requires the logistics chain to be operational and staffed adequately.

In the interconnection scenario the transport of fuel becomes negligible and the jobs related to it are going to be lost.

Regarding activity (c), the construction, installation of or upgrades to the power plant or interconnection, it is clear that both alternative scenarios will generate significant employment for a limited time during the time of their construction. Whether the installation of a higher RE capacity or of the interconnection to the mainland will generate a higher level of employment, most likely depends on the size of the island. For large islands, large capacity additions will be required in terms of the installation of wind turbines and photovoltaic systems and, hence, a high level of temporary employment will be created. Since there are significantly higher levels of economies of scale with the interconnection, e.g. the effort to install an underwater cable with a small or large capacity is more or less similar, the employment effect of this scenario is lower for large islands compared to small islands.

While it is clear that employment relating to point (a) will be local and on the island, this is much less clear for points (b) and (c). Whether the effects on employment of fuel transport and the installation of the new RE systems or interconnection will be local and, on the island, or mainly relate to the mainland, will need to be studied island by island, with a focus on the current location of the logistics hub and an evaluation where staff for the construction could be sourced. Again, the probabilities are higher, that the employment effect for larger islands, which are likely to have the infrastructure and employment pool required are higher, than for smaller islands.

C. Impact on Trade Deficit

As mentioned in sections II. A and C, the electricity generation using fuel is quite costly and has a significant impact on the trade balance of Greece. To compare the two alternative scenarios, it would be necessary to study the level of local value generation of each of them.

Regarding the scenario of increasing the share of RE by installing wind and solar systems, the value chain is relatively well understood. Especially in the case of solar systems and to a slightly lesser degree for wind, a larger share of the value created is local, since the value of the panels and inverters, two main components which are typically imported, has decreased significantly in recent years. The development of the project, obtaining all the licences and permits, per definition is a local activity. With construction of the system and the financing of it, the situation is not so clear. These could be performed using local labor and local financing institutions. However, both of these could also be sourced from abroad.

Regarding the scenario of installing a grid connection to the mainland, a larger share of the cost is dedicated to the cables themselves, as well as the transformer stations. In the Greek context, it has been stated that the connection of the Cycladic islands has been delayed, because a local manufacturer of the cables experienced delays in setting up the manufacturing expertise and capacity. This shows that the economic impact which can be generated by sourcing components locally is taken quite seriously by politicians, regulator and the public utility. Whether the interconnection will help reduce the trade deficit, will depend on the local sourcing options.

D. Export of Goods and Expertise

A factor which is hardly mentioned in the context of deciding on electrification options for islands in Greece, is the expertise which would be established locally. Through its geography Greece has a natural competitive advantage with the numerous inhabited islands. As mentioned in section II. D. Greece was a first mover in gaining experience with RE systems on islands. There are few other market segments in which Greece has a strong competitive advantage

Creating a growing market segment for hybrid power systems within the country, additional expertise could be established and transferred to private companies. This could lead to Greek companies and international companies with a presence in Greece using the strong hybrid engineering base, to export their knowledge and expertise to many other countries in the world. Globally 65 mill. people live on islands with less than 1 mill. inhabitants which equals a share of 0,9% of the world population. There are approx. 2,000 islands between 1,000 and 100,000 inhabitants, which can be considered as natural mini-grids [12]. Thus, the potential for deploying this type of expertise is significant.

E. Effect of a Larger Pipeline of Projects

In its framework, RAE suggests considering the different factors with the main focus on cost project by project, e.g. interconnection of island X with the status quo of diesel power generation or the installation of a RE system on the same island X.

An effect which is omitted by this approach, is the economy of scale effect, when various islands are considered at the same time. Would it be possible to develop, plan and execute RE systems on a larger number of islands at the same time, the cost would decrease significantly. Larger volumes of materials could be sourced, components could be standardised, which would also have a cost reduction effect for the O&M at a later stage and installation teams, that would have already gained experience with the components and systems would be able to install faster and with less errors. Important cost savings could also be obtained on the financing side, which ultimately drives the level of cost (LCOE). Since the cost of structuring the financing is the same, for projects of 1, 10 and 100 MWs the unit cost would be reduced. Also, a different pool of more professional investors could be addressed with a larger project portfolio and, hence, financing cost would most likely be reduced further.

V. SUMMARY AND OUTLOOK

In this paper, we analysed the economic impact of various electrification options for islands, using RAE's framework of evaluating such options as the foundation. We discussed other factors apart from the pure financial evaluation in terms of the ENPV are important and particularly shed light on the potential effects of employment, the trade deficit and building expertise in the special domain of installing and operating larger RE systems on islands.

While a detailed quantification of these effects is suggested for the future evaluation of individual islands and projects, it can be stated that, for larger islands such as Crete, the economic impact of reduced electricity generation cost may outweigh employment considerations. However, it may still be valuable to take these additional factors into consideration, also in order to address and preempt negative reactions from local workers and possibly unions.

For smaller islands, however, the economic impact through the losses of jobs may outweigh the purely financial benefit of reduced power generation cost and a detailed analysis should, hence, be performed.

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