Feed-in tariffs for promotion of energy storage technologies

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Abstract

Faster market integration of new energy technologies can be achieved by use of proper support mechanisms that will create favourable market conditions for such technologies. The best examples of support mechanisms presented in the last two decades have been the various schemes for the promotion of renewable energy sources (RES). In the EU, the most successful supporting schemes are feed-in tariffs which have significantly increased utilization of renewable energy sources in Germany, Spain, Portugal, Denmark and many other EU countries. Despite the of successful feed in tariffs for RES promotion, in many cases RES penetration is limited by power system requirements linked to the intermittency of RES sources and technical capabilities of grids. These problems can be solved by implementation of energy storage technologies like reversible or pumped hydro, hydrogen, batteries or any other technology that can be used for balancing or dump load. In this paper, feed-in tariffs for various energy storage technologies are discussed along with a proposal for their application in more appropriate regions. After successful application on islands and outermost regions, energy storage tariffs should be also applied in mainland power systems. Increased use of energy storage could optimise existing assets on the market.

Keywords: feed-in tariffs, energy storage, renewable energy sources, intermittency, islands

Introduction

In 2007, the EU decided on a set of compulsory renewable energy targets for 2020: an overall 20 percent target (European Commission 2005; European Commission 2008). However, the intermittent nature of renewable energy sources (RES) like wind, solar and waves is one of the limiting factors for their penetration in power systems, especially autonomous systems. Apart from progress in forecasting techniques (Giebel et al. 2003) or providing information to end-users regarding management of uncertainty (Tsikalakis et al. 2009a), energy storage applications

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can provide substantial help in managing intermittency (Barton and Infield 2004). Energy storage is also set as one of four pillars of the EU Post Carbon Society (Carvalho et al. 2009). Efficiently designed financial schemes for storage systems may contribute to EU energy policy 20-20-20.

The available options for energy storage and integration of different energy and resources flows that could help solve intermittency problems in the islands energy systems have been proposed using the Renewislands methodology (Duić et al. 2008). Case studies and calculations for pumped hydro and hydrogen have in many cases been proposed (Duić and Carvalho 2004; Caralis and Zevros 2006; Krajačić et al. 2008) or have been recently implemented, like in Madeira (EEM 2010) or are under final construction, like on Ikaria Island in Greece (PPC 2010).

Efficient management of batteries in small island power systems with increased RES penetration can provide (in terms of adequacy in case of disturbance) both economic and operational benefits for the power systems operators as shown in (Tsikalakis et al. 2004) for the island of Kythnos. Similarly, storage systems for islands based on the size of their energy systems have been proposed (Kaldelis et al. 2009), suggesting that storage could even contribute to a cost reduction in electricity production in such power systems.

Hydrogen has also been proposed as a storage means (Lund et al. 2007; Zoulias and Lymberopoulos 2007; Parissis et al. 2009). Electrolytic H_2 production could be used as a load management method for wind power in weak distribution grids as explained in (Korpas and Greiner 2008). H_2 production and storage may become a viable option in areas where reinforcements of existing grids are costly or controversial due to environmental concerns. A similar conclusion is the advantage of the wind–hydrogen system over wind-only systems due to the fact that energy generation is manageable, hence bringing it closer to demand, as argued by (Agustin and Lopez 2008).

As RES penetration gains pace for autonomous or weakly interconnected islands, operators issue instructions for temporarily disconnection of a part of RES production. Similar problems will be faced by large power systems as RES penetration reaches certain levels. Potential use of this excess electricity occurs through heat pumps and thermal energy storage intended for harsh winter climate areas (Lund 2005) or by use of ice banks or other cold energy storage systems in regions with cooling needs.

For islands where water scarcity is a reality, desalination can be considered as an alternative solution (Calero and Carta 2004; Karagiannis and Soldatos 2010; Psychogiopoulos et al. 2008). Subsequently, there are also places where desalination could effectively be applied in combination with renewable energy sources and pumped hydro storage systems (Segurado et al. 2010) and (Akash, Al-Jayyousi, and Mohsen 1997) . Storage systems used in transport systems could also help RES integration (Lund and Kempton 2008).

As the EU strives to reach goals in its energy policy, energy storage could make a great contribution if similar successful mechanisms were to be used for promoting

RES. The FIT for storage and desalination technologies could be also applied in other parts of the World in order to attract investors to interesting solutions.

After a short description on design and application of Feed-in Tariffs (FIT) in various aspects of renewable energy sources and a description of their benefits, a design methodology of FITs for three types of energy storage methods and one Demand Side Management (DSM) method desalination are provided. Emphasis is given on Pump hydro storage technology, a mature storage technology and battery storage as well as Desalination systems. . Finally, some conclusions are made on the value of the proposed methodology.

Feed-in Tariffs Application and Design

The problem of storage systems is that they increase the cost of already expensive distributed and renewable energy sources, making them mostly in market terms, even less economically viable. For the case of hydrogen, the additional price has been estimated within the range of 43 c€/kWh to 171 c€/kWh, as shown in (Agustin and Lopez 2008; Krajačić, et al. 2009). However, some exceptions for battery systems (Tsikalakis, 2004) and hydrogen for the island of Corvo (Parissis, 2009) suggest that under the circumstances, storage can be a viable option.

However, it should not be overlooked that energy storage may provide even more benefits for power systems, which is difficult to evaluate and accordingly remunerated (Wals and Hendriks 2004). Indicatively, energy storage can help in local integration of solar energy (Kelsey 2006), avoiding local upgrades of the distribution system (Rau and Tayor 1998) or even contribute to facing power quality issues (Swaminathan and Sen 1998).

To overcome financial barriers and create favourable market conditions for energy storage technologies, support schemes and policies must be developed. Feed-in tariffs, Green Certificates, tendering procedures, tax initiatives, and investment initiatives are examples of schemes that have been accepted by different governments and energy regulatory bodies.

As explained by (Meyer 2003), due to the relatively high costs of production, wind power and other renewable sources of electricity, cannot in a free commercial market compete against mature technologies such as large hydro, combined cycle plants based on natural gas, efficient coal-fired combined heat and power plants or nuclear power plants. Therefore, special support systems are needed for RES-E until such technologies become commercially competitive. Recent experience from around the world suggests that feed-in tariffs (FIT) are the most effective policy in encouraging rapid and sustained deployment of renewable energy (Couture and Gagnon 2010). Also, as explained by (Gonzalez 2008), FIT has made Spain and Germany two of the most successful countries in the public promotion of electricity from renewable energy sources (RES-E). FIT has led to the emergence of a RES-E technoinstitutional complex made up of learning networks between RES-E producers, RES-E equipment suppliers, local communities, policy makers and NGOs (Gonzalez and Gual 2007).

Currently, only Greece has policy that supports installation of hybrid systems that include energy storage. Greek law (Hellenic Republic Ministry of Development 2006) regulates the policy, which is currently under revision. The main characteristic is that one tariff is set for electricity from an intermittent RES source, which is directly fed to the grid, while another is set for electricity produced by storage units. There is also a restriction on the amount of energy from the grid that can be used for filling of storage. (Solano-Peralta et al. 2009) proposed FIT systems for the hybrid systems in Ecuador. The use of thermal energy storage in Denmark was indirectly supported through a triple tariff system used for CHP generation since excess capacities in CHP units can be used to relocate hours of electricity production if thermal energy storage is added to the CHP plant (Lund and Andersen 2005).

There are several different ways to structure a FIT policy, each containing its own strengths and weaknesses. (Couture and Gagnon 2010) presented an overview of seven different ways to structure the remuneration of a FIT policy. In general, they divided FIT into two broad categories: those in which remuneration is dependent on the electricity market price, and those that remain independent of it. In the same paper, the advantages and disadvantages of different FIT models were examined, and an analysis of design options was made focusing on the implications for both investors and society. (Haas et al. 2004; Gonzalez 2008) conclude that the specific design elements of support schemes and not so much the type of chosen support scheme are a major factor for their success. Political commitment and other factors including the granting of administrative authorisations are also important as they may cause delays in investments and render RES-E investments unattractive. This means that beside financial, there are many other barriers for RES-E installations identified by (Oikonomou et al. 2009; Suarez et al. 2009), in their work they also propose methodologies for overcoming identified barriers for RES-E installations. As presented by (Garcia and Menendez 2006), utilities have been accused in the past of using third-party grid access as an obstacle to RES-E deployment, this and similar barriers should be addressed before implementing a FIT application for energy storage development.

By providing different support levels for various types of technologies, FIT are more likely to promote different types of technologies than say other instruments, which prioritise the cheapest technologies (Gonzalez and Gual 2007). This is an important characteristic for FIT as there are many storage options on the market in various development stages.

A stepped FIT is characterised by lower tariff for technologies, locations and plant sizes possessing a greater efficiency (Gonzalez 2008). Stepped FIT is a tool in reducing produced surplus and, consequently, the societal burden (Huber et al. 2004). Reducing support as the initial investment provides a return that can also be justified in order to reduce a windfall in profits for investors. In contrast, support was not adjusted according to the RES-E potentials of different locations, which is another positive element of a stepped FIT (Ragwitz et al. 2007). Reductions in support levels for new plants are linked to cost reductions due to economies of scale and learning effects (Gonzalez 2008). Similar reduction of over profit for

producers due FIT application could lead to de-escalation of FIT over time. The de-escalating of the feed-in tariff alleviates the burden on consumers who have to provide the funds for the subsidy through a specially designed RES-E tax. However, if technological progress envisaged in the policy design is not as quick as expected, the penetration of RES might abruptly cease when the feed-in tariffs fall below the technology's levelised cost (Danchev et al. 2010).

(Lesser and Su 2008) explains the main difficulty with the development of FIT compared to other schemes. FIT requires policymakers to define administratively FIT attributes, specifically payments amounts for individual technologies (e.g., wind, solar, geothermal), payment structures (e.g., fixed or declining), and payment durations. All three attributes can require significant 'guesswork' on the part of policymakers regarding future market conditions and the pace of technological improvements. On the other hand, (Lipp 2007) concludes that the advantage of the FIT is that it differentiates various renewable energy (RE) technologies, at different stages of development that have different generation costs. Moreover, the FIT do not narrow competition, because in the interest of keeping construction costs low, developers try to buy the cheapest and best technologies and have thus driven the cost of technology down (Lipp 2007). It could then be concluded that FIT for storage technologies (hydrogen and batteries) will help such technologies to "move up" on learning curves. As presented by (Lipp 2007), in some countries FIT has a long history and an adequate administration to handle its procedures. In these countries, the use of FITs in storage systems could easily be accepted and would not affect the market greatly.

(Lipp 2007) explains specific benefits that countries plan to gain using a FIT application. Most countries support the development of RES for the following reasons:

- Ensuring security of supply (reducing dependence on fossil fuels and creating diversity of supply).
- Reducing greenhouse gas emissions (and other environmental effects of the energy sector).
- Fostering innovation and broadening industrial capabilities (e.g. to improve export potential, skills and enhance competitiveness).
- Increasing local and regional benefits (e.g. through job creation, manufacturing, economic development).

It is desirable to meet these objectives in the most cost-effective manner and this therefore is main reason for conducting a detailed cost benefit analysis before the application of storage systems (Parissis et al. 2009).

As shown by (Saenz de Miera et al. 2008), extensive public support for electricity from renewable energy sources (RES-E), in addition to environmental and socio-economic benefits, has also resulted in RES-E decreasing the total price of electricity. The additional amount of RES-E, supported by the German RES-E policy (EEG), has reduced the wholesale price of electricity in 2005–2007 by 6.4 €/MWh (Rathmann 2007), while increasing the RES-E fee by 3.8 €/MWh. Thus, (Saenz de Miera et al. 2008) concludes that without the RES-E support, the retail price of

electricity would have been 2.6 €/MWh higher than it actually has been. Economic benefits have been reported in the operation of the Cretan power system (Tsikalakis 2003) due to the FIT scheme for wind turbines.

The design of FIT for application in storage system is rather simple and could be easily performed by Energy Regulatory Agencies or Electricity Market Operators and assisted by experts from TSO and DSO. The calculations necessary for evaluating a FIT design could be carried out by using energy planning models as described (Lund et al. 2007; Connolly 2009).

Feed-in Tariffs for Energy Storages

In general, there exist two basic installations for storage systems, i.e. storage installed as separate unit (cf. Figure 1) or as part of a hybrid system (cf. Figure 2). The installation in a hybrid system does not necessary mean that producing RES units (wind or photovoltaic or any other power plant) is physically installed at the same location as the storage unit. It could be just a conceptual combination of these two plants where each unit has its own grid connection but are operated as a single hybrid system.
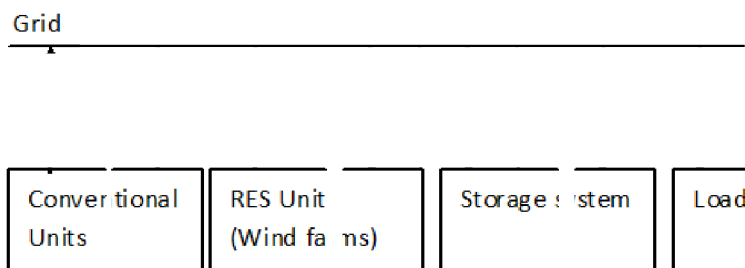
Figure 1. Storage system as separate unit.
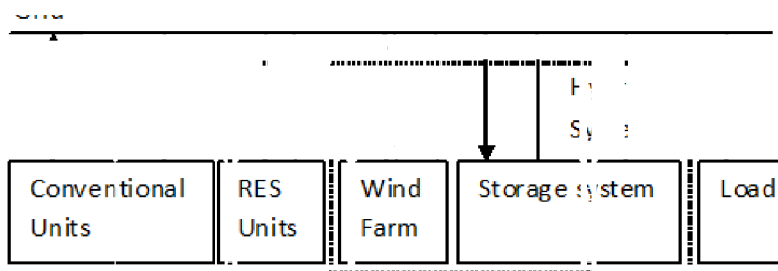
Figure 2. Storage system as part of a hybrid system.

storage systems as separate units are mostly used in big power systems with numerous production units, hence the size of storage units is larger. The best such representative installations, currently operating worldwide, are large pumped hydropower plants. Hybrid systems are more common on the islands and in standalone applications.

Feed-in Tariffs for Pumped Hydro Storage - PHS
Pumped or reversible hydropower stations (PHS), not installed as hybrid systems, use energy from the grid to raise water to an upper reservoir. This energy may

come from all the power plants in the system. In order to avoid harnessing power from conventional stations used for pumping and increasing emissions of pollutants, these kinds of PHS units should be supported only in systems with an established certification of the renewable origin of electricity ("guarantees of origin") –(GO). As mentioned in the introduction, FIT should be different with respect to project size, application, location or resource intensity and the same factors should be applied in supporting PHS.

$FIT_{PHS_{WGO}}$ represents FIT, paid for electricity produced by PHS with the amount equal to electricity used for pumping and decreased by the total efficiency of the PHS system. This means theoretically that electricity produced by PHS could also gets amount of guarantees of origin for RES-E, only decreased by the PHS system efficiency. This is illustrated by the equation below:

$$PHS_{GO} = \eta_{PHS} \cdot W_{GO} \quad \text{(eq. 1.)}$$

where PHS_{GO} are guarantees of origin assigned to electricity produced by PHS and W_{GO} are guarantees of origin for wind electricity supplied from the network. η_{HPS} is the total efficiency of PHS calculated by

$$\eta_{PHS} = \eta_{T} \cdot \eta_{p} \quad \text{(eq. 2.)}$$

where η_{T} is the turbine and generator efficiency and η_{p} is the pumping efficiency. η_{PHS} is an important factor and must be determined from technical documentation for proposed PHS or typical groups of PHS .

If η_{PHS} is 70% and if guarantees of origin are standardised at 1 MWh , then for 1 MWh of $E_{PHS_{WGO}}$ (RES-E coming from PHS with provable renewable origin of electricity) $\text{or } 1\ PHS_{GO}$ will need to supply 1.4285 MWh of E_{WGO} (RES-E coming from wind power plants with provable renewable origin of electricity) or 1.4285 W_{GO}. Complex accounting of GO requires a central registry which should be located at the energy market system operator and supported by power system operators (TSOs or DSOs). The importance of the given GO is explained by (Ragwitz et al. 2009) who states that most probably, EU-wide trading of RES-E is likely to take the form of an exchange in guarantees of origin (GOs). Although there is obvious support for storage technology in the novel EU energy policy, according to the new RES directive (The European Parliament and the Council of the European Union 2009), the production of electricity in pumped storage units from water previously pumped uphill is not treated as a renewable electricity. Consequently, it cannot receive guaranties of origin that are recognized at an EU level nor accepted by the European Commission. The aim here is to avoid twofold counting of produced

renewable electricity. In the scenario that PHS uses only electricity with W_{GO} for pumping, and the turbine has a load factor <=20%, FIT should cover total costs of electricity production which will be paid for the electricity posessing PHS_{GO} and is calculated by formula:

$$FIT_{PHS_{WGO}} = \left(\left(\frac{TIC_{PHS} \cdot R + OMC_{PHS}}{E_{PHS_{WGO}}} \right)_{WGO} + \left(\frac{EPC_{WGO}}{\eta_{PHS}} \right)_{WGO} \right)_{E_{PHS_{WGO}}} \quad \text{(eq. 3.)}$$

where TIC_{PHS} is the total investment cost in PHS, OMC_{PHS} is yearly PHS operation and maintains costs , $E_{PHS_{WGO}}$ is the total delivered electricity to the network by PHS. EPC_{WGO} represents the market price of RES-E used in pumping. WGO indexes only indicate to which renewable origin of electricity the terms in brackets are related.

The annuity factor R is defined as:

$$R = \frac{i}{1 - (1 + i)^{-N}} \quad \text{(eq. 4.)}$$

where, i is the discount rate and N the payback period of the investment.

The size of Hydro Power Plants and Pumped Hydro Storage plants varies from a few hundred kW to hundreds of MW, leading consequently to a big span in installation costs. Another characteristic of PHS is that it could be built by adapting existing structures (adding a pump station and pumping penstock to existing hydropower plants which already have both reservoirs or by adding upper or lower reservoir, penstock, reversible turbines or turbines and pumps to existing water reservoir as described in the case studies of STORIES project Deliverable 2.1. (Tsikalakis et al. 2009b)).   In the same deliverable, total costs of Hybrid Wind Pumped Hydro Storage WHPS and PHS are given by the formulas showed in Table 1. New developments of PHS and the respective installation costs and details are described by (Caralis, Rados, and Zervos 2010) and (Deane, O'Gallachoir, and McKeogh 2010).

FIT suggestions for PHS systems should take into account the local particularities of possibly developing PHS and accordingly, suggestions should propose one or several levels of FIT_{PHS}. For a specific energy system, the limit on turbine load factor in PHS, supported by a different level of FIT, can be optimized. This can be carried out according to desirable levels of excess production from RES units or according to the needs of supply security or energy autonomy of the system as described by (Kaldellis, Zafirakis, and Kavadias 2009), or wind capacity index and the reservoir's capacity index as used by (Caralis, Rados, and Zervos 2010).

Table 1. Overview of the formulas and assumptions for the PHS and WHPS cost estimation.

Equipment – Cost symbol	Data/Formula for Cost Estimation (€)
Wind Farms (C_W)	1200 €/kW
Pumps (C_P)	$C_P = N_P \cdot C_{0,P} \cdot \left(\dfrac{P_{P,rated}}{H_P^{0,3}} \right)^{0,82}$, $C_{0,P} = 1814$
Hydro-turbine (C_T)	$C_T = C_{0,T} \cdot \left(\dfrac{P_{T,rated}}{H_T^{0,3}} \right)^{0,82}$, $C_{0,T} = 4687$
Reservoir (C_R)	$C_R = 420 \cdot V^{0,7}$
Penstock ($C_{Penstock}$)	$1.25 \cdot \sum_I \left\{ \left[\underbrace{(W_M \cdot \pi D_I \cdot e_I \cdot L) \cdot C_M}_{Material\ Cost} + \underbrace{(\pi \pi_I \cdot L) \cdot C_I}_{Insulation\ Cost} + \underbrace{\left(1.5 \cdot \dfrac{\pi D_I^2}{4} \cdot L \right) \cdot C_E}_{Excavation\ Cost} \right] \right\}$
Grid connection (C_{GC})	4%*(C_P+C_T+C_R+$C_{Penstock}$)
Control system (C_{CS})	1.6%*(C_P+C_T+C_R+$C_{Penstock}$)
Transportation of equipment (C_T)	2.4%*(C_P+C_T+C_R+$C_{Penstock}$)
Personal (C_P)	30%*(C_P+C_T+C_R+$C_{Penstock}$)
Others (C_O)	2%*(C_P+C_T+C_R+$C_{Penstock}$)
Operation and Maintenance (OMC_{PHS})	2%*(C_P+C_T+C_R+$C_{Penstock}$+C_W)

If the PHS system turbines have a capacity factor greater than 20%, meaning they operate in excess of 1750 full load hours, the PHS system should then receive one FIT until it fulfils the quota of 1750 full load hours (or energy equivalent). FIT covering this production will allow PHS owners to make a return on investment at a set discount rate and within an expected time period. Another tariff between 1750 and 2750 full load hours is directly linked to the price of electricity used for pumping. Its purpose is to stimulate additional use of PHS in storing excess intermittent energy and thus reduce curtailment. The third tariff allows minimal earnings in storing excess and is set when PHS operates in excess of 2750 hours. In systems with one penstock, similar pump and turbines power, and no extra inflow of water in the upper reservoir, it can hardly be expected that turbines will operate in excess of 2750 full load hours. However, operation hours will be directly linked to system design and for purpose of the PHS system.

Table 2. FIT according to capacity factor.

Working hours at full load (or energy equivalent),	FIT
<1750 h	$FIT_{PHS\ WGO}$
1750-2750	$1.055 \cdot \dfrac{EPC_{WGO}}{\eta_{PHS}}$ (eq. 5.)

>2750	$1.005 \cdot \dfrac{EPC_{WCO}}{\eta_{PHS}}$ *(eq. 6.)*

Table 2 presents just one example of calculating stepped FIT and as mentioned before, and these limits will most probably be case related. Here, stepped tariff is calculated from investor's point of view while another approach for calculating stepped FIT could be trough the system optimization. Therefore, the recommendation is to calculate stepped tariff for the group of similar case studies through system optimization of the following parameters: security of energy supply or energy autonomy, reduction of RES-E excess rejection, desirable RES-E targets/penetration levels, system regulation, costs and benefits of PHS installation.

Wind potential and hydraulic head are site-dependent features, which strongly affect the attractiveness and profitability of the investment, but do not affect the hybrid wind and PHS energy contribution. In achieving a desirable hybrid wind and PHS energy contribution or a peak demand supply for a turbine, a specific wind energy amount combined with a specific storage capacity are required (Caralis, Rados, and Zervos 2010).

When contracted, $FIT_{PHS_{WCO}}$ should last for some period. A period of 12 years seems reasonable from an investor's point of view and contracting should cover a 5 year period after FIT is inured (this provide some security to investors and system planners). Following this 5 year period, a revision of FIT is recommended.

Including 100% of the tariffs for protection against inflation is best way to ensure stability for investors. The amount of the FIT for electricity produced in plants using renewable energy sources during the validity of the electricity purchase contract is adjusted annually with respect to the retail price index. This is carried out by taking the FIT from the previous calendar year and multiplying it with the annual retail price index from the previous calendar year, i.e.

$$FIT_{YPHS} = FIT_{YPHS-1} \cdot IRP_{YPHS-1} \quad \textit{(eq. 7.)}$$

where FIT_{YPHS} is the incentive price for the current calendar year. FIT_{YPHS-1} is the incentive price from the previous calendar year. For the first year, it represents the amount of the tariff item FIT_{YPHS}, prescribed by the tariff system. IRP_{YPHS-1} is the annual retail price index according to official data from the Central Bureau of Statistics for the previous calendar year. $YPHS$ is the yearly index.

(Danchev et al. 2010) describes a system where the feed-in tariff schedule is updated each year, while taking into consideration the inflation rate. However, the compensation is not complete, but amounts only to 25% of inflation. The reason being is that anything less than full compensation provides incentives for constantly

improving the efficiency of the subsidised unit through innovation, learning, and so on.

Another criticism against the FIT has been that favourable tariffs have typically not been reduced in step with technological development (Meyer 2003). A supplementary solution would be to adjust the tariff for new installations at regular intervals taking into account the best technology on the market (bench marking principle).

When additional inflow of water in the upper reservoir exists, enabling load factor of turbines >=20% (or higher of any other calculated desirable limit), FIT for electricity produced in this way is calculated according to eq.8:

$$FIT_{PHS_{TGO}} = \left(\left(\frac{TIC_{TPS} \cdot R + OMC_{TPS}}{E_{PHS_{TGO}}} \right)_{TCO} \right)_{E_{PHS} - E_{PHS_{WGO}} - E_{PHS_{NOGO}}} \quad (eq.\ 8.)$$

$$E_{PHS_{TCO}} = E_{PHS} - E_{PHS_{WGO}} - E_{PHS_{NOCO}} \quad (eq.\ 9.)$$

$$E_{PHS_{WGO}} = \eta_{PHS} \bullet E_{WGO} \quad (eq.\ 10.)$$

$$E_{PHS_{NOGO}} = \eta_{PHS} \bullet E_{NOGO} \quad (eq.\ 11.)$$

where $E_{PHS_{TGO}}$ is electricity produced by turbinating extra inflow of water, $E_{PHS_{WGO}}$ is electricity produced by PHS with GO (by E_{WGO} - energy taken from the grid with W_{GO} is used for pumping) and $E_{PHS_{NOGO}}$ electricity produced by PHS without GO (by E_{NOGO} - energy taken from the grid without W_{GO} is used for pumping). TIC_{TPS} represents total investment costs for a hydropower plant (turbines, generators, penstock and eventually upper reservoir without pumping part). The $FIT_{PHS_{TGO}}$ should only cover the cost of PHS when operating as a hydropower plant using extra inflow of water which means that TIC_{TPS} should be determined from the ratio $\dfrac{E_{PHS_{TGO}}}{E_{PHS}}$. Extra inflow of water in the upper reservoirs could be easily determined as pumped volume will be always known. FIT for

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electricity produced from PHS if there are no guarantees of origin for electricity used for pumping, is calculated using:

$$FIT_{PHS_{NOGO}} = 0 \quad \text{(eq. 12.)}$$

meaning that the operator of PHS is buying electricity and selling back $E_{PHS_{NOGO}}$ at market price. This mode of PHS work should be allowed only if there are no scheduled requests for pumping of RES-E from the system operator in order to avoid curtailment of RES-E.

If TSO or DSO due to some reason request the PHS operator to pump and fill upper storage, and if they cannot provide GO, the PHS owner should receive compensation for carrying out this operation (usually done in accordance with rules for balancing energy and is prescribed in network operation codes).

A proposal for organising the market in terms of invoicing, payments, insuring GO and fees for FIT is showed on Figure 3. In organising such systems, it will be desirable to have Wind Power Dispatch Centres supporting DSO and TSO (Estanqueiro et al. 2008). This would enable undertaking a precise decision on what amount of electricity would be sourced from wind power plants and fed directly to system, and what would be used for pumping. This is important if GO is also to be determined for the PHS system, meaning the RES privileged producer will only get the amount of GO for its electricity directly absorbed by the system while part of the GO will be passed to PHS, decreased by its efficiency. In this way, twofold counting of produced RES-E is avoided and it is then possible to track RES-E, thus organising payments according FIT. Market operators at the end of each month or any other agreed payment period could easily calculate what amount of money, according to prescribed FIT, should be given to RES and PHS producers. As is also shown on Figure 3, it is then possible to show final consumers the amount of GO and RES consumed therefore validating their payments.
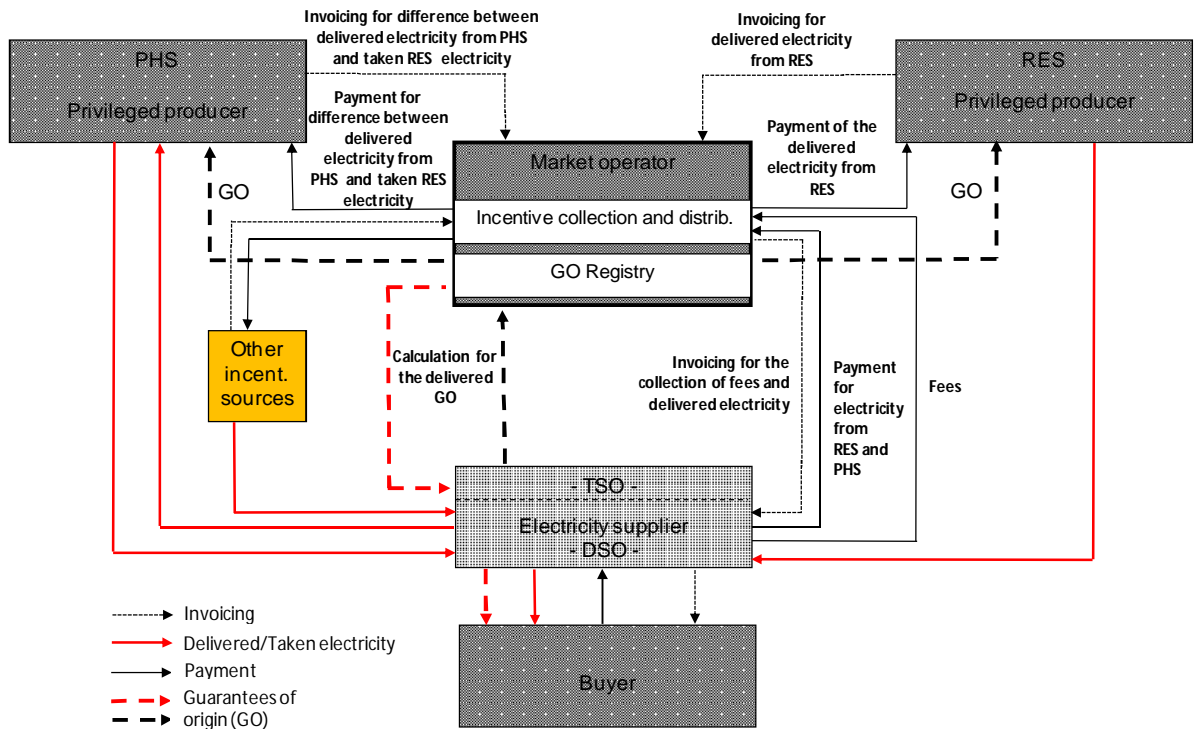
Figure 3. Invoicing, payments and GO flows for FIT.

Feed-in Tariffs for Hybrid Wind Pumped Hydro Storage - WHPS

If the market operator cannot ensure GO of origin for electricity taken and delivered from storage units, then it is possible to set up FIT tariffs according to Greek law (Hellenic Republic; Ministry of Development 2006).

In order to cover costs of electricity production, the following condition must be always applied

$$FIT_T \geq EPC_T \quad \textit{(eq. 13.)}$$

The contribution of the WHPS, together with economical and reliability indexes, are used to describe the performance of the power system after WHPS integration. The conventional units' EPC EPC_C, the electrical system's EPC EPC_S and the turbine's EPC EPC_T are used to describe the economic impact of the WHPS on the electrical system. The most critical is the EPC_S, when compared with the current cost, the resulting benefit -if any- from the WHPS integration is defined. The EPC_T is important for the private investor, indicating a first estimation of the required price for the turbine's electricity production, and providing the feasibility benchmark for

the investment. Finally, the modification of the EPC_C on account of WHPS integration is critical for the ESO[1] in order to accept this price.

The electricity production cost of the turbine EPC_T is defined under the assumption that the whole investment is considered as a means to provide guaranteed electricity supply during peak demand, hence wind energy sold at a fixed price is considered as inflow:

$$EPC_{T} = \frac{TIC_{WPS} \cdot R + OMC_{WPS} + CE_c - BE_W}{E_T} \qquad \text{(eq. 14.)}$$

where TIC_{WPS} is the total investment cost, OMC_{WPS} is the operation and maintenance cost of the WHPS, CE_C is the cost of conventional energy used for pumping, the actual energy production E_T and BE_W is the benefit from wind energy directly absorbed by the grid. If the market price is p_m, then:

$$CE_C = p_m \cdot E_{P,C} \qquad \text{(eq. 15.)}$$

and if the fixed price for wind power is p_w, then

$$BE_W = p_W \cdot E_{W,hi-A} \qquad \text{(eq. 16.)}$$

The electricity production cost of the conventional units EPC_C is defined as:

$$EPC_{C} = \frac{TIC_C \cdot R + OMC_C}{E_C} \qquad \text{(eq. 17.)}$$

where TIC_C is the total investment cost of the essential conventional units, OMC_C the operation and maintenance cost, and E_C is the conventional energy production. The OMC_C has a fixed cost part, a variable cost part and the fuel cost.

OMC_C = FixedCost+VariableCost + FuelCost (eq. 18.)

The electricity production cost of the electrical system EPCS is calculated as (assuming that the redundant units are uninstalled):

$$EPC_{S} = \frac{TIC \cdot R + OMC}{E_{Total}} \qquad \text{(eq. 19.)}$$

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[1] The autonomous islands are excluded from the market liberalization and the system operator remains the owner of the local power stations.

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where *TIC* includes the cumulative investment cost of all power plants (essential conventional units, WHPS and wind farms outside the WHPS); the *OMC* includes the fixed cost, the variable cost and the fuel cost for the operation and maintenance of the system; and E_{Total} is the total electricity demand.

## Feed-in Tariffs for PHS in the Ios Island Case Study

The Ios case study will be used as an example to show how the proposed formulas for FIT work. Ios is an island in the Cyclades Complex and its electrical supply is part of the autonomous Paro-Naxia system, which includes five main islands (Paros, Naxos, Ios, Sikinos, Folegandros) and some smaller islands.The only local power station is located in Paros with 10 Internal Combustion (IC) power units at a cumulative capacity of 61.4 MW. All the islands are interconnected but this system is considered venerable and centralised with high energy transportation losses and stability problems. The annual energy demand in Paros power system is estimated at 189.56 GWh, and the peak demand of 61.2MW with a load factor of 37.6%. Estimations for Ios refer to 12.6 GWh with a peak demand of 3.9MW. Ios has high wind potential and several existing water reservoirs, which are currently used for irrigation and may be cumulatively exploited for a PHS (Tsikalakis et al. 2009c).

Table 3. Ios case study data.

Rated power of the turbine – MW	8.0
Rated power of pumps – MW	6.5
Capacity of the reservoir - m^3	120000
Installed power of WT – MW	18.3
Additional installed power of WT - MW	13.5
EPC_{WGO} **- €/MWh**	87.42
η_{PHS}	0.696
I	15%
N – payback years	8

The energy planning model H2RES described in (Lund et al. 2007; Krajačić, et al. 2009;) has been used for modelling the system behaviour with installed PHS, a reduction of curtailed energy and operating hours of a PHS station. The H$_2$RES model is designed to support the Renewislands methodology (Duić, Krajačić, and Carvalho 2008) and is primarily used for balancing the hourly time series of water, electricity, heat and hydrogen demand, appropriate storages and supply. The main purpose of the model is energy planning for the islands and isolated regions, which operate as stand-alone systems. It can also serve as a planning tool for power producers using renewable energy sources that are connected to bigger power systems. Over time, the model has evolved and several new modules have been developed like wave, biomass, solar heat and desalination. Several papers describe the H$_2$RES model and provide details of its operation (Duić, Krajačić, and Carvalho 2008), (Duić and Carvalho 2004), (Duić, Lerer, and Carvalho 2003), (Lund et al. 2007). The main characteristic of H$_2$RES model is that it uses technical data from equipment specifications, hourly meteorological data for intermittent sources, and according to the description in (Duić, Lerer, and Carvalho 2003), energy balancing is regulated by the equations.

In 2010, annual energy demand in the Paros power system was estimated at 246.3GWh and peak demand <t 74.8MW. The estimated hourly data for 2010 has been used in H_2RES. It was also assumed in the calculations that 18.3 MW of wind was already installed in the system with an additional 13.5 MW following installation of the PHS system (Table 3). With the limit on hourly wind penetration at 30% and without PHS and new wind installations, it was possible to satisfy 19% of yearly electricity demand while rejecting 30% of total wind potential. With the installation of PHS used for peak shaving at 82.5% of the dynamic weekly peak, it was possible to store 19% of all wind potential. In this case, PHS turbines supplied 3.5% of total demand and the capacity factor equalling 12 %. Under the same conditions and with 13.5 MW of extra wind installed, capacity factor of turbines in PHS were increased to 20%, accounting for a supply of 6% of total electricity demand. Wind share in the total demand was 23% with 34% representing the rejected potential. Figure 4 presents a H_2RES Simulation of the power system on Paros in January. The high rejected potential is caused by low demand and favourable wind conditions.
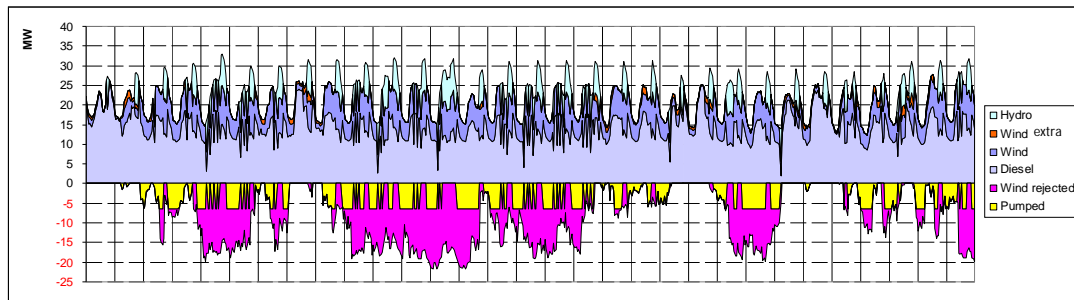
Figure 4. H_2RES Simulation of the power system on Paros in January (development of PHS in IOS) – dynamic weekly peak

Equipment cost for TIC_{PHS} is calculated according Table 1 and does not take into account the cost of a lower reservoir, in its current state. The calculated TIC_{PHS} is 6.8 mil. € and OMC_{PHS} is 97,226 €.

Table 4 and Figure 5 present calculated stepped FIT in the Ios island case. Possible extra earnings for PHS owners if working in excess of 1750 hours are marked by a yellow colour.

Table 4. Proposed $FIT_{PHS\,WGO}$ for PHS on Ios with the existing lower reservoir and 20% turbine load factor.

Working hours at full load (or energy equivalent)	$FIT_{PHS\,WGO}$ [€/MWh]
<1750 h	240
1750-2750	132.5
>2750	126.2
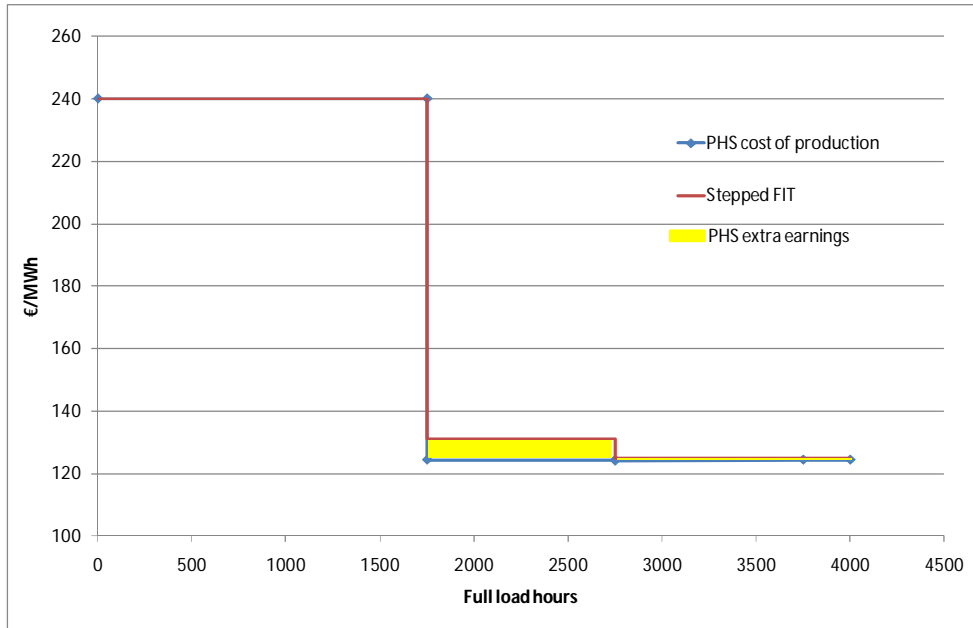
Figure 5. Stepped FIT

This $FIT_{PHS_{WCO}}$ should be valid for PHS with 1 MW to 10 MW of installed power turbines and for installations that already have lower reservoirs. Bigger systems and different configurations of PHS installations require additional calculations by using equations 1-6 and Table 1 .

For example, if the system on the Ios island requires the installation of a lower reservoir of the same size as the upper, the FIT for a load factor <1750 h (or energy equivalent) should be at least 263 €/MWh.

If the same principle for designing a FIT is applied to case studies calculated by (Caralis, Rados, and Zervos 2010), the average FIT for all islands will be 422 €/MWh, in the cases where it was assumed that hydro-turbine's peak demand supplies 50% and 43% energy contribution. The high FIT is due to different conditions for system design but also due to large distances on the islands sizes. Therefore, FIT for the Crete would be 269 €/MWh while for the Megisti Island it is 1065 €/MWh. It is interesting to note that if the discount rate in the design of FIT is set to i=5% and the payback period set to 20 years as used by (Caralis, Rados, and Zervos 2010), the average FIT calculated for their case studies is 240 €/MWh for a turbine size of PHS ranging from 1 MW to 10 MW.

Feed-in Tariffs for WHPS Ios Case study

A more detailed financial analysis of the Greek hybrid system is given in (Papathanassiou et al. 2008). Some of the results for the Ios Case study are showed in (Tsikalakis et al. 2009b) and (Caralis, Rados, and Zervos 2010).

The installation of WHPS contributes to a decrease in total EPC for the system and yearly savings are in the range of 2.2 mil €, including significant avoided emissions. Since WHPS also uses up to 6.3 GWh of electricity from conventional pumping units, resulting in 1260t of emitted CO_2, so it is desirable to install a registry of GO to

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enable WHPS treatment as a RES power plant. In the both calculated cases for the Ios Island, despite storage installation there was still a certain amount of rejected wind generated electricity. If the amount of this rejected electricity is significant, wind producers should receive compensation for their losses. On the other hand, they could also share the burden in solidarity with consumers. Alternatively, compensation could be made to a special fund used for installations that reduce the amount of curtailment (storage, demand side management).

Feed-in Tariffs for Hydrogen Storage Systems HSS

The typical hydrogen storage system includes a water electrolysis unit, a hydrogen storage tank and a fuel cell. Electrolytic hydrogen is produced when excess energy is generated by renewable electricity-generating technologies. Hydrogen is then stored in a gaseous form and can be used as a feedstock for the fuel cell in order to produce electricity when needed. Additionally, hydrogen can be used for transport purposes. In this case, the calculation of feed in tariffs could be more complicated, since part of the payback should come from transport fuel prices. Installation costs of electrolyser, hydrogen storage, control system and compressor should be divided between electricity and transport costs.

FIT for hydrogen storage could be calculated in a similar manner to *eq 3.* for PHS

$$FIT_{H2_{WGO}} = \left(\left(\frac{TIC_{H2} \cdot R + OMC_{H2}}{E_{H2_{WGO}}} \right)_{WGO} + \left(\frac{EPC_{WGO}}{\eta_{H2}} \right)_{WGO} \right)_{E_{H2_{WGO}}} \quad (eq.\ 20.)$$

where TIC_{H2} is total cost of investment in HSS, OMC_{H2} is yearly operation and maintenance costs of HSS, $E_{H2_{WGO}}$ is total delivered electricity to the network by HSS from electrolysed water. EPC_{WGO} represents the price of RES electricity used in electrolysing water. η_{H2} is the total efficiency of HSS and is calculated by

$$\eta_{H2} = \eta_{ELY} \cdot \eta_C \cdot \eta_{FC} \quad (eq.\ 21.)$$

where η_{ELY} is the efficiency of electrolyser, η_C is the efficiency of the compressor and hydrogen storage and η_{FC} is the efficiency of fuel cells. η_{H2} is an important factor and must be determined from technical documentation relating to the proposed hydrogen system or is taken as an average of values for η_{H2} .

Similar to the several levels of FIT for PHS, $FIT_{H2_{WGO}}$ should also have several levels so that a single price is paid until the fuel cell reaches a desired level of a full load capacity. Subsequently, the load factor FIT is calculated from the equation :

$$FIT_{H2_{WGO}} = 1.02 \cdot \frac{EPC_{WGO}}{\eta_{H2}} \quad (eq.\ 22.)$$

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Feed-in Tariffs for HSS – Milos case study

Milos is a Greek island situated on the south-western part of the country, specifically in the group of islands called Cyclades. Combining and introducing wind energy and hydrogen storage into the Milos power system has shown that a reduction on fossil fuel dependency, an improvement in supply security and a decrease in the production of harmful fossil fuel emissions are feasible and can be undertaken at a lower cost than current power generation. (Parissis et al. 2009). For Milos, the thermal units' capacity can be also reduced. Annual electricity demand for the Milos island is approximately 39,729 MWh with peak demand equal to 8.5 MW. In order to meet this demand, the existing power system includes 8 thermal generator sets with a total capacity of around 11.25 MW and a small wind park comprising 3 wind turbines with a total installed capacity of 2.05 MW and a 13.9% share in demand (Parissis et al. 2009).

Table 5. Milos case study equipment and O&M costs.

Equipment	O&M	Installation
Fuel Cell -1 MW	4,418 €/year	1,500,000 €
Electrolyser – 2MW	50,000 €/year	2,000,000 €
Hydrogen storage tank – 4000 kg	4,000 €/year	1,600,000 €
Other data		
EPC_{WGO} - €/MWh		87.42
$E_{H2_{WGO}}$ -kWh		2,353,161
η_{H2}		0.3575
I		15%
N – payback years		8

In this case, $FIT_{H2_{WGO}}$ should be equal to or greater than 50 c€/kWh and should be paid until fuel cell reach full load capacity factor of 27% (or energy equivalent). Subsequently, the following load factor equation should be used to determine the feed-in tariff above desired load factor level:

$$FIT_{H2_{WGO}} = 1.02 \cdot \frac{EPC_{WGO}}{\eta_{H2}} \qquad (eq.\ 23.)$$

When not taking into account other benefits like (fuel savings, avoid emissions, etc.) described in detailed in (Parissis et al. 2009) the additional fee that should be collected in Milos in order to cover $FIT_{H2_{WGO}}$ is 3 c€/kWh. Furthermore, if all benefits are taken into account, the total price of electricity could be less by 0.1 c€(Parissis et al. 2009), meaning that there is no need for an extra fee. In the report provided by (Parissis et al. 2009), a detailed description of cost-benefit analysis and subsides required for hydrogen storage technologies is given.

Feed-in Tariffs for Batteries Combined with PV Systems for Higher Penetration Levels

PV- batteries systems are the most common solution for off-grid applications. Thousands of such systems exist all over the world in trying to meet rural

electrification needs such as in the Sahara desert regions (Labed 2008). However, these systems are out of the scope of this paper.

Large battery installations have started becoming a reality and the Battery Energy Storage Station in Alaska (Golden Valley Electric Association 2010). It has been reported that the system has avoided 82 disconnection events, with such events potentially affecting up to 310,000 customers for a maximum of 725 minutes of disconnection time during 2006.

Batteries have been considered as a means of providing support in power system dispatches (Yau et al. 1981), and have also been taken into account as models for providing a spinning reserve. Their potential impact on power quality issues should be also acknowledged (Swaminathan and Sen 1998).

Here emphasis is placed on grid-connected RES-batteries operating in autonomous power systems, like islands. Even more focus is given on evaluating FIT scheme for relatively high RES penetration levels. Under these operating conditions, batteries may be mainly required to reduce surplus electricity from RES, as well as provide partially support in increasing adequacy of the power system (Tsikalakis. Tassiou and Hatziargyriou, 2004) and smoothen as much as possible the output of the operating conventional units in the power system. With relatively low penetration, the impact of energy storage here taken to be batteries, is expected to be more limited than in the case of higher PV penetration.

The reason for selecting PVs for the case study is the fact that the time to produce energy is better determined than in the case of wind, during the daytime and the fact that PV cost is significantly higher per installed kW than wind. As explained in the Corvo case study, it may be preferable, in both operational and economic terms, to increase PV penetration not by installing additional PV capacity but by installing storage and more specific batteries, which is not a site-specific technology. The aim of the proposed FIT scheme is to provide incentives for combining storage and RES in order to increase PV penetration on island power systems.

The parameters possibly affecting operation of the proposed system and which should be taken into account when designing FIT for batteries are the following:

The penetration level (PenLevel). Below a penetration level of about 12-13% (case specific which should be evaluated with power system simulation tools), FIT for storage is unified since no additional RES production is injected into the grid. If the storage device provides other ancillary services such as frequency or voltage support, then the manner of remuneration should be calculated, but this is beyond the scope of this paper.

The PV capacity (PVCap). As it increases and surpases the capacity when curtailment takes place, the remuneration for additional PV should be reduced in a gradual manner since additional power system benefits will also be reduced. This will discourage and at the same time protect potential investors from building larger PV plants if problems exist in injecting power to the grid. At the same time, this could also lead investors to consider storage or deferrable loads in accommodating PV capacity and hence alleviate PV curtailment.

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The Storage capacity in terms of Ah and their conversion to kWh (BatCap): The storage value varies depending on the storage capacity. Even low values may provide aid in support the power system, whereas in some cases increasing storage capacity may significantly lead to very limited additional benefits. This will also be discussed in the case study. There should be additional incentives to balance batteries and PV capacity and to increase as much as possible the benefits of the power system, especially in terms of fuel consumption and avoidance of emissions. Moreover, it should be stressed that batteries present highly non-linear behaviour. High charge/discharge rates, especially for lead acid batteries can drastically shorten battery lifetime. Therefore, a higher capacity may be required to avoid such phenomena and prolong battery replacements periods.

The inverter capacity in terms of kW (InvCAp). This has a close connection to BatCap, since these two parameters should correlate. Usually the value of an inverter in kW ranges from 20% to 5% of the storage capacity. The impact of increasing inverter capacity above 10% of battery capacity (analogous to C10 parameter for batteries) is discussed. Potential benefits or drawbacks and ways of taking it into account under FIT are suggested for the specific case study.

The Fuel price (FuelPrice). When the units are identical and consume the same type of fuel, its evaluation is much easier than for multi-fuelled power systems. Changes in fuel prices should somehow be reflected on the FIT value. This will draw investors to power systems where fuel savings are greater. Investors might also endeavour to optimise production during hours when fuel benefits are higher, i.e. when more expensive units are expected to operate. However, caution should be taken so that FIT is not overtly sensitive to fuel price because fuel price fluctuation may create uncertainty in investors and have the opposite result.

Therefore, the function for the FIT, apart from the considerations on the payback period and improved IRR, should be like function 24 below. The correlation between various parameters, some of which have a larger magnitude correlation, should be analysed by simulating power systems under high PV penetration for various energy storage capacities. Initial analysis can be made by using logistic tools that take into account not only RES potential and demand but also the technical minimum of the thermal units and reserve policy, i.e. how much load and PV production uncertainty will be considered by the power system operator.

$$FiT = function\left(PVcap, BatCap, InvCAp, PenLevel, Fuel\Pr ice\right)$$ (eq. 24.)

In order for FIT to become more effective in increasing PV penetration, storage should be charged using excess PV electricity. The discharge should aim in reducing conventional power plant operation time but the rate will be maintained below 12.5% of the battery capacity to prolong battery lifetime. The most critical value for changing FIT is the *PenValue* above which PV curtailment takes place. The suggestion is to have one FIT block for penetration values when no curtailment is expected. More focus and a more elaborate scheme, narrower steps should be provided above for higher penetration in order to take into account the increase in PV curtailment.

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Feed-in Tariffs for PV and Batteries Under High Penetration

This case study represents of the Island of Corvo, one of the nine islands in the Azores archipelago, located in the western part of the archipelago. There is only one settlement, Vila Nova do Corvo, with about 400 inhabitants. The island's demand of approximately 1086 MWh with a peak of 204kW is met by two diesel gen-sets at 120kW and two at 160kW, i.e. a total of 560kW. Usually, demand is met by two generators, one from each group. The fuel cost in Corvo is the highest in the entire archipelago, nearly 5 times the average in Azores and about 0.816€/L for electricity production. On Corvo Island, the supply security is a real and frequent concern, since bad weather conditions commonly create oil shortages on the island. To reduce Corvo's dependency and secure supply, the implementation of an energy system that combines RES and storage can be a promising solution. The solar radiation potential on the island is 3.12kWh/m^2/day. In all cases, a 50% parameter is considered for PV production while the load forecast error is considered a normal distribution function with a mean value 7.09% of the forecasted value, as explicitly described in (Tsikalakis et al, 2009a)

First, potential tariff scheme used to reflect the case of PV curtailment is described. This will be the basis of calculations for part of the FIT referring, firstly to battery capacity and secondly to inverter capacity.

For the case of Corvo, the general form of the suggested FIT which depends on fuel price, is based on eq25. FIT for the rest of the parameters will be calculated and eq.25 will be used for updating the FIT according to the change in Fuel Price (FP) as a last step.

$$FIT(FP) = FIT \cdot \left\{ 0.95 + \frac{0.05 \cdot FP}{0.816} \right\}$$ *(eq. 25.)*

The PV capacity considered in the simulation, the initially expected production and the expected curtailment is shown Table 6. For simplicity, solar trackers have not been considered and the slope is equal to the geographical latitude at 31.5^0 for the island. It is clearly shown that both PV curtailment and the percentage of PV production not delivered to the grid increase as PV capacity increases, consequently reducing the benefits for the island grid.

Table 6. PV capacity considered in the simulations and expected PV curtailment.

Installed Capacity [kW]	Expected PV production [MWh/yr]	Expected PV curtailment [MWh/yr]
0	0	0
15.5	14.9	0
155	149.1	18.51
185	178	34
283	271.3	86.5
400	384.8	190.3

In order to calculate the FIT, the change in fuel consumption will be taken into account for various *PenLev* values in Table 7. For the first group of penetration level, the proposed FIT is the same with the highest provided in the Portugal. In this case, no additional production is planned. In the last column, x represents total annual PV production. The fuel savings refer to the savings when production is increased from 12-16% and so on.

Table 7. FIT for PVs on Corvo without storage.

Penetration level (PenLev) [%]	PV production [MWh/yr]	Fuel savings [tn/Additional MWh injected/yr]	Proposed FIT [€/MWh]
0-12	0-130	No Curtailment/not considered	450
12-16	130-173	0.21	$\dfrac{450 \cdot 130 + 0.21 \cdot FP \cdot (x-130)}{x}$
16-25	173-271	0.204	$\dfrac{380.73 \cdot 173 + 0.204 \cdot FP \cdot (x-173)}{x}$
25+	271	0.169	$\dfrac{303.25 \cdot 271 + 0.169 \cdot FP \cdot (x-271)}{x}$

The additional income for the potential investor arising from increased installed capacity, should be equal to the increase in savings for the power systems, so that the clear economic position for the power system remains the same with conditions that do not lead to curtailment. Subsequently, the potential investor is encouraged to optimise the operation of the PV plant and gradually increase its capacity following any increase in demand on the island.

Considering Batteries

Various values of lead acid battery capacity, *BatCap*, have been considered in the simulation runs with Inverter capacity (*InvCap*) at 1/10th of *BatCap*, as given in Table 8. The update in battery content as a function of time depends on the exchange with the island grid, based on Peukert's equation (eq.26).

$$I^{n} \cdot Ti = cons\tan t \qquad (eq.\ 26.)$$

where I is the charge/discharge battery current , n is the Peukert number in the range of 1.05 – 1.40, here taken as 1.30, and Ti is the charge or discharge period.

Table 8. Capacity limits for the considered batteries

Capacity range (CR)	Upper limit (Lmt) of Battery	Upper limit of Inverter

	Capacity [kWh]	Capacity [kW]
1	40	4
2	80	8
3	160	16
4	320	32
5	640	64
6	960	96

The remuneration of batteries on annual basis takes the form of providing a service,, and is based on *BatCap* values and the fuel savings achieved during operation.

In this case, storage mainly helps in providing part of the necessary spinning reserve for operation of the power system. Little exchange with the power grid is expected. Even a small battery capacity can significantly improve the economics of the power system with benefits somewhat falling as battery capacity increases. The benefits in both cases, with and without PVs, evaluation and the proposed remuneration scheme for battery capacity is shown in Table 9.

Table 9. The remuneration scheme for various Battery Capacity levels at a penetration level below 12%

CR	Remuneration [€/kWh of battery]	
	Without PV	With PV
1	$82.1 \cdot BatCap$	$53.8 \cdot BatCap$
2	$\dfrac{82.1 \cdot Lmt(1) + 3.33 \cdot (BatCap - Lmt(1))}{BatCap}$	$\dfrac{53.8 \cdot Lmt(1) + 19.1 \cdot (BatCap - Lmt(1))}{BatCap}$
3	$\dfrac{41.7 \cdot Lmt(2) + 38.6 \cdot (BatCap - Lmt(2))}{BatCap}$	$\dfrac{36.45 \cdot Lmt(2) + 35.06 \cdot (BatCap - Lmt(2))}{BatCap}$
4	$\dfrac{40.12 \cdot Lmt(3) + 11.96 \cdot (BatCap - Lmt(3))}{BatCap}$	$\dfrac{35.75 \cdot Lmt(3) + 13.5 \cdot (BatCap - Lmt(3))}{BatCap}$
5-6	$\dfrac{26.04 \cdot Lmt(4) + 0.1 \cdot (BatCap - Lmt(4))}{BatCap}$	$\dfrac{24.63 \cdot Lmt(4) + 0.2 \cdot (BatCap - Lmt(4))}{BatCap}$

The way in which batteries assist in increasing energy injected into the grid and reducing PV power curtailment is shown in Figure 6. The increased grid injection helps in reducing fuel consumption on the island as shown in Figure 7. Such servicing of batteries should be accordingly remunerated in order to entice investors to invest more on storage rather than on PVs when increased penetration is expected. Part of the additional benefits for the power system have been remunerated due to additional PV production based on the formulas presented in Table 7. These benefits are reduced for all cases when battery capacity exceeds 320kWh, mainly for a PV capacity below 200kW. It is almost as beneficial to increase battery capacity for 400kW installed PV capacity from 640kWh to 960KWh

as it is to increase battery capacity from 320kWh to 640KWh for a 283kW installed PV capacity.
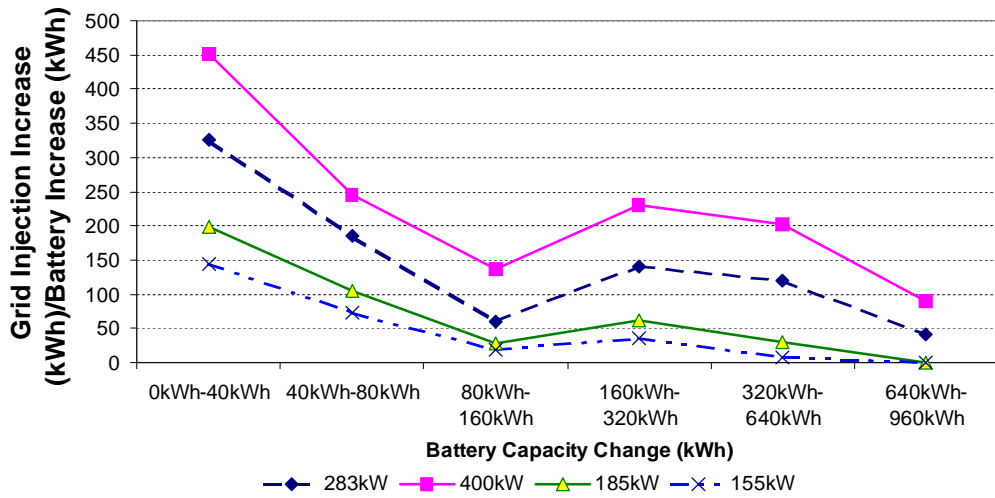

Figure 6. Grid Injection increase due to change in Battery capacity.

The difference between the savings in fuel and the PV remuneration is used as the basis for calculating suggested tariff schemes at various penetration levels.
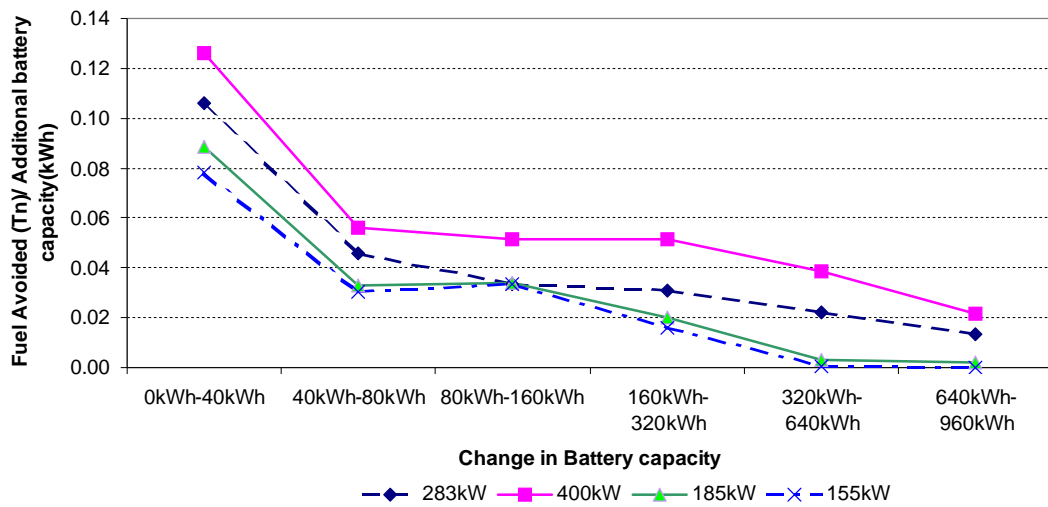

Figure 7. Fuel avoided due to change in Battery capacity

Table 10. The remuneration scheme for batteries at penetration levels above 12% for various Battery Capacity and penetration levels

CR	Remuneration [€/kWh of battery]		
	PenLev=12-16%	**PenLev=16-25%**	**PenLev>25%**
1	$35.42 \cdot BatCap$	$27.3 \cdot BatCap$	N/A
2	$\dfrac{35.42 \cdot Lmt(1) + 8.79 \cdot (BatCap - Lmt(1))}{BatCap}$	$\dfrac{27.3 \cdot Lmt(1) + 5.13 \cdot (BatCap - Lmt(1))}{BatCap}$	

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3	$\dfrac{22.105 \cdot Lmt(2) + 39.88 \cdot (BatCap - Lmt(2))}{BatCap}$	$\dfrac{16.22 \cdot Lmt(2) + 16.04 \cdot (BatCap - Lmt(2))}{BatCap}$	
4	$\dfrac{31 \cdot Lmt(3) + 2.24 \cdot (BatCap - Lmt(3))}{BatCap}$	$\dfrac{16.13 \cdot Lmt(3) + 1.16 \cdot (BatCap - Lmt(3))}{BatCap}$	
5	$\dfrac{16.62 \cdot Lmt(4) + 1.89 \cdot (BatCap - Lmt(4))}{BatCap}$	$\dfrac{8.64 \cdot Lmt(4) + 1.44 \cdot (BatCap - Lmt(4))}{BatCap}$	$\dfrac{10.79 \cdot Lmt(4) + 2.18 \cdot (BatCap - Lmt(4))}{BatCap}$
6	$\dfrac{16.62 \cdot Lmt(4) + 1.89 \cdot (BatCap - Lmt(4))}{BatCap}$		$\dfrac{7.08 \cdot Lmt(5) + 5.53 \cdot (BatCap - Lmt(5))}{BatCap}$

Doubling Inverter Capacity

Additional analysis is linked to inverter capacity. Increasing inverter capacity allows, in case of emergency, to have higher power provision from the battery helping in increasing adequacy of the power system until a new unit is committed. This reduces uncertainty for the power system operators and under circumstances can lead to avoidance of committing additional operating units. Additionally helps in increasing the PV excess electricity that can be stored. As a policy, to avoid very high rates of exchange, which would shorten battery lifetime, the rate of charge/discharge under steady state conditions is at minimum the 12.5% of the battery capacity.

In all cases increasing inverter capacity, fuel consumption will be reduced as shown in Figure 8.
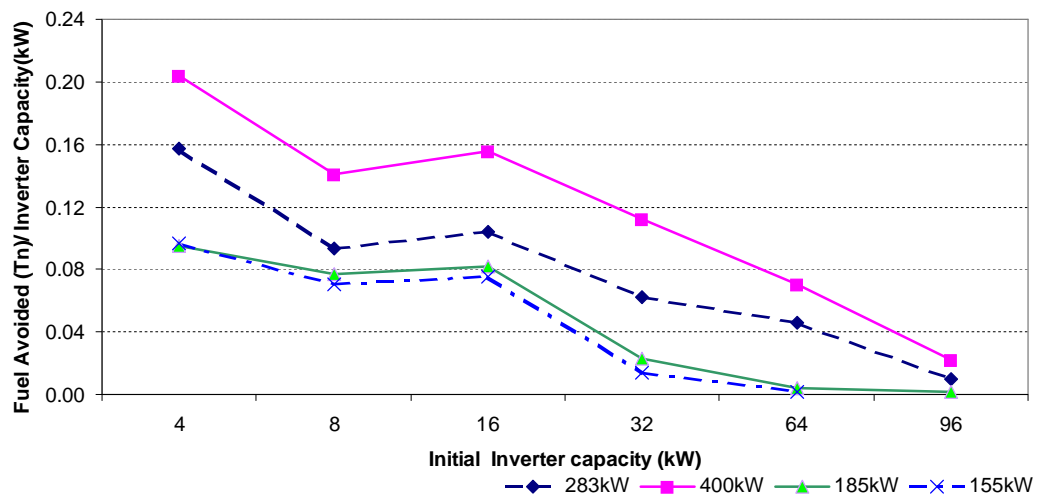
Figure 8. Fuel avoided when inverter capacity is doubled as inverter capacity changes

As in the case of batteries, the investor willing to increase inverter capacity up to 20% of the battery capacity is remunerated as a service provision per year. When PV curtailment is expected, the additional PV injection due to the higher capacity exchange rate has been remunerated using the scheme described in Table 7. The additional benefits, that have not been covered by the formulas in Table 7 should

be provided as remuneration for the increase of inverter capacity. The formulas describing the additional remuneration are based on the simulation run for Corvo are provided in Table 11. InvCap is the increase in inverter capacity which should be linked to both battery capacity and the existing inverter whose capacity the investor would like to double.

Table 11. The remuneration scheme for inverters for penetration level above 12% for various Inverter capacity values

CR	Remuneration [€/kW of inverter]		
	PenLev=12-16%	PenLev=16-25%	PenLev>25%
1	$17.68 \cdot InvCap$	$3.15 \cdot InvCap$	N/A
2	$\dfrac{17.68 \cdot Lmt(1) + 35.37 \cdot (InvCap - Lmt(1))}{InvCap}$	$\dfrac{3.15 \cdot Lmt(1) + 10.67 \cdot (InvCap - Lmt(1))}{InvCap}$	
3	$\dfrac{26.52 \cdot Lmt(2) + 41.46 \cdot (InvCap - Lmt(2))}{InvCap}$	$\dfrac{6.91 \cdot Lmt(2) + 30.21 \cdot (InvCap - Lmt(2))}{InvCap}$	
4	$\dfrac{33.99 \cdot Lmt(3) + 2.05 \cdot (InvCap - Lmt(3))}{InvCap}$	$\dfrac{18.56 \cdot Lmt(3) + 2.61 \cdot (InvCap - Lmt(3))}{InvCap}$	$\dfrac{1856 \cdot Lmt(3) + 2.61 \cdot (InvCap - Lmt(3))}{InvCap}$
5	$\dfrac{33.99 \cdot Lmt(3) + 2.05 \cdot (InvCap - Lmt(3))}{InvCap}$	$\dfrac{10.59 \cdot Lmt(4) + 1.61 \cdot (InvCap - Lmt(4))}{InvCap}$	$\dfrac{1059 \cdot Lmt(4) + 2044 \cdot (InvCap - Lmt(4))}{InvCap}$
6			$\dfrac{15.52 \cdot Lmt(5) + 7.74 \cdot (InvCap - Lmt(5))}{InvCap}$

The power system benefits are negligible for low capacity PVs where no PV Curtailment occurs, and in instances of high inverter capacity. For lower inverter and battery capacities, the additional economic benefits on Corvo are significant and no additional remuneration is provided to PVs since no production changes occur. Thus, additional remuneration should be provided only when increasing an inverter's capacity to obtain these benefits as described in Table 12.

Table 12. The remuneration scheme for various Inverter capacity values at penetration levels below 12%

CR	Remuneration [€/kW of inverter]
1	$30.9 \cdot InvCap$
2	$\dfrac{30.9 \cdot Lmt(1) + 142.17 \cdot (InvCap - Lmt(1))}{InvCap}$

3	$$\frac{86.53 \cdot Lmt(2) + 87.51 \cdot (InvCap - Lmt(2))}{InvCap}$$
4	$$\frac{87.02 \cdot Lmt(3) + 0.6 \cdot (InvCap - Lmt(2))}{InvCap}$$

An Illustrative Comparative Example

The following two examples presenting the same PV penetration at 15.8% show the efficiency of the proposed scheme based on the annual simulation results.

   a. One 283kWp PV with 99.5MWh un delivered to grid
   b. One 185kWp PV combined with a 320kW battery capacity and 64kW inverter. Finally, only 6.6MWh of PV production is not delivered to the island power system as opposed to the expected 34.5MWh, taking into account no form of storage and identical PV capacities.

Even though PV production finally delivered to the grid is the same for both options, the benefits for the power system increases by 4700€ for solution B compared to solution A. Hence, additional remuneration should be provided for the battery service and more incentives for increasing capacity of the inverter to 20% of the battery capacity.

According to Table 7, remuneration for PVs should be 382.8€/MWh for both case studies. According to Table 10, Scenario B should receive remuneration for batteries equal to 16.62€/kWh and since Inverter Capacity is increased, this should be remunerated according to Table 11 at 18.02€/kW. Assuming the following installation costs, 500€/kW for the inverter, 150€/KWh for storage and 4000-7000€/kW for PV installation, the IRR for both these solutions can be calculated by neglecting all other subsidies. The project lifetime is 20 years and two battery replacements are planned within this period (6-7 years battery lifetime).

For solution A, the maximum IRR is 1.46%, however if PV installation prices exceed 5000€/kW the project cannot be paid back.

For solution B, the maximum IRR is 4.77%, while if installation prices exceed 6000€/kW, the investment becomes economically unfeasible. Therefore, in addition to much higher IRR in solution A, solution B is much less sensitive to PV installation prices.

Even if PV production was remunerated at 450€/MWh for solution A, the IRR would be 3.16% and the maximum PV installation price would have been 5500€/kW, providing no additional benefit to the power system.

Thus, the proposed tariff scheme clearly improves the economics for both the investor and the tariff scheme if PV penetration on Corvo is to be increased to such an extent so as to inevitably result in the curtailment of PV production. This scheme manages to give incentives for considering storage as one of the solutions in increasing penetration rather than simply adding PV capacity.

Feed-in Tariffs for RES Meeting 100% of Desalination Systems Requirements

Desalination via Reverse Osmosis (RO) is not a direct electricity storage method as are the above studied technologies. Nevertheless, it is a load whose output can be controlled easier than other loads and far more importantly, it produces a commodity that can be easily and safely stored, i.e. potable water. Simultaneously, it is a load requiring significant energy demand. For every 1m^3 of desalinated water approximately 2.8-4.5 kWh of electricity is required when energy recovery devices are connected to brine stream. The mentioned figures also depend on water salinity and plant design. The energy share of water production costs can range from about 30% to 50%, depending on energy costs, process types and design.

When compared to other desalination methods, e.g. evaporation or thermal process, RO provides significant flexibility in adding capacity and is available in various sizes from a few kW of consumption and a few litres of potable water per hour up to tens of cubic meters and a capacity of some hundreds of kWs. The modular nature of this technology and its flexibility makes it an ideal candidate for studying its operation with RES in more detail.

RO desalination has been used in previous articles by the authors for utilising excess electricity by RES in island power systems, either for Cyprus (Tsikalakis 2009c), the Greek islands of Milos (Tsikalakis 2009b) and Kythnos (Psychogiopoulos, Tsikalakis and Hatziargyriou, 2008) and the Cape Verde (Sequrado et al.,2010). All of these papers present very promising results on the potential benefits from the cooperation of desalination with RES especially in the potential wind power curtailment reduction. These benefits are viewed not only from the aspect of the power system but also from the aspect of RES investors, even if have not investing in a desalination facility.

Water requirements on island power systems increase during the summer period due to higher population numbers and higher average temperatures. During the same period, islands have a much higher demand than during the winter period making Desalination an even more difficult load to cope with (Hatziargyriou et al, 2006). Fortunately, PV production during summer time generally increases, achieving an efficient compensation for increased demand caused by desalination.

The above characteristics for the desalination load have led us to further analyse a potential FIT scheme for desalination customers willing to meet 100% of their demand via PVs and the approach to be followed in implementing this.

Our case study is the small island power system on Mljet close to the Dalmatian Coast. An additional reason for selecting PVs is the restriction against installing wind power on Croatian islands. On the island, there are already three small RO desalination plants while the major electricity and water consumer on the island, Hotel Odissej, transports water from the mainland to meet its demand.

Feed-in Tariffs for Desalination Systems in PV- Mljet Case Study

Mljet is located in the southern Dalmatian archipelago, 30 km west from Dubrovnik and south of the Peljesac Peninsula, separated from the Peninsula by the Mljet

channel. Mljet is an elongated island, with an average width of 3 km and 37 km long, encompassing a total island area of 100.4 km^2. The island economy is based on farming, viticulture, wine making, olive growing, cultivation of medicinal herbs, fishing and tourism. The island's peak demand is 1580kW in August, while the total demand of 4.4GWh is covered by two 10kV submarine cables linked to mainland Croatia.

Two particular cases were further investigated. The first case is the installation of PVs on the premises of the existing desalination plants. The second case refers to the installation of a desalination plant and a PV near the major consumer, the hotel premises. In both cases, PVs and the desalination plant are interconnected to the island's distribution grid.

Table 13 provides the names and the annual energy demand of the existing desalination plants. In the same table, the PV capacity for meeting 100% of demand is provided.

Table 13. Desalination plants data.

Desalination plants	Kozarica	Sobra	Blato
Energy demand [MWh]	12.54	51.14	62.27
Installed PV capacity [kW]	9.42	40.8	44.9

The current tariff scheme for remunerating PV production is provided in Table 14. Remuneration is reduced as installation capacity increases, but the reduction is not proportional, especially for a capacity greater than 30kW. Thus, the PV investor does not have the incentive to add small additional capacities above 30kW like some of the PVs in Table 13. It should be noted that a 31kW PV plant receives a 27% lower annual remuneration when compared to a 30kW PV installation. This is clearly not justified by the almost negligible reduced benefits of a more "centralized" installation of PVs.

Table 14. Remuneration of RES in Croatia.

10kW<PV [€ct/kWh]	46.81
10kW<PV<30kW [€ct/kWh]	41.3
PV>30kW [€ct/kWh]	28.91

The proposed Feed-in tariff scheme for investors willing to invest on PVs when they have already installed desalination plants is described in eq.27.

$$FIT = FIT_b \cdot \frac{b_2}{Cap} + FIT_c \cdot \frac{(Cap - b_2)}{Cap} \qquad (eq.\ 27.)$$

In this case, if B and C are two successive installation capacity ranges according to Table 14, Cap is the installed PV capacity and b_2 is the upper limit of capacity for applying the previous Feed In Tariff (FIT) scheme. The new fixed FIT price for the PV owner is obtained from the linear regression formula. Thus, the higher the PV

capacity, the lower the FIT price, as the current remuneration scheme suggests, but not to the extent so as to discourage installers from additional capacity at a park.

Table 15 compares the FIT for the PVs at the desalination plants before and after the introduction of the proposed tariff scheme.

Table 15. Comparison of new and old tariff scheme in Croatian Desalination plants.

Desalination plants	Kozarica	Sobra	Blato
Old FIT [€ct/kWh]	46.81	28.91	28.91
Updated FIT [€ct/kWh]	46.81	38.02	37.18

Assuming an installation cost for all the required equipment (including converters etc) equivalent to 7000€/kW at a 6% discount rate, the Financial Indices for PV installation can be calculated as described in Table 16 for both the proposed and the current tariff scheme.

Table 16. Financial indices for PVs at existing Desalination plants with both current and proposed tariff scheme.

	IRR [%]	Payback [yrs]
Kozarica (Same tariff)	8.05	15.17
Blato Old Tariff	0.975	61.93
Sobra Old Tariff	0.786	Not paid back
Blato Proposed Tariff	4.11	28.30
Sobra Proposed Tariff	4.14	28.08

Clearly the current tariff scheme proves to be inefficient for those investors willing to promote "green" electricity and a clean way of producing water for the local population.

The updated tariff scheme provides much more reasonable pay back periods, although somewhat above the usual lifetime of PVs, and with a small installation capacity or subsidy the payback period can be reduced even further. It should be noted that the proposed FIT has equivalent results when reducing or subsidising the installation cost by at least 25%.

Coincidently, losses avoidance will be 3.3MWh and the corresponding emissions avoidance will be 99.6tn CO_2. The achieved economic benefit for the power system will be in the order of 50.87€/MWh, lower than the additional FIT tariff. However, the additional employment created, emissions avoidance and the potential decrease in installation costs justify this deviation in the FIT price.

General Conclusions and Recommendations

In this paper, feed-in tariffs for various energy storages and desalination systems are discussed along with a proposal for their application in regions most suited for such application. Widespread use of energy storage could optimize the existing

assets on the market. These facilities (power plants, transmission lines, etc.) will make more money, and hence their worth will increase.

FIT design for both concepts of storage system application is rather simple and it can be easily performed by Energy Regulatory Agencies or Electricity Market Operators with the assistance of experts from TSO and DSO. After successful application on the islands and outermost regions, tariffs for energy storages should be also applied to mainland power systems.

To increase RES-E penetration, other technologies like thermal energy storage, cold storage, electric vehicles or V2G could be supported by FIT, similar to those presented in this paper. These technologies should be supported since in the long-term they could provide greater benefits to communities and outweighing the effects of their cost. The hypothesis has been already proven by FIT for wind energy. Many experts claim that in most places wind power would even now be competitive if conventional energy stopped receiving hidden subsidies. If the costs of fossil fuels were to reflect all the environmental damage they cause, such fuels would actually be much more expensive. Another issue overcome by FIT is market competition between RES and conventional technologies. Once a wind turbine is installed, market competition cannot make it to work more efficiently. This implies a relatively high investor risk on an uncertain and competitive market (Meyer 2003). Wind power costs can be affected by the electricity market by up to 20% at the most in terms of total production costs. Whereas production costs for coal-based electricity production can be influenced by more than 50% by the market (Hvelplund 2006). Competition in the area of wind power mainly relates to the wind turbine producers with competition resulting in an 80% decrease in wind power costs during the last 20 years (Meyer 2003). Similar to wind technology FIT for storage could lead to competition on the producers' side.

In the both calculated case studies for the Ios Island and use of PHS and WPHS, despite a storage installation, there still was certain amount of rejected wind electricity. If this amount is significant, wind producers should then receive compensation for their losses or on the other hand, they could share the burden with consumers. Alternatively, compensation could be directed to a special fund used for installations, which would reduce the amount of rejected production (storage, demand side management). It has also been shown that RES owners present clear benefits for investing a proportion of the resources on desalination or provide part of their profit to desalination plant owners in order to reduce critical electricity excess production.

Prior to application of the scheme, it is important to solve other potential barriers and to evaluate domestic conditions such as potential of renewable energy resources and geographical conditions, current and future political environment, economic environment and technological preconditions. The FIT should reflect the desirable and possible rates of increase in RES utilisation in terms of capacity and share in the energy mix. Another parameter to be checked is the state of the electricity grid and the type of connection across the area.

Furthermore, it is expected that the Regulator analyse financial schemes and according to information received from utility companies (operating costs, base rate, amortization depreciation, investment, taxes and rate of return) offer proposals for new schemes every 4-5 years.

Identifying comparable conditions in other countries where a financial mechanism for RES hybrid and storage systems (for example Greece) has already been implemented would be very helpful.

According to Article 5 of DIRECTIVE 2009/28/ (The European Parliament and the Council of the European Union 2009), production of electricity from water in pumped storage units that has previously been pumped uphill is not treated as a renewable electricity (RES-E), and cannot thus receive guaranties of origin that will be recognized at the EU level and accepted by the European Commission. Moreover, according to the same EU Directive, electricity used by the pumped storage is included in the final gross energy consumption, which means that if used, it will increases the amount of energy from renewable sources that should be achieved by the year 2020. On the other hand, all electricity produced from renewable energy sources (directly delivered to the grid or used to pump water uphill or for any other dump load) will be treated in the final gross electricity consumption as renewable energy sources without taking into account storage efficiencies. This regulation avoids the twofold counting of RES-E but energy storages are also discriminated as all stored energy is treated as consumption. The introduction of FIT for storages with traceable GO could lead to better system designs and improved efficiencies. Consequently, FIT for storage should only be used in a system where traceable GO exists in order to make sure that the storage is not used to store electricity from conventional power plants and thereby just adding a loss in efficiency if the feed-in tariff for "discharging" the storage may be too high.

Batteries can be used for increasing penetration in small island systems with PVs. The proposed FIT remunerates batteries and inverters as a service and not as an energy flow taking also into account the potential benefits in the power system. The proposed FIT scheme tries to make PV investors consider storage if they want to increase their production share in the island power system above certain penetration level which can lead to power curtailment and discourage them from adding PV capacity that neither will be fed into the grid nor significant benefits to the power system will bring. The efficiency of the proposed FIT scheme for the same penetration level, around 15%, to make combination of storage with PV more attractive than simply increasing PV capacity has been profoundly shown in the arithmetic example.

The methodology and calculations of FIT for energy storage and desalination have been shown in the several case studies. The results show that the development of FIT for storage is justified from several points of views (fuel savings, economic benefits, reduction of CO_2 emissions, higher RES penetration and better RES utilization). Strong support and political will on local, national and international level to have FIT for energy storage systems and thus increase RES penetration is crucial for further development and application of storage technologies.

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Acknowledgements

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