Can El Hierro be 100 % electric-renewable?

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Foreword

This summer, the media have abundantly reported that the El-Hierro island in the Canaries could now count on a 100 % renewable electric mix. As a matter of fact, these reports were based on only two hours during which the Gorona del Viento (GdV) installation managed to reach the objectives announced in the project document. Full of enthusiasm, Ségolène Royal, the French minister of Environment and Energy, rewarded the project on behalf of the “Syndicat des Energies Renouvelables”

What is the situation today for this installation inaugurated in June 2014? a considerable investment, leading to a complex system with more than 34 MW of installed production power (diesel, wind and hydraulic turbines, each for about one third) when the peak electric demand is only 7.6 MW that is a factor four less.

The reality of the performances after six months of effective exploitation: the renewable fraction for the three most favourable months, July to September, has been 42 %. For the half year, the figure is even more disappointing with only 30 % renewables.

The reasons behind these very modest performances with respect to the announced goal, which, moreover for the year 2015, lead to a considerable cost of the renewable MWh which is going to cost four times more than the MWh produced by the diesel plant and a cost of the avoided CO_2 exceeding 1000 €/ton? As shown in this document, they are first the limited wind resource, which according to data could not have allowed a renewable fraction larger than 50 % and second, the nature of the contract signed by the Spanish state which does not encourage GdV to strive for the optimal environmental performances.

To summarize: unrealistic objectives, deplorable governance and a technical semi-failure very costly for the Spanish citizen.

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I) List of main data and results

- On the El-Hierro island (~10 000 inhabitants), the 2015 electric energy consumption has been 44.3 GWh. This corresponds to an average power of 5.1 MW with peaks at 7.6 MW.
- Before the installation of Gorona del Viento (GdV), this demand and the grid stability were covered by the diesel-fired plant at Llanos Blancos. It is modular, with several engines whose nominal powers range from 0.8 to 1.9 MW. The installed diesel power is larger than 11.2 MW and its thermal-to-electric efficiency is of the order of 36 %. It sells its energy to the grid at a price of the order of 200 €/MWh.
- **The GdV project has cost 82 M€ out of which only 46 M€ correspond to an investment by members of the GdV consortium. The rest corresponds to regional, national and European subsidies.** Two partners in the consortium are the local council (60 %) and a regional technical institute (10 %). The last partner (30 %) is ENDESA (owned by the Italian utility ENEL). ENDESA also owns and operates the Llanos Blancos plant.
- With **Gorona del Viento** which adds **a 11.5 MW wind park** and a set of **4 hydroelectric turbines for a total of 11.32 MW**, the total installed power on the island exceeds the average demand power by a factor 6 and the peak demand power by a factor 4.
- GdV only started its real activity at the end of June 2015. The year elapsed since its inauguration (June 2014) must have been used to fill the fresh water reservoirs and realize some tests.
- **Over six months since July 1st 2015, GdV has only covered 30.2 % of the electric demand of the island. Except for two well publicized hours on August 9, the stability of the grid was ensured by the diesel plant which, for 99.2 % of the time, provided at least 25 % of the demand power. Over these 184 days, for a global time equivalent of more than 25 days, the demand was entirely covered by the diesel production.**
- During the windy period (July, August), it was necessary to curtail the production of the wind farm since it could even have exceeded the sum of the total demand power (~5MW on average) plus the power of the pumps (6 MW). On the contrary, during the fall, windless episodes lasting at least two days have been observed. Given the small size of the lower reservoir, this simple fact alone ensures that GdV will never be able to cover 100 % of the annual electric demand.
- **Even with GdV, the island can't do without a fossil-fired diesel plant such as Llanos Blancos, able to cover the peak demand power. Moreover, as the plant must be available 100 % of the time, there will no saving on the operation and maintenance costs of this plant. The only savings will be on diesel fuel.**
- The summer wind production (from July to September) was such that the wind energy sent to GdV was enough to pump at least 11 times the volume of the lower reservoir. On the other hand only ~20 % of the pumped up water was returned to the reservoir to produce hydroelectricity. Given the capacity of the desalination plants of the island, it is thus evaluated that at least 60 % of the pumped up water was circulated up and down in a useless merry go round without producing any electricity.
- There was never more than 30 % of the total installed hydroelectric power used at any given time. For most of the fall, the few bursts of hydraulic power never exceeded 0.5 MW that is less than 20 % of the nominal power of each of the four turbines.
- **It can be shown that with the wind profile observed over the last six months of 2015, the renewable fraction could not have been larger than 47 %.** If one assumes that, for reason of grid stability, a fraction of the demand power of the order of 25 % must be produced by systems with inertia such as a diesel engine or a hydroelectric turbine, the maximal renewable fraction had to be smaller than 45 %.
- Since these optimal results imply that all wind power has been used to produce energy either by direct injection into the grid or via the detour by the pumps and the turbines, these values can only be lowered if a fraction of the wind energy sent to GdV is used to pump water for irrigation.
- According to reports, GdV expects to be paid ~7 M€ for its activity during the year 2015. **This puts the cost of the electric MWh produced in 2015 by GdV at ~800 € and the cost of the avoided ton of CO_2 at more than 1000 €.**
- The contract that the consortium signed with the Spanish government does not really reward the electric production by GdV and thus does not encourage reaching the optimal renewable fraction. It even discourages the production by means of the hydraulic turbines as they are paid more when they remain idle than when they produce energy.
- All these results are of course known by the engineers working at GdV. In fact, they were predicted with a remarkably good accuracy and publicly announced, by inside experts before the inauguration of GdV.

II) Introduction

On the El-Hierro island, the Spanish and the Canarias regional governments have provided public financial support to the implantation by the Gorona del Viento (GdV) consortium of a very original electric energy production system. Using the unique geographical characteristics of El-Hierro (volcanic island with a caldera situated in the trade wind zone) GdV combines a wind farm to a hydroelectric system including two water storage reservoirs, connected by two pipelines, a pumping station and four hydroelectric turbines (Fig.1).

Fig.1 Layout of the Gorona del Viento electric production system. Not shown on the picture is the Llanos Blancos diesel plant located near the coast close to the pumping plant.

Last summer, El-Hierro made it to the headlines, world-over, with articles such as this one extracted from El Pais (August 20th)[2]:

> "*Eight months ago, a delegation of the Seychelles islands visited El Hierro with an objective: learn more about Gorona del Viento, epicentre of a project which aspires to energy self-sufficiency to provide light and water from 100 %-renewable sources. If the famous visitors from the tropical archipelago in the Indian Ocean were to return to the island in the Canarias, they would check that indeed, the miracle has happened. On the calendar of El Hierro, August 9 will be recorded as an historical date. This day, the hydroelectric plant managed to provide the entire consumption of the 10 000 inhabitants of the island without the recourse to oil. Although this lasted only for 4 hours, the duration is enough to demonstrate that the idea conceived several decades earlier was not a dream.*"

Since then, in newspapers, web posts and TV programs, El Hierro has been heralded as pioneering a new paradigm for the production of electricity.

Consider for instance the more recent publications. On December 26th, in an article in the media "Universo Canarias", under the title "Thanks to Gorona del Viento the smoke has disappeared over El-Hierro" (which should be understood as saying there is no more smoke emitted by the diesel-fired plant)[3] M. Sanchez the vice-president of the El-Hierro council, the leading partner in the GdV

[2] Translated from http://elpais.com/elpais/2015/08/20/opinion/1440090526_582046.html
[3] http://www.universocanario.com/siete-islas/el-hierro/presidente-del-cabildo-de-el-hierro/cabildo-de-el-hierro/en-el-hierro/el-humo-se-acaba/con-la-gorona-del-viento/juan-pedro-sanchez/357064 . One can note first

consortium, is quoted saying “the hydro + wind production has reached an annual average of 50 % on the island”.

In fact, on January 2nd 2016, in an article of the local media “El Dia” under the title “The plant Gorona del Viento surpasses the best previsions”[4] more modest performances are mentioned. It is now written that the average hydro-wind production was only 30 % over the last six months and reached levels between 49 % and 55 % only for the months of August and July. It is not mentioned where the “best previsions” could be found and the “100 % electric self-sufficiency” is now only mentioned as a goal for the future (“con vistas”).

In another document published on Xmas by the “Universo Canarios”[5] under the title “Gorona del Viento is blowing full sails in El-Hierro” it is said that the partners of the GdV consortium are: the El-Hierro council (60 %), a local technical institute (10 %) and the electric firm ENDESA (30 %). It is also written that it is expected that GdV will spare the emissions of 29 222 tCO_2/year. Finally, in this text the ultimate renewable electric production is announced at 30 GWh which according to the article should correspond to a 75 % renewable fraction. The coherence of these figures with REE data is discussed in Sec. VIII.

In the same media, the article “Gorona del Viento : a gold vein” (December 12th 2015)[6] tells us that the project has cost 82 M€ out of which only 46.03 M€ have been invested by the consortium, the rest (35.97 M€) being a subvention from the Spanish government and from Europe. The article also says that the consortium expects to receive ~1 M€ for an almost half-year operation of GdV in 2014 and ~7 M€ for the full year of 2015. On the other hand, according to the text, these large sums do not correspond to the price that GdV is going to be paid for the energy it has delivered to the island’s grid. This energy will only be paid 11 187 € for the year 2014 and 118 138 € for the year 2015.

In the last section of this work, from an analysis of the contract signed between the GdV consortium and the Spanish state[7] we explain why the energy produced only corresponds to few percent of the total sum that GdV will receive and also how the terms of this contract explain the management of the GdV installation which, using data provided by the Spanish grid, we illustrate in sections IV to VII.

Anyhow, in 2015, prizes and official distinctions in Spain[8] and abroad (prize of the French “Syndicat des Energies Renouvelables” from the hands of the French minister of environment[9]) have been awarded to the local government and to the consortium which manages GdV. Obviously, GdV is an experiment which attracts a lot of highly positive attention.

It is indeed worth a close consideration in view of the difficulties encountered by many third world and even emerging countries in providing much needed electricity to their citizens. Moreover, even in developed countries the notion of 100-%-renewable electric self-sufficiency is sometimes presented as a goal achievable in a not too distant future and this not only by ecologic associations but also by official agencies[10].

Since answering the question in the title with a “no” will require just one paragraph of Sect IV, this work rather attempts to analyse how GdV has really worked over the recent past and what best performance with respect to the advertised goal “100 % electric auto –sufficiency” it may have reached given the wind blowing over the island and finally what may explain why so little effort has been made by the GdV consortium to come close this best possible performance.

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that the figure (50 %) given by M Sanchez contradicts the title and second that in a typical media fashion, the text is less affirmative than the title and only states that “the smoke is disappearing…” (“… se está acabando” instead of “… se acaba”).

[4] http://eldia.es/canarias/2016-01-02/22-Central-Gorona-Viento-supera-mejores-previsiones.htm

[5] http://www.universocanario.com/siete-islas/el-hierro/el-hierro/gorona-del-viento-/sopla-toda-vela-/357013

[6] http://www.universocanario.com/siete-islas/el-hierro/el-hierro/la-gorona-del-viento-/un-filon-millonario/356322

[7] « Boletín Oficial del Estado », N°230, Sec.I, p. 77325, 25/09/2013, 9944, Orden IET/1711/2013. https://www.boe.es/diario_boe/txt.php?id=BOE-A-2013-9944

[8] http://prensa.elhierro.es/2015/11/25/el-hierro-premio-verde-2015/ y http://www.elhierrodigital.es/inicio/elhierro/item/4269-el-hierro-galardonada-con-el-premio-ones-mediterrania-2016

[9] http://www.enr.fr/actualite/113/Madame-Segolene-ROYAL-remet-le-12e-trophee-des-energies-renouvelables-a-Monsieur-Alpidio-ARMAS

[10] For instance the Fraunhofer Institute in Germany or the French government environmental agency ADEME.

III) Characteristics of Gorona del Viento, of El-Hierro electric and water production system.

Gorona del Viento produces energy by means of a wind farm of five turbines (Enercon E-70 2.3 MW) for a total installed power of 11.5 MW.

But the original feature of GdV lies in its hydroelectric component which is supposed to provide the necessary energy storage to compensate for the fact that the production of the wind turbines is both fluctuating and desynchronized from the electric needs of the islanders. As we shall see the hydraulic turbines are also meant to contribute to the stability of the island's electric system.

GdV uses fresh rather than salt water for both ecologic and economic reasons. Indeed any leak in a salt water reservoir entails a risk of pollution of the ground water. On El-Hierro, wells in the water table play an important role in the irrigation system: they provide more than half a million m^3 of fresh water every year. Moreover, using fresh water opens another option for GdV: some of the water pumped into the upper reservoir could be used to gravitationally feed the island's irrigation system.

The volume of the lower reservoir is 150 000 m^3 [11] while that of the upper reservoir is 380 000 m^3 [12]. Given the difference in elevation (h=655m), the theoretical mechanical energy content (E_{mec} = m.g.h) of the lower reservoir is 267 MWh. In practice, drawdown effects will reduce this value. For this reason we consider that 230 MWh is a more likely value for the mechanical energy available for storage.

The reservoirs are connected by two pipelines[13] so that it is possible to pump water while letting simultaneously some water flow down.

The pumping station has a total power of 6 MW[14] while the power of the turbines in the hydraulic plant is 11.32 MW[15].

From the information available to us, we estimate that it takes 1.18 MWh of wind power[16] to raise 1 MWh of mechanical energy and that, on the way down, it takes 1.18 MWh of mechanical energy to produce 1 MWh of hydroelectricity. Thus to produce 1 MWh of hydroelectricity one has to spend $(1.18)^2$=1.4 MWh of wind energy which corresponds to a 29 % energy loss (1/1.4=0.71).

In addition to GdV, the island can rely on a diesel-fired power plant of 11.78 MW located at Llanos Blancos[17]. This plant is owned and operated by ENDESA which on the other hand is a partner in the GdV consortium at a 30 % level.

The growth of El-Hierro population, tourist economy and agriculture would not have been possible with only the water extracted by wells from the water table. As said above it corresponds approximately to 1500 m^3/day. This natural water resource is complemented by the production of several desalination plants implanted at three sites at least. According to a document of Nov. 2013 the

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[11] *"Lower reservoir : located in the vicinity of the "Llanos Blancos" plant, storage capacity 150 000 m^3, rockfill dam with maximum height 23 m, 15 m of maximum water level with a maximum elevation of 56 m above sea leve, 2 mm HDPE geomembrane for waterproofing, repairable under water."*

[12] *"Upper reservoir: Located at the "La Caldera" crater, maximum capacity of 379 634 m^3 , 12 m of maximum water level with maximum elevation of 709.5 m above sea level, 2mm high-density polyethylene (HPDE) geomembrane for water proofing, repairable under twater."*

[13] *"Penstocks: two, one 800 mm in diameter and 3015m long for the pumping system and the other 1 m diameter and 2350m long for generation, both made of S355NL steel and running in parallel through a 530 m long gallery, pumping suctions from the lower reservoir through a S355NL steel penstock encased in concrete that is 1 m in diameter and 188 m long."*

[14] "*Pumping plant : contains two 1.5 MW pump sets driven by 1500/500 kW power regulators and six 500 kW pump sets ; installed in a new building.* "

[15] *"Hydro plant : four Pelton turbine-generator groups of 2.83 MW of power each, with maximum flow during generation of 2 m^3/s and a total head of 654 m. "*

[16] In its answer to a query, the grid manager REE wrote that electricity of the diesel-fired plant is never used to pump water in GdV. This is in line with what GdV is supposed to demonstrate and the Sect. 1 of the contract signed with the Spanish state. Moreover, it is supported by REE data which show that electric power sent to pumping is always less than wind energy. We could not obtain direct information from GdV on the efficiencies of the pumping system and of the hydraulic electric production.

[17] High speed diesel engines 4 stroke, 6 Caterpillar 3516, 1.1-1.6 MW; 1 Caterpillar D-398, 0. 8 MW; 2 MAN-Holeby 9L21/31, 1.9 MW. Given the technology and the small powers, one can expect thermal to electric efficiencies in the range 34-38 %.

maximal cumulated capacity of all the plants should be 8750 m^3/day[18] by 2015. The same document mentions that this figure includes an extension of the Cangrejo plant by 2400 m^3/day in anticipation of the start of GdV. Finally, the expected annual volume produced by the plants in 2015 (1 400 000m^3) tells us that the average load factor of the desalination plants is approximately 0.5.

IV) REE Data, Gorona del Viento first year and answer to the title question.

On its website, le Spanish grid manager REE (Red Electrica de España)[19] provides information on electric demand and on the three electric productions (diesel, wind, hydro) on El-Hierro island with a 10' time resolution. As a matter of fact, only three sets of data are independent as it can be checked that at any time demand is equal to the sum of the three productions (algebraic sum since "hydro" is negative when some of the wind power is not used to cover demand but sent to GdV in order to pump water)

The REE data tables have many more columns for other means of production and in particular "Solar fotovoltaica". For El-Hierro, these columns are always empty. It thus appears that the photovoltaic production on the island (there is some) is either not injected into the grid or not available to REE when it prepares its data files.

GdV was inaugurated in June 2014. Fig.2 shows how the demand (upper envelope of the coloured area: yellow topped by green) was covered from June 2014 to August 2015. Demand oscillates about a 5 MW value. Before June 2015 it is almost entirely covered by the production of the diesel-fired plant. Using the REE data plotted in Fig.2, R. Andrews[20] has calculated that over the period from Jan 1st to June 30th 2015, of the total electric energy demand (21.369 GWh; average power 4.92 MW) only 7.81 % was provided by GdV (7.17 % wind; 0.64 % hydro).

With GdV operational, the total installed production power on the island has now reached (11.5 + 11.32 + 11.78) 34.6 MW, a value which is a factor 6.5 larger than the average demand power and a factor 4.6 larger than the demand peak power (7.6 MW)

Only at the end of June 2015 did GdV really begin to show significant signs of activity. For this reason the analysis presented in this document corresponds to the six months of 2015 beginning on July 1st 00:00.

Fig.2 also shows that the magnitude of the electric demand is not modified by the start of GdV. Thus the island's activity including whatever electric consumption was required for the activity of the desalination plants (which Ref. 18 sets at 4.62 kWh/m^3) was not affected by GdV.

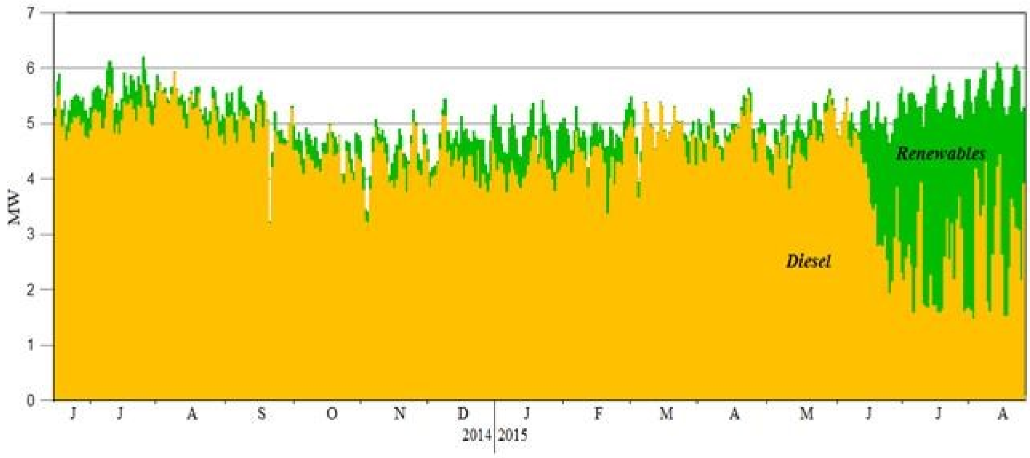

Fig.2 Average daily power of electric production (MW) on El Hierro from June 2014 to August 2015.(Courtesy of R. Andrews)

[18] Directrices de Ordenación Sectorial de Energía, Tomo II, Memoria Justificativa, p.47 TOMOII_MEM JUST_fir.pdf

[19] For the production of November 1st 2015 type : https://demanda.ree.es/movil/canarias/el_hierro/total/2015-11-01

[20] Since September 2015, R. Andrews regularly publishes detailed analyses of the performances of GdV on the site « Energy Matters ». The web address of his latest post is : http://euanmearns.com/el-hierro-renewable-energy-project-end-2015-performance-review-and-summary/

Let us now turn to the question in the title. According to REE (Fig. 2) the average power demand on El Hierro is 5 MW. Over one day, it corresponds to an electric energy of 120 MWh. The capacity of the lower reservoir of GdV (150 000 m^3) approximately corresponds to 230 MWh. Thus to prove a negative answer it is sufficient to check that on El Hierro there are windless episodes lasting at least two days. As we will see (Sect. V) **the data provided by REE show that it is indeed the case** (last week of September 2015 for instance)**.**

Note that if one would accept wasting expensive fresh water mostly generated by means of desalination plants by letting the full capacity of a supposedly full upper reservoir (380 000 m^3 equivalent to about 500 MWh) flow down on the hydraulic turbines and dumping to the sea that amount of water which the lower reservoir can't accept, it would take only four days and a half without wind to support the negative answer. Episodes of such length with almost no wind production have also been observed in 2015.

The rather formal question of the title is thus answered. Incidentally, this already shows that building **an installation such as GdV will not spare the cost of investing in a dispatchable fossil-fired plant such as the one at Llanos Blancos powerful enough to cover 100 % of the electric demand. Also, there will be no gain on the operational costs of this plant (personnel and maintenance).**

One can now turn to the only remaining questions: what is the maximum amount of fuel that can be saved and does it justify the investment made on GdV ? Moneywise, it is interesting to consider different viewpoints; first that of the investors in the consortium and among them to consider separately the private company ENDESA which also owns the diesel-fired plant whose operation is affected by that of GdV and the two other partners (the local council and the technical institute) which have only invested public money; second that of the Spanish citizen which not only has contributed to an initial subvention but is also paying every year for the operation of GdV according to the terms of the contract signed between the consortium and the Spanish state (Ref. 7). One may also consider whether the investment is justified from an ecological viewpoint that is mostly by reductions of CO_2 emissions[21]. Although a full answer to all these questions requires following the electric demand and the wind production over at least a full year of effective operation of GdV, we propose a first partial analysis in Section VIII based on the information collected for the year 2015.

In Section VII, using REE wind and demand data for the first half year of real operation of GdV, we explore possible optimal, or at least improved, operational schemes which could have been followed (but have not been). We then calculate the maximal renewable fraction which GdV could then have reached given the metered wind resource.

Before we do that, it is worthwhile studying the effective performance of GdV over the second half of 2015 (Secs. V and VI). This will show that GdV has certainly not been operated in an optimal mode leading to rather inefficient renewable energy and water managements which could appear strange until one reads the terms of the contract (Sec. VIII).

V) **August 9, the *historical date***

Let us analyse the *miracle* which happened on this day to which "El Pais" has assigned the adjective *historical*. Fig. 3 presents the evolution of the electric demand and of the three productions as given by REE. Note that the negative part of the (green) hydro curve correspond to power sent to GdV for pumping. It corresponds exactly to that fraction of wind energy which was not sent directly to the grid to cover the difference between demand and diesel production: i.e. the wind excess. On the other hand, when the green curve is positive, it measures the hydroelectric power sent to the grid by GdV. Fig.4 shows how the island's demand was covered by a mix involving diesel (yellow), wind (dark green; in fact that fraction of wind energy not sent to GdV) and hydro (blue).

[21] Of course, among the benefits associated to the construction of El Hierro there are the potential market opportunities for this technology as well as the experience gained in the management of electric grids incorporating a high percentage of fluctuating renewable energies. However, it is very difficult to quantify such potential gains since few islands present the same topographical and meteorological characteristics as El-Hierro and since transposition to more multinational integrated grids is far from trivial. I also not consider as a benefit the fact that GdV is now used as a mean to attract ecology-minded tourists on the island with the associated increase in air-traffic and CO_2 emissions.

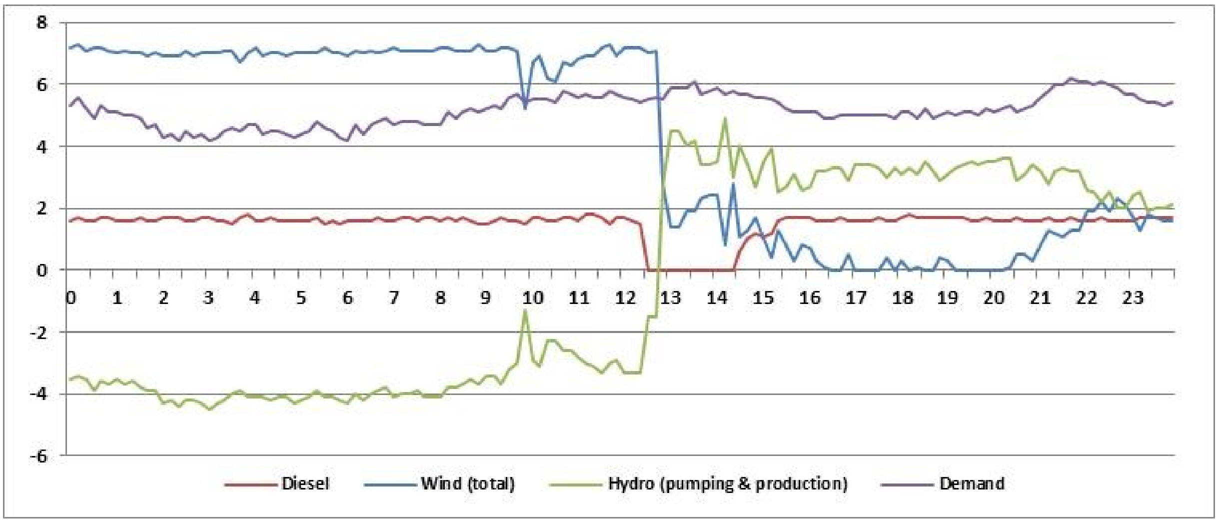

Fig.3 Demand and the three productions along August 9 2015.The power vertical scale is in MW.

During two hours (not four as wrongly reported by El Pais), from 12:30 à 14:30, electric demand was entirely covered by a mix consisting only of wind and hydro production. It appears that the diesel-fired plant which during all morning was providing a constant base production (red curve) was stopped by engineers at 12:30. Two hours later it was restarted returning to the same base production level. It is also seen that the wind production which all along morning exceeded demand fell abruptly around 13:00 probably as a result of turning off, one by one, all the operating wind turbines. Then, for one hour and a half, the balance of the grid was ensured mostly by water falling from the upper reservoir.

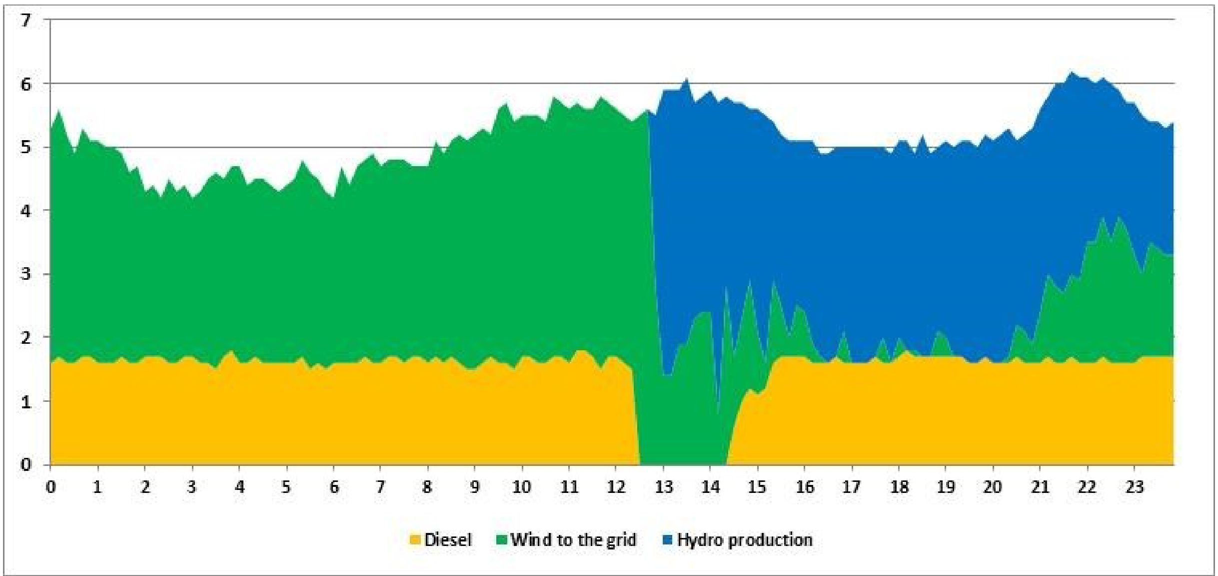

Fig.4. Coverage of El-Hierro electric demand along August 9. The power vertical scale is in MW.

In many ways the curves in Figs.3 and 4 are more indicative of a planned technical commissioning test – probably requested by REE to demonstrate that GdV could indeed fulfil the terms of the contract signed with the Spanish state – which had the side benefit of providing GdV with a much publicized staged "feat" much needed after more than one year without any decent result to offer to the admiration of the media.

VI) Analysis of six months of Gorona del Viento operation.

Let us now look at how GdV and the electric El-Hierro system have been operated over the second half of 2015. This is shown in Fig. 5 which is the analogue of Fig.4.

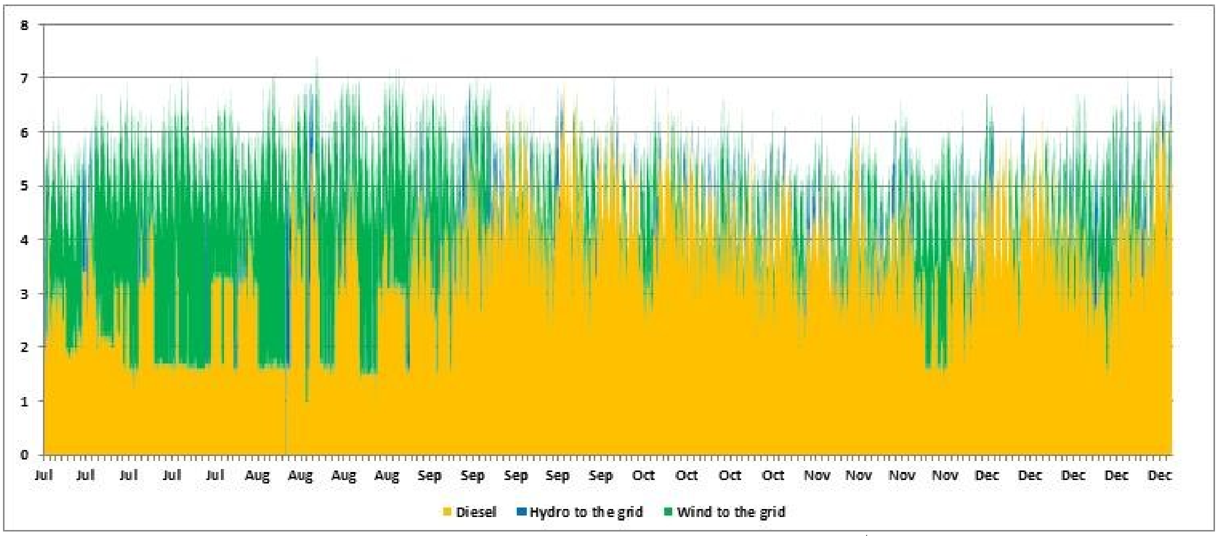

Fig.5. Coverage of El-Hierro electric demand for six months beginning July 1st.The power vertical scale is in MW.

With some attention, in Fig.5 on August 9, one can detect the thin green vertical line touching the horizontal axis which corresponds to the two-hour-100-%-renewable event discussed in the previous section. Otherwise, over six months (184 days) the renewable fraction has only amounted to 30.2 % out of which the hydraulic production counted for 3.7 %. Moreover for the time equivalent of 24 days, the diesel production covered more than 99 % of the demand. More than 99.2 % of the time the fraction of demand generated by diesel was in excess of 25 %.

How can one understand this rather poor result?

In Fig.5 it is seen that diesel power is always maintained above 1.5 MW that is about 30 % of the average demand. This may be imposed by prior contracts, regarding either a minimal usage of the Llanos Blancos plant or the island's fuel procurements[22].

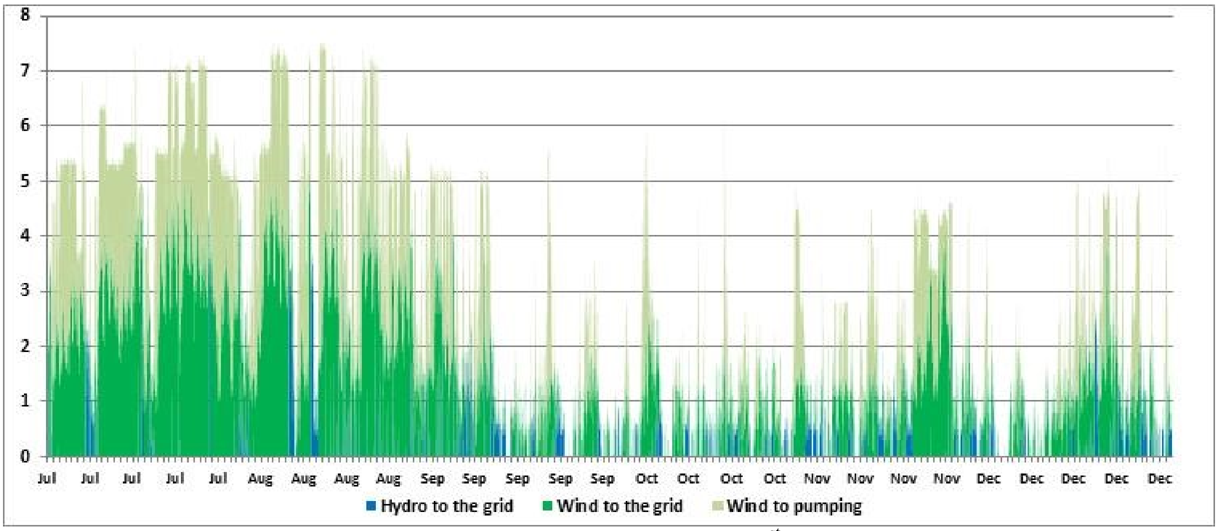

Fig.6. GdV wind and hydro production for six months beginning July 1st.The power vertical scale is in MW. The dark green area corresponds to that fraction of wind production directly sent to the grid while the light green area shows the fraction kept within GdV for pumping purpose. The dark blue area corresponds to the hydraulic production.

However, in our opinion the main reason is to be found in grid stability conditions imposed by REE. The voltage-frequency stability of the grid requires some inertia from the island global electric

[22] In order to explain the strange management of GdV we have sometimes to make assumptions since all requests for more detailed information on either the energy or the water managements which were sent to GdV or the El-Hierro water council have not been answered

production system. Such an inertia, which the wind turbines can't furnish, is provided by rotating turbines whether they are powered by the combustion of diesel or by falling water. Therefore, at least a fraction X of the electric demand must come from one of these two productions which have in addition the advantage of being dispatchable (at least, as long as "fuel" is available, be it diesel or water present in the upper reservoir and simultaneously space available in the lower reservoir). In Sect.VII we discuss as a function of X how the GdV energy production could have been optimally used. It is clear that until now the partners of GdV have been more inclined to use diesel (owned by ENDESA) than hydroelectric production to ensure grid stability. We believe that, as will be discussed in Sect. VIII, the motivation for this priority given to diesel production is mostly financial.

A consistent usage of the hydraulic production is also hampered by a lack of reliability of the wind production profile. As fig. 6 shows, sometimes (July August) there is too much wind for the storage capacity, sometimes (September, October) there is none and thus no power (or almost none) to feed the grid let alone to pump water.

The total wind power delivered by the GdV wind farm corresponds to the upper envelope of the dark and light green areas. It is seen that two-day-long windless episodes do happen on el Hierro so that recourse to diesel-fired production will always be needed (thus, our answer the question in the title).

Keeping in mind that the total installed wind power is 11.5 MW while the delivered wind power never exceeds 7.6 MW one is led to believe that during windy periods the wind production is also curtailed as is for instance the case in the UK or Germany when there is too much wind to be accepted by the grid. Again such a curtailing may be imposed either by a combination of grid stability requirements plus the 6 MW limit on the pumping power. Of course, this curtailed ("aborted") wind power appears nowhere in REE accounting.

From Fig.6 one also notes that when there is wind (July & August) the ratio of the area of the blue zone to that of the light green zone (wind power used for pumping) is very small. Even taking into account that a fraction of wind energy (29 % in our analysis) is lost in the storage-to-hydropower process, this indicates that most of the pumped-up water was not used to produce electricity.

It is also remarkable that at no moment GdV did use more than 26 % of the 11.3 MW power of the hydroelectric turbines. Moreover during the fall, most of the time, there was never more than 0.5 MW (less than 5 %) in an active production mode. One can wonder whether there is not a mismatch between the power of the wind farm (11.5 MW), of the pumping station (6 MW) and of the hydroelectric turbines (11.38 MW). On the other hand, as we will see the terms of the contract lead to a financial reward of any installed hydro power even when it remains idle.

By means of a back-of-the-envelope calculation we will now show that during summer most of the pumped up water was simply "wasted", that is it was used neither to produce electricity, nor to compensate evaporation from the upper reservoir nor to increase the water stored in the upper reservoir nor diverted away for human usage such as for instance irrigation. It was simply uselessly returned to the lower reservoir just to ensure that some water was there, made available to employ the wind power which had to be diverted to pumping. Thus most of this excess of wind power was also "wasted". Since this problem only arises when there is a strong coupling between energy and water managements we concentrate on the summer period from July 1st to September 30th. In the fall season, when there is little wind, all the hydraulic components of GdV are mostly at rest so that no problem can occur: energy not produced can't be wasted!

How much water has been pumped up in July, August and September?

The period considered here is July 1st 00:00 to September 30th 23:50. The uncontroversial figure is the energy sent to Gorona del Viento for pumping; that is the absolute value of the negative part of the *hydraulica* column in the REE data: 3513.98 MWh.

To pursue the analysis one has to introduce two other pieces of information: a) the mechanical energy equivalent of 150 000 m^3 once it has been lifted to the upper reservoir. The theoretical value using ($E=mgh$ with $h=655m$) is 270 MWh. We will use it since a lower value only makes results worse, b) the electric to mechanical efficiency of the pumping system (pumps and mechanical losses in the pipe). We assume that 1.18 MWh of electric energy are used to move up 1 MWh of mechanical energy.

Via pumping the mechanical energy equivalent of 3513.98 MWh of electric energy is thus 3513.98/1.18 = 2977.95 MWh. Transformed into a volume of water leaving the lower reservoir it gives: (2977.95/270) x 150000= 1 654 418 m^3, thus an average of 17982.8 m^3 per day. Over three months the pumped water corresponds to 11 times the volume of the lower reservoir.

How could this water have been used?

The only uncontroversial data available to us is the positive part of the *hydraulica* column of the REE table: 481.25 MWh.

Because we chose $(1.18)^2$=1.4 for the roundtrip efficiency (up then down) for electric energy production, this means that 481.25 x 1.4 = 671 MWh of surplus wind energy have been effectively used to produce hydraulic electricity. Thus only 19.06 % of the total energy sent by the wind farm to the pumps of Gorona del Viento have been used to return electric energy to the grid. Because the mechanical to electric energy efficiency of the (down-going pipe + turbine) system is 1.18, to produce 481.25 MWh of electricity it has been necessary to let ((481.25 x 1.18)/270) x 150 000 = 315 486 m^3 return to the lower reservoir via the hydraulic turbines. Again, one finds that 80 % of the pumped water had to find another usage than hydroelectric production. What could this usage be?

We assume that neither the upper nor the lower reservoirs are leaking. Some of the pumped water had to compensate evaporation from the upper reservoir which is intense during summer months. According to the El-Hierro water council it amounts to 16 700 m^3 [23]. It could also have been used to store water in the upper reservoir. If we make the extreme assumption that this upper reservoir was empty on July 1st, the most that could be stored was 380 000 m^3. We are thus left to guess the fate of (1 654 500 – 315 500 – 16 700 – 380 000 =) 942 300 m^3.

Could the water surplus have been used for irrigation?

One can doubt it. Indeed the daily flow to the irrigation system would correspond to an average of 10 250 m^3/day a value which exceeds the maximal water production (wells + desalination plants) of the island. It would also have required a rather powerful pumping system to transfer water from the upper reservoir to the irrigation pipeline system located on the other side of the volcano (>120 l/s).

How much pumped water was then wasted?

In addition even if one assumes that the surplus of pumped water was usefully employed for human usage via the irrigation system, one faces a problem. How could this large amount of water be simply made to be present in the lower reservoir in time for pumping?

Indeed, taking into account that according again to the El-Hierro water council the evaporation loss of the lower reservoir over summer was 29 500 m^3, this reservoir which we can assume to be full on July 1st (150 000) must have been able to receive (1 654 500 +29 500 – 315 500 – 150 000 =) 1 218 500 m^3 thus an average of 13 245 m^3/day which exceeds by 30 % the entire water production potential of the island.

The only way out of this dilemma is to assume that an important fraction of the water was simply let to flow down the pipe into the lower reservoir without producing electricity (there was no need for it since diesel production was preferred) just to make sure that there was water available to use (to waste, in fact) the wind energy sent to the pumps.

In the absence of an answer from GdV we can for instance assume that the 2400 m^3/day desalination plant assigned to GdV in the documents (Ref. 18) working constantly at full capacity took a fraction of the task. If so a minimum daily average of (13 245 -2400=) 10 845 m^3/day had to be wasted in a useless merry-go-round. This corresponds to 1 000 000 m^3 over three months or about 60 % of the pumped water (and wind energy sent to pumping).

This simple analysis shows that GdV was certainly poorly managed over the last five months at least in comparison to its publicized ambitions (100 % electric renewable).

The above simple demonstration was based entirely on energy sums over three months or on daily averages. A more detailed analysis with the 10' time resolution allowed by the REE data shows that the situation was in fact much worse. Some days it was even necessary to inject close to 24 000

[23] Value extracted from the www.aguaselhierro.org web site in the document PHI_API_1.3.5_D8_Anexo_Usos_Y_Demandas.pdf, p.57 "III.4.1 Demandas de Agua en producción Hidroeólica de Energía". However the figures in this document which were published some years before the start of GdV might require confirmation as they state that more than 129 000m^3 of water should evaporate from the two reservoirs in a year.

m^3 to make sure that enough water was present in the lower reservoir to match the wind power sent to GdV's pumps.

VII) Optimal use of GdV

In this section, using the wind power and demand power profiles of the last six months we try to make the best possible usage of the former to cover the latter defining thus the optimal renewable fraction that GdV could have reached.

On El Hierro, the primary source of renewable power is wind. Hydraulic power is secondary. As any secondary production – derived here from wind electric production – it comes with a loss occurring both at the pumping stage which raises the water from the lower to the upper reservoir and at the production stage (friction in the pipeline and turbine efficiency). In the results presented below it is assumed that from 1.4 MWh of wind electric energy injected into GdV, the installation can only return 1 MWh as hydro-electricity to the grid (storage efficiency: 1/1.4 = 71 %).

Thus, for a given wind electric production, the largest renewable fraction will be obtained when as much as possible of the wind production is directly injected into to grid to cover demand. The hydraulic production would then correspond to the transformation – at a 29 % loss – of that fraction of wind power which sometimes exceeds demand.

On the other hand, as said above the voltage-frequency stability of the grid requires some inertia from the island global electric production system. Such an inertia, which the wind turbines can't furnish, is provided by rotating turbines whether they are powered by the combustion of diesel or by falling water. Therefore, at least a fraction X of the electric demand must come from one of these two productions.

For the wind production of GDV and the demand of El Hierro both registered by REE, we will determine the maximal renewable fraction that can be achieved when it is additionally required that a minimal fraction X of the demand comes from dispatchable sources (diesel or hydraulic). What X should be, to ensure grid safety is known to REE. It depends on how the islanders utilize electricity and in particular on the cumulated power of the electric machinery and appliances which may be turned on or off without notice. Although for the sake of simplicity and in the absence of information, we will assume X to be an adjustable constant, our analysis could also be adapted to any time dependent function X(t). For instance, the actual management of the grid by REE over the six month period starting at July 1st 2015 relied on an average dispatchable (diesel + hydraulic) fraction X equal to = 73.4 %. Moreover X was larger than 25 % for more than 99.4 % of the time. It was only equal to 0 % for half an hour on August nine at midday essentially, we believe, for testing purposes.

In a first stage of the analysis, we consider only wind and diesel. Diesel always covers the base production corresponding to a fraction X of the average demand as recorded by REE. To calculate this base production we consider X to be a fraction of the demand smoothed over one day in such a way that daily fluctuations are eliminated while weekly or monthly variations are still taken into account.

Because we are looking for an optimal use of renewable energy, the difference between this base production and the real demand is covered by wind electric power (also using REE data) whenever possible. When there is not enough wind power, the complement has to be provided by the diesel production in addition to the base production it already covers. When there is too much wind, the excess is sent to GdV to pump water which in this first stage of the analysis is thereafter released without any production of electricity in the turbines (as was in fact the case in the summer of 2015 for probably at least 60 % of the pumped-up water). This excess wind power is thus simply discarded.

Fig. 7 illustrates the first stage of our calculation for a value X=25 %, and the six months from July 1st to December 31th. The electric demand of the island as measured by REE corresponds to the upper envelope of the ensemble of yellow (diesel) and dark green (wind sent to the grid) zones. The light green zone shows the discarded wind power. Thus the ensemble of dark and light green zones sitting on top of the diesel production corresponds to the wind production as recorded by REE (the same that was already shown in Fig.6).

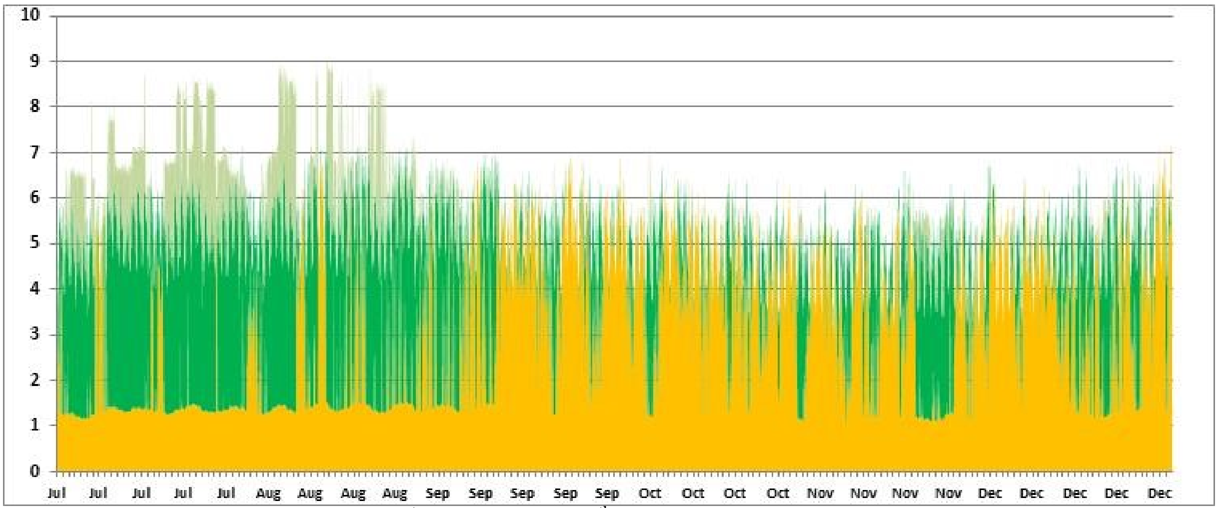

Figure 7. For the period from July 1st to December 31th and a requested dispatchable base X=25 %, the yellow zone gives the diesel power (in MW) while the dark green zone gives the wind power that can be used to cover demand. The light green zone corresponds to the excess wind power which is sent to GdV and discarded in this first stage of the analysis.

In a second stage of the analysis, we use the excess of wind power to produce hydraulic electricity which in turn is utilized to replace diesel production whether in the dispatchable base production or when there is not enough wind production. In this way, all wind can be used either directly via injection into the grid or indirectly after a transformation into hydro-electricity. No wind energy and no pumped-up water are lost. For X=25 % and the same six months this leads to the results shown in Fig 8. The yellow and dark-coloured green zones correspond to diesel and wind power sent to the grid just as in Fig.7. Now the light green zone no more represents discarded wind power but rather wind power used for pumping water at GdV for a future hydro-electricity production. As compared to Fig. 7, a fraction of the diesel power has also been replaced by hydro-electric power (dark blue zone).

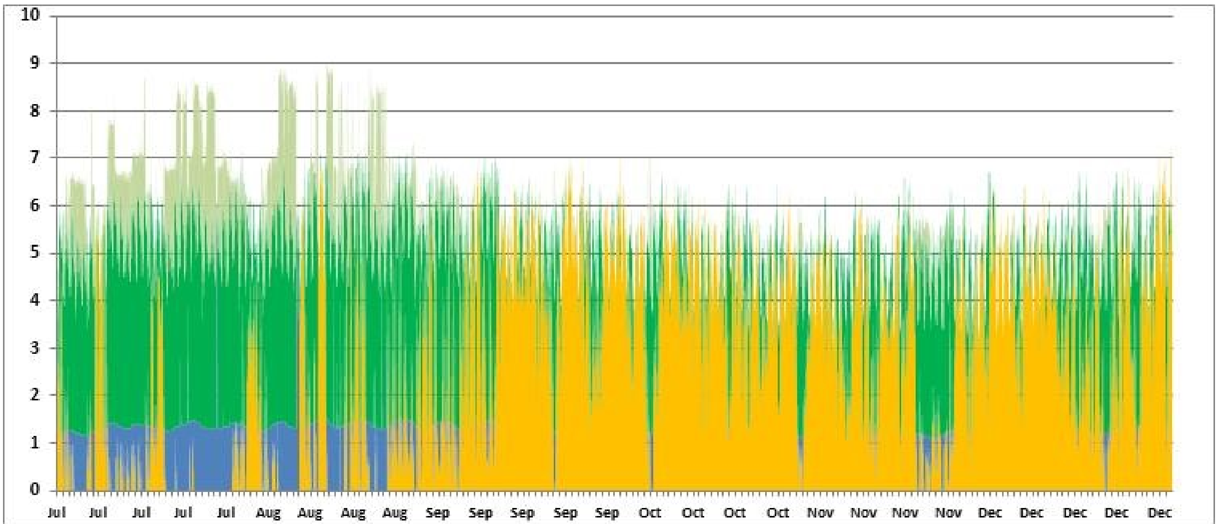

Figure 8. For the period from July 1st to December 31th and a requested dispatchable base X=25 %, the yellow zone gives the diesel power (in MW) while the dark green zone gives the wind power that can be used directly to cover demand. The light green zone corresponds to the excess wind power which is sent to GdV and, at this second stage of the analysis used for the production of hydro-electricity. The hydraulic production delivered to the grid corresponds to the blue zone.

Here, we are concerned with an evaluation of the optimal renewable fraction achievable for the metered wind production under the condition that X % of the demand comes from diesel or hydraulic sources. As soon as some hydraulic production is possible, our algorithm uses it to replace diesel production. In Fig.8 this leads to abrupt transitions in the production scheme. On the other hand, since these are two dispatchable productions, and since, as Fig.9 will show, there is no constraint coming from the amount of water in both reservoirs, it is possible to effect smoother transitions between the two forms of dispatchable productions for instance by limiting power gradients. Doing this would obviously not change the time integrated renewable fractions shown in Fig.10.

Fig.9 shows what would happen to the mechanical energy content of the lower reservoir. This energy content is here measured in MWh rather than in cubic meters. The correspondence adopted is that a full lower reservoir with a capacity 150 000 m^3 corresponds to a potential mechanical energy of 230 MWh. We took the lower reservoir to be three quarters full on July 1st. Since there are two pipelines connecting both GdV reservoirs we considered that it was possible to pump water while simultaneously let it flow down to the turbines to produce electricity.

Because in this optimal scheme, the pumped water is rapidly released to produce hydro-electricity taking the place of diesel production, the amount of mechanical energy (of water) in the lower reservoir never becomes zero. The volume of this lower reservoir is therefore not a limiting factor[24]. This result holds true for the entire range of values of X studied below.

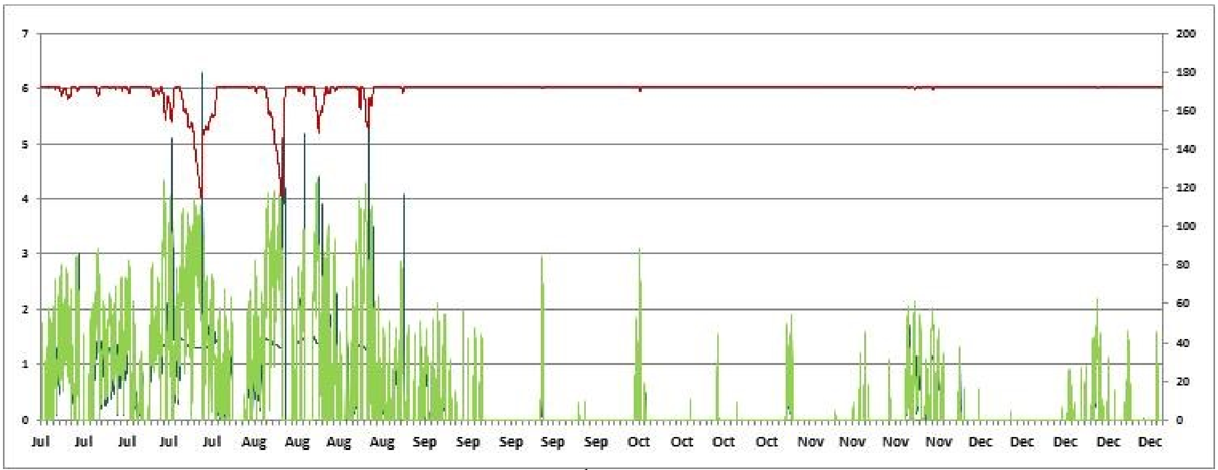

Figure 9. For the period from July 1st to December 31th and a requested dispatchable base X=25 %, the red curve (right scale in MWh) shows the evolution of the mechanical energy (or equivalently the volume of water; see text) stored in the lower reservoir. The green curve shows the wind power (left scale in MW) used for pumping while the blue curve shows the hydro-electric power sent back to the grid.

We can now calculate the optimal renewable fraction as a function of the requested dispatchable base power (X). The results are given in Fig. 10 for the first and second stage of the calculation. In the second stage, all wind energy recorded by REE has effectively been used either via direct injection into the grid or to pump water which later produced hydro-electricity.

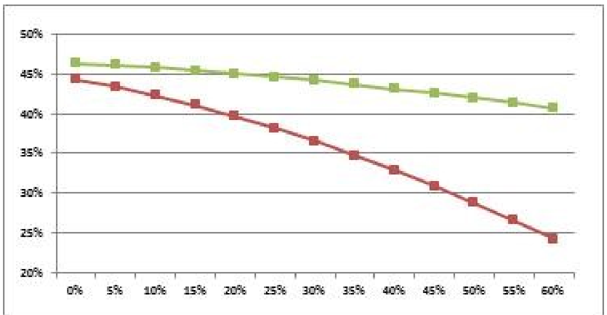

Figure 10. For the period from July 1st to December 31th and a requested dispatchable base X varying over the range [0 %, 60 %] the red and green curves give the optimal renewable fraction in the first and second stage of our analysis respectively.

24 Injection of water into to the lower reservoir is only needed to compensate evaporation. From the El-Hierro water council figures we estimate the necessary flux at 550 m^3/day or 6.4 l/s.

As expected at each stage of the analysis the renewable fraction is maximal when there is no request that a fraction of the demand be covered by diesel or hydraulic production (X=0). The fall of the red curve is fast because, as X and the base production moves up, more of the wind production (light green zone in Fig.7 and 8) has to be discarded. On the other hand, the green curve which corresponds to the full use of GdV power (wind plus hydraulic) decreases more slowly since all the wind power is now used. The decrease only reflects the loss (29 %) in the transformation from wind power into hydro-electric power as more wind power is being diverted to pumping.

From the past six months of operation we find that the maximal renewable fraction achievable by GdV is at most 46.3 %. It decreases to 44.6 % when for instance the grid requests that the diesel-plus-hydraulic production should correspond to at least X= 25 % of the averaged demand and to 43.1 % when X is taken to be 40 %.

Of course diverting some of the pumped-up water for irrigation purpose will lower the renewable fractions.

We also find that over these six months (184 days) the demand must then be entirely (100 %) covered by the diesel production for a duration equivalent to 44 days.

VIII) **First estimates of global costs and performances**

Up to now we have been working with reasonably solid and independent data since they were provided by the grid operator REE, a public entity which is not a member of the GdV consortium. As mentioned earlier, the requests for detailed information addressed to GdV have not been answered. We are thus left standing on the more unstable ground of analysing the information from the communication department of GdV, as it is further transcribed by the media, a process well known to introduce additional distortions.

Indeed, what is remarkable is the wide range of GdV performances to be found in the media. For instance, from the texts, the renewable fraction ranges from 100 %, already, or in some unspecified future, to lower values down to that observed by REE over the last six months: 30 %. Even more, within the same article, up to three different goals may be announced under different forms. Take for instance, Ref.5 from UniversoCanario which, for some future, mentions a GdV electric production of 30 GWh said in the article to correspond to a 75 % renewable fraction and to a reduction of CO_2 emissions by 29 222 t (five significant figures!). Since the steadily growing electric demand of the island was already 44.3 GWh in 2015, 30 GWh only correspond to a renewable fraction of 68 %. On the other hand, as REE (Ref. 19) tells us that the production of CO_2 associated with 1 MWh of electric energy produced by the Llanos Blancos plant is 0.75 tCO_2/MWh, a reduction of the emissions by 29 222 t should correspond to an 88 % renewable fraction. What is obvious is that no firm goal is really set and that a sufficiently wide range of performances is announced for at least one of them to be reachable. The only thing that comes out clearly is that the 100 % renewable goal without which the project would probably never have been funded and subsidized is not anymore an objective for the foreseeable future.

As said above, a comprehensive analysis of GdV requires both more transparency from the consortium and from ENDESA when it comes to the Llanos Blancos plant as well as a full year of significant operation of GdV such as happened in the last six months which witnessed the *miracle* reported in the El Pais article. The first condition which in principle should be expected for a project which has received more than 43 % of public subsidies will certainly not be obtained without a strong political pressure. The second requires that we wait six more months till the end of June 2016.

Still, we can already make some financial estimates for the year 2015 using the expected GdV earning figures for that year which has been announced in more than four recent articles: 7 M€ (see for instance Ref.6). Ultimately this sum is going to be paid by all Spanish citizens since the price paid by consumers of electricity is the same everywhere in the country whatever the cost of production in the islands. The total 2015 production of GdV is 8742 MWh. This puts the effective price of the GdV MWh at 801 €. For the Spanish citizen, this amount must be decreased by the cost of the MWh that Llanos Blancos didn't have to produce. According to reports, the price charged by ENDESA for its diesel electric production is of the order of 200 €[25]. Thus in 2015 the real effective cost of a GdV

[25] Information extracted from http://www.eldiario.es/canariasahora/premium_en_abierto/unelco-endesa-luz-monopolio-deficit_de_tarifa-renovables-petroleo_0_250225145.html

MWh is ~600 € that is a factor three higher than when produced with diesel engines, a factor 12 higher than the cost of electricity in the peninsula and at least twice the cost of the most expensive renewable electric production. From the 7 M€ earnings for 2015, we can also calculate the cost of an avoided ton of CO_2. According to REE the transfer of 8742 MWh away from a diesel production has saved 6556 tCO_2. This puts the 2015 effective cost of one tCO_2 at 1068 €!

If based on the announced earnings for 2014 (1 M€) and 2015 (7 M€) we allow ourselves to make a prediction for a full year of operation at the level witnessed over the last six months, we would foresee GdV being paid ~10 M€ while producing an energy of the order of 15 GWh. For the Spanish citizen, such figures put at 470 € the cost of the MWh produced by GdV and at 890 € the cost of an avoided tCO_2.

The previous paragraphs have discussed the GdV situation, financially and ecologically, from the viewpoint of the Spanish citizen who ultimately has to bear the cost. One can also consider it from the point of view of members of the consortium for which according to our Ref.6, GdV should be the equivalent of a *gold mine*. The situation is not exactly the same for the local council (Cabildo) and the Technical Institute for which their 60 % and 10 % share of the 7 M€ serve first to cover their contribution to operational and maintenance expenditures and second to reimburse the costs of their investments of 27.6 M€ and 4.2 M€ respectively.

For ENDESA, a complete financial balancing requires taking also into account the loss of revenues at the Llanos Blancos plant as well as the gain associated with the cost of the diesel-fuel which ENDESA didn't have to buy. As said above, no gain should be expected for the operation and the maintenance of the diesel-fired plant which has to be available 100 % of the time. At 200 €/MWh, the 2015 loss in revenue of Llanos Blancos has been 1.75 M€. Since textbooks tell us that burning 1t of diesel generates about 3.2 tCO_2[26], using REE figure for the CO_2 emission for each diesel-generated electric MWh (0.75 tCO_2/MWh) we estimate that in 2015 the operation of GdV has avoided buying about 24 000 barrels of diesel oil. As we don't know the price of the diesel oil delivered on El-Hierro, we can't pursue the analysis of the corresponding savings for ENDESA. We can only say that a value larger than 72 €/bl leads to a gain for the Llanos Blancos part of the ENDESA operation.

The technical management of the GdV installation is controlled by ENDESA which alone among the three partners has within its personnel the adequate competence. In all likelihood, it is ENDESA which has dictated the wording of the contract signed by the consortium with the Spanish state (Ref.7). The analysis of this contract explains why it is not really in the financial interest of the consortium to generate too much renewable electricity with the wind turbines and not at all with the hydraulic component of GdV. In fact, as it is written, the contract rewards GdV much more when its hydraulic turbines are idle than when they produce energy.

First we note from the sect.3 of this contract that the electric energy generated by GdV is not paid much – 15.57 €/MWh – compared for instance to the price paid for diesel-generated electricity. This tariff is only meant to cover the variable costs of energy production ("Coste variable de generación horario"). As a result, in 2015, the electricity produced by GdV will only generate a 136 100 € earning[27] that is only few percent of the 7 M€ which GdV expects to receive next March from the hands of the Minister of Energy.

If GdV is not paid for energy production, that is to reach or even approach the advertised 100%-renewable goal, what it is paid for? The answer is given in the Sects. 4 and 5 of the contract. **GdV is paid not for what it does but for what it might do, just as an insurance company: "garantía de potencia"**

In Sect. 4 there are several formulae which explain how the annual earning **R** is calculated. They boil down to the following simple form:

$$\mathbf{R = P_t \,.\, r. \,(F_{eff}/F_{ref}),}$$

where **Pt** (in MW) is the total installed power of the hydraulic turbines. Nowhere in the contract, the power of the pumps nor those of the wind turbines are explicitly mentioned in the

[26] Such a value puts the thermal to electric efficiency of the El-Hierro diesel engines at 36.7 %.

[27] In the Ref.6 published on December 12 by UniversoCanario, a smaller figure is given: 118 138 €. We believe that this article published before the end of the year didn't take into account the December production.

calculation of the earnings[28]. On the other hand, **r** (in €/MW) covers a) the annual cost of the investment of the entire installation per MW, b) plus the annual fixed cost of global operation per MW c) plus the annual cost associated with the initial filling of the reservoirs per MW d) plus a "retribución" destined to make sure that the project is rentable enough (it can reach 122 000 per MW). The quantity $\mathbf{F_{ref}}$ is a dimensionless reference annual available power load factor which the contract sets at 30.5 %. Apart from **r**, the performance of GdV which decides on the annual earning is thus the effective power load factor $\mathbf{F_{eff}}$ **that is the annually averaged fraction of the installed hydraulic power that GdV has made available to the grid operator, should REE have needed it to stabilize the grid**. Thus, it is in the financial interest of GdV to maximize $\mathbf{F_{eff}}$ at values larger than $\mathbf{F_{ref}}$ in order to get its money back as quickly as possible.

The interesting point here is that what is rewarded is not the real contribution to grid stability which as we have seen, except for two hours, has been always ensured by the diesel-fired plant. What gets money to GdV is **its potential at offering such a guaranty** without having to effectively use it. As a matter of fact, using it would diminish the guaranty, unless the amount of wind power directed to GdV at the same moment was sufficient to pump up the same amount of water that one has let flow down. The formula explains why the installed power of the turbines $\mathbf{P_t}$ can exceed by a factor two that of the pumps since nowhere in the contract the earnings are connected with the pumps. It also explains why the power delivered by the turbines has never exceeded 30 %. The formula shows that the annual earning of GdV depends on the installed hydraulic power whether it is idle or not. Increasing $\mathbf{P_t}$ and thus the idle hydraulic power tends also to increase $\mathbf{F_{eff}}$ which would become equal to 100 % for $\mathbf{P_t}$ going to infinity.

Given the terms of the contract, from the point of view of the consortium, the financially optimal situation is the following: having a) a volume of water in the upper reservoir at least equal to what the lower reservoir can hold, b) as much as possible hydraulic power in a state of readiness and c) the lower reservoir empty. Fig.9 shows that it is not what would have happened if a maximal use of pump-up water to produce hydraulic electricity had been organized. Indeed, for such an "optimal" use the lower reservoir would rapidly have returned to its initial level until some wind energy was sent to the pumps. On the contrary, if one follows what did happen during the last six months, one finds that the strategy adopted by GdV ensured that the lower reservoir would always be empty or near empty that is in position to accept a maximal amount of hydraulic energy. In a sense, the GdV project has not been built and managed to optimize the renewable fraction nor the EROEI (Energy Return On Energy Invested) but rather to maximize the €RO€I (Euro Return On Euro Invested).

Of course, from time to time REE has to verify that the power guaranty announced by GdV does exist. This probably explains the carefully planned two-hour event on August 9. We must certainly expect to witness such demonstration events at least once a year, most probably during the windy period (June, July and August). It is also likely that GdV needs to check regularly that any of its four turbines which remain idle most of the time, is really in working condition. From that point of view it would be interesting to know if the bursts of hydraulic productions observed in the fall (Fig. 6) did involve some rotation in the use of the turbines. Indeed, the power of each of them is larger than that of the delivered hydraulic production.

Rewarding effective contributions to the grid stability has long been a standard procedure in the integrated electric systems. It is part of their daily technical and financial management. What is more recent is the notion of "capacity factor" in which the owner of a plant is paid per MW just for the fact that its plant is there ready to offer a contribution to grid stability. This notion is presently very much discussed because the decision by politics to favour a growth of wind and solar productions is leading to a gradual destabilization of the grid. Therefore, some owners of gas-fired plants whose business plan is destroyed by the priority of injection granted to renewables are threatening to mothball their plants unless the grid pays them for staying connected, idle but ready for production[29].

[28] They are of course present implicitly in the investment costs which are however only scaled with respect to the power of the hydraulic turbines.

[29] For instance the coming gas-fired plant at Landivisiau in Brittany has obtained to be paid ~40 M€ per year for the stability of the grid in a region of France which otherwise is betting his future entirely on renewables and without admitting it, on the nuclear plant at Flamanville in the nearby region of Normandy. In Germany the EoN Irsching gas-fired plant is negotiating a similar deal (https://de.wikipedia.org/wiki/Kraftwerk_Irsching).

However, in contrast to GdV, this is a situation in which a privately owned utility requests to be paid because it can offer a technical compensation to the damage to grid stability generated by competitors who are at an advantage only thanks to a political decision.

The irony in the case of GdV is that there was no problem of grid stability on El-Hierro before GdV existed. The diesel-fired plant was able to provide both power and grid stability (as a matter of fact, it is still doing both). The wording of the contract makes it so that GdV is not paid for the energy it produces, nor for the grid stability it ensures, but for a **potential** contribution from its hydraulic component to a grid stability that on the other hand its wind component is **effectively** damaging. One might thus describe the present situation on El-Hierro as: rewarding the guilty one!

Acknowledgement
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Late addition

As this text was already completed, I was made aware of a document published in Diaroelhierro on June 23rd 2014, that is a few days before the inauguration of GdV, by two engineers who had worked on the GdV project, Ms. S. Gonzales and J. Falcon[30]. In it, the two engineers want to dismiss what they call the *grandiloquent sentences* concerning GdV, insisting that, under the best possible technical conditions, it will not achieve a better than 55 % renewable fraction (in Sect. VII, using wind and demand data for the last six months, we find 46 %) and that 25 % is going to be closer to reality (in Section VI we show that only 30 % have been observed over the last six months). Although they do not discuss the terms of the contract signed with the Spanish state, they also argument that GdV will necessarily lead to an increase in the effective cost of producing 1 MWh of electric energy on El-Hierro. They also insist that nothing in the project can be considered innovative. In retrospect, this document shines with lucidity, honesty and precision, something which has escaped most comments published since them.

[30] http://www.diarioelhierro.es/t26496/pag02.asp?Id_registro=151989&BDi=INICIO&Id=26496&Md=7