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Brief Report

Green villages by Wind + Solar + Hydrogen

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Abstract: This paper describes 5 steps on the move to cost-effective green villages, powered mainly by Solar, Wind and Hydrogen. In Britain, there are around 6000 villages comprising almost half the total population. These village dwellers wish to reduce their expensive energy bills, achievable by profitably going green with local Wind and Solar generation of electricity plus Hydrogen energy storage. The first step is to measure the total energy usage in the village. This defines the size of the required renewable private wire energy installations. The second step calculates savings on grid bills for electricity, natural gas and petroleum transport products, to ensure rapid payback for the renewables to be installed. A third concern is the planning permission for Wind/Solar installations that may take months to approve. Perhaps the most important requirement is to attract investment in the fourth step. Finally, the fifth step is to procure and commission the equipment needed in the village to prove that local energy can beat the present centralized grid energy systems, using Hydrogen as the vital energy storage molecule to fill gaps in Wind/Solar supply.

Keywords: wind-generation; solar generation; hydrogen energy storage

1. Introduction

For decades, we have discussed using distributed energy to power our homes, heat buildings and drive vehicles, replacing the present centralized national electric grid, gas network and gasoline distribution systems with local renewables. The first inkling of this dispersed energy concept appeared in 1998 [1] when it was demonstrated that local biogas could power homes using a 1000 tube Solid Oxide Fuel Cell (SOFC). If every home in UK had such a green CHP (Combined Heat and Power) generator, then fewer power stations and pylons would be built, and energy security would be high. Japan has been the only country to progress this significantly [2], installing almost 1 million fuel cells in homes. Unfortunately, biogas was not available, so natural gas and other fossil fuels like kerosene were used, but not green.

A recent advance [3] concerns green Hydrogen which can be generated locally from renewables, stored onsite and used for all energy needs. Since 1990, the rapid development of fuel cells generating electricity from Hydrogen has enabled provision of combined heat and power locally, increasing independence from the centralized electricity grid. The results are reduced costs with increased security. Haldane in Cambridge had understood the benefits of Hydrogen much earlier in 1923, and this was emphasized through Bockris in 1970 by defining 'Hydrogen Economy', which is now approaching reality 54 years later [4].

Wind and Solar are the most economic universally available renewable energy sources. Cities with dense populations may not be able to access sufficient power from such technologies, but villages can. Since villages account for much of the dispersed UK population, almost half of 64 million British people [5], the potential for demonstrating and dispersing local power is substantial [6]. But storing the renewable energy is necessary and Hydrogen is the best storage molecule.

Keele is perhaps the best UK example of 2 MW Wind turbines and 4 MW of Solar providing local energy to a population of 12,000 (**Figure 1**), but there was only 2 MWh battery storage on-site, insufficient to avoid grid dependence [7] and less than 200 kW of Hydrogen. To fill gaps in Wind/Solar, 5 MW of green Hydrogen production with 60 MWh storage in Hydrogen gas tanks would be appropriate to cut the import of expensive grid electricity, giving substantial savings.

Other types of renewable energy should be mentioned, for example hydropower, biomass and geothermal, which have been successful in Norway and Iceland, but these are complex in Britain and cannot compete economically at present with Wind/Solar/Hydrogen [8,9]. More densely populated cities like London and Birmingham are not dispersed and have little installed Wind/Solar compared to farms [10], so different approaches are required to make cities green in future [11]. At present, the UK Government plan is to deliver electricity from offshore Wind farms by pylons and cables to London, Birmingham and other cities, costing about £60billion, also controversial because of the large number of ugly new pylons/cables crossing country areas [12], plus electricity prices five times higher than necessary. London and Birmingham have the lowest amount of renewable energy across England regions [13], whereas rural areas have most.

This paper describes the distributed power alternative in detail, as applied to a model village, defining the five steps to success. As mentioned above, there is a scaling issue because a large city has too dense a population that overpowers the available Wind/Solar energy available locally, whereas a single home can install Solar panels and a battery to reinforce the Grid connection, but payback is far too long to be cost-effective at this small-scale. Hence, there is a range of population densities, not too high and not too small, that gives optimum and satisfactory economic return, which is the purpose of this report [14]. To get the economics right, it is necessary first to understand the three present energy grids: Electrical, gas and petroleum, that are powering present villages.

Figure 1. Wind and Solar installation at Keele, a unique example of a UK village with Wind and Solar but insufficient Hydrogen storage.

2. Background

The UK Government published its energy consumption figures for 2022 [15] illustrated in **Table 1**, showing the total has dropped slightly since 2021, but transport is still rising inexorably. The grid prices for 2024 are also shown, indicating that Britain is among the highest-price countries worldwide, incentivizing the changes proposed in this paper.

Table 1. UK energy split in 2022.

Energy supplied	TWh	Percentage	PRICE £/MWh (2024)
Electricity Grid	274	20	360
Gas Grid	442	31	77
Petroleum	652	46	155
Biomass etc.	41	3	
TOTAL	1409	100%	

It is always a surprise to see that petroleum, mainly used in transport, dominates this table, yet electrification has had little impact on this liquid hydrocarbon fuel sector, at present only a few percent green. UK Grid electricity by contrast has become greener through installation of large offshore Wind farms, more than 50% renewable on average in 2022.

This lack of green transport is a long-term problem for villages, since vehicles cannot easily be counted as they drive through, while the cars owned by local citizens are often refuelled elsewhere. Natural gas has also not gone green, and this causes a further problem until homes are fully electrified, or green gases such as biogas or Hydrogen are fed though pipelines. Thus, the energy audit in villages in difficult. An exception is a private site such as Keele University (**Figure 1**), the size of a large village, which has estimated annual energy use of 63 GWh [7] that includes a number of vehicles on campus, where 12,000 students do not run cars. Keele is adapting its estate for more electric car chargers and perhaps Hydrogen buses by installing suitable new infrastructure fed by Wind/Solar.

The primary message from **Table 1** is that the UK electricity Grid would have to grow 5 times larger to replace all present UK transport and gas energy sources across the UK, an unlikely prospect. Local distributed green energy will be easier and much more economic, as the cost comparisons are defined next.

3. Steps

3.1 Methodology

The methodology is defining the 5 steps necessary to transition the village to Green, first calculating the full energy bill, second to work out the savings in transitioning, third overcoming barriers like Planning Permissions and safety risks, fourth obtaining finance from investors, and fifth procuring then commissioning and running the new energy system. The primary step is to work out the annual energy bill for the village, ready to compare with the bill to be expected from a

Wind/Solar/Hydrogen local power plant. The main point is that grid energy prices have been rising rapidly in recent years, as shown in **Figure 2** [15]. Everyone asks why electricity is so expensive compared to Wind/Solar and the answers are complex. But the Grid monopoly is a key problem because it is huge, spending enormous sums of money in transporting power, yet not storing much electrical energy. A recent study [16] suggested that more than 370,000 miles of new power lines will be needed over the next few years to decarbonise Britain using the National Grid, essentially doubling the cost of the electricity generated largely by offshore Wind. In addition, UK energy has substantial tax and displays some of the highest energy prices globally. In 2024, prices fell significantly and may drop further. Such price fluctuations must be considered carefully over the length of the project to predict potential profits.

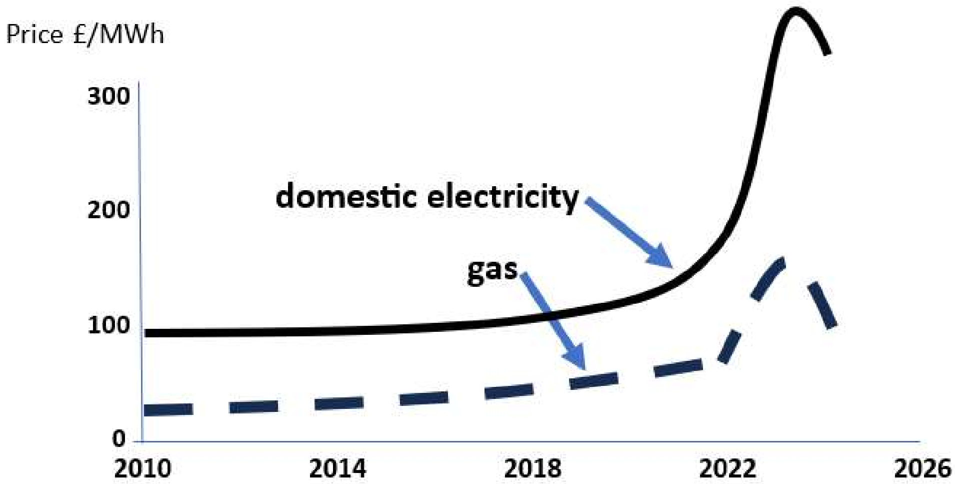


Figure 2. Smoothed rise in energy prices in UK from 2010 to 2024.

Therefore, the first priority is to calculate the present total energy bill for the village, using the prices shown in **Table 1**. Of course, these prices vary a lot depending on several factors, but the main result shows that the total bill is large, much higher than that expected from Wind/Solar/Hydrogen.

Table 2 shows that a private wire village uses 12 GWh of electricity each year, with 38 GWh of gas and 13 GWh estimated for transport using petrol and diesel fuel (less than a quarter of that expected for the average UK village transport-energy). **Table 2** shows the total annual bill in 2022 for the 12,000-citizen village calculated according to the prices shown (NB these can vary a lot) for comparison with an estimated Wind/Solar/Hydrogen bill.

Table 2. Annual Energy bills for a typical village of 12,000 people.

	GWh/a	Price £/MWh	Bill M£/a (2024)
Electricity	12	360	4.3
Gas	38	77	2.9
Petrol/Diesel	13	155	2.0
TOTAL	63		9.2
WIND/SOLAR/HYDROGEN estimated		50	3.2

3.2. Calculate savings from installation of Wind/Solar/Hydrogen

The second imperative is to work out the savings that would follow from the installation of local Wind/Solar/Hydrogen generating and storage equipment.

The numbers in **Table 2** show that the village using Wind/Solar/Hydrogen saves up to £6M per annum by moving from grid to distributed power, using Wind/Solar/Hydrogen, if the energy price can be cut to £50/MWh. The methods used for calculating the levelized cost of UK electricity in 2023 are described in [17]. MW scale onshore Wind and Solar are the most economic routes at £36/MWh and £37/MWh respectively, but the addition of Hydrogen equipment will increase this by a significant sum, estimating £50/MWh for final energy cost in the village.

Calculating the additional cost due to Hydrogen storage depends on the installations desired by each village. One essential piece of equipment is the electrolyser used to produce Hydrogen from water. A typical 5 MW PEM electrolyser installed in two containers by ITM Power costs £4.6M and the 2-ton storage cylinders nearby cost £0.4M. Another container is required for a battery that can buffer the fluctuations in the Wind/Solar power, typically costing £1M for a 5 MWh energy storage capacity. New pipes need to be installed to carry the pure Hydrogen to the village grid, where a combined heat and power (CHP) unit can generate electricity around 2 MW and hot water near 1 MW for the private site when Wind/Solar are low. This could be a combustion generator container. Heat storage using the village hot water grid can be used to consume excess input power when Wind/Solar are high, especially useful in winter. For the village example in **Table 2**, three top investments are therefore required: The £5M for 5 MW PEM electrolyser + cylinder needed to store renewable energy as Hydrogen gas in a 2-ton tank at 30bar pressure; £5M for 6 MW Solar panels installation: £5M for 6 MW Wind turbine, £2M for pipes and CHP unit, plus a £1M battery, totalling £18M, suggesting that 3 to 4-year payback is near the mark.

A decision has to be made about how much natural gas and petrol/diesel can be profitably displaced by Wind/Solar/Hydrogen, since these heat and transport fuels are not likely to be electrified for some time. From the numbers in **Table 2**, the annual profit per GWh of replaced grid electricity is about £0.4M whereas that for petrol/diesel is around £0.16M. Natural gas replacement delivers lower profit, less than £0.1M for each MWh displaced. Therefore, first focus on replacing grid electricity using Wind/Solar/Hydrogen maximizes the payback. But the remaining diesel/petrol and natural gas are 80% of the climate-change problem, so should be addressed as soon as possible, looking forward to Net Zero by 2030.

3.3. Planning issues and other barriers

Planning permissions for onshore Wind turbines have been sparse since 2015 when Prime Minister David Cameron effectively banned them. Only 21 Wind turbines were installed onshore in England between 2015 and 2022, after only 12 planning applications were accepted. In 2022, for example, Keele was the only site where Wind turbines began operating [18]. In 2023, Mark Pepper of Ambition installed the largest onshore Wind turbine in UK at 4.3 MW (**Figure 3**) to produce energy for his Boys Club and surrounding poor area near Bristol Docks [19], after 5 years of planning submissions. Only 2 turbines began operating onshore throughout UK that year, illustrating the poor English progress towards local green energy infrastructure, contrasting starkly with China which installed more than 300 GW of new Wind/Solar/Hydro in 2023 [20].

In July 2024, a new government policy document was issued to make onshore Wind planning equal to other energy technologies in Britain [21]. Before this Government change in policy, it was impossible to plan and build green villages based on a combination of Wind and Solar. This stated 'Delivering our clean power mission will help boost Britain's energy independence, save money on energy bills, support high-skilled jobs and tackle the climate crisis. We are therefore committed to doubling onshore Wind energy by 2030. That means immediately removing the de facto ban on onshore Wind in England, in place since 2015. We are revising planning policy to place onshore Wind on the same footing as other energy development in the National Planning Policy Framework (NPPF)'. As a result, large numbers of planning bids for onshore Wind are now being submitted and considered, and advice is becoming available to get local planning permission through the process. The shortest time to obtain permission has been 3.9 months and the longest 15 years, with costs upwards of £60,000 for a large turbine.

Figure 3. Largest UK onshore Wind turbine starting generation in 2023 installed near Bristol Port by a boys' club leader.

Now the new UK government has been elected in 2024, onshore Wind banning was stopped in the first week and a commitment to doubling onshore Wind by 2030 was announced, that should add another 15 GW of green electricity supply to local communities. The new law to produce much more green energy from 2024 is going through Parliament to create a new national company 'GB Energy' by 2025, which will be committed to getting green energy to local villages, with commitment to make more Hydrogen to replace fossil natural gas for vehicles and buildings. £8.3billion has been budgeted but details are not yet announced.

Large Solar is also getting approval and the planning process Is being accelerated. But planning permission is still produced by local elected councillors and the surrounding communities must be consulted. Installing Hydrogen facilities may also be problematic and needs close study. A typical problem emerged in Crawley during 2022 when the local council stopped the Hydrogen (liquid not gaseous) bus depot from fully commissioning [22]. 10 Hydrogen buses became stuck in carparks waiting for the negative views of local councillors to be resolved. 2000 kg of Hydrogen stored on-site are straightforward, but above that level, the bureaucratic procedures must be applied and have taken 24 months already, stopping the full Hydrogen bus fleet from running at the biggest such depot in Europe.

Hydrogen must satisfy Gas Regulations and must also complete Health and Safety measures [23]. Consent for small projects may be obtained through the Town and Country Planning Act 1990. Land rights need to be secured, as for other infrastructure projects. An Environmental Impact Assessment may also be required for on-site storage and pipeline installations.

The Health and Safety Executive (HSE) requires compliance with the following regulations:

- Gas Safety (Management) Regulations 1996—concerns the flow of gas through the network. All gas transporters must prepare and submit a safety case to HSE (Hydrogen Safety Executive). This identifies the hazards and risks, explains how they are controlled, and describes the system in place to ensure that controls are applied. The gas transporter will be audited to ensure compliance with their safety case
- Pipeline Safety Regulations (1996)—concerns pipeline integrity. These regulations set out requirements in respect of pipeline design, construction, installation, operation, maintenance and decommissioning. For example, pipelines should be equipped with emergency shut down valves and its design should take account of the need for maintenance access.
- Storage of Hydrogen is regulated by The Planning (Hazardous Substances) Regulations 2015 and/or the Control of Major Accident Hazards Regulations 2015 (COMAH), depending on the quantities involved. COMAH sets a high bar of requiring operators to take all measures necessary to prevent a major accident and limit consequences for human health and the environment. The operator must have in place various strategies, including safety plans, emergency plans and a Major Accident Prevention Policy.
- Under the Hazardous Substances Regulations, no consent is required to store less than two tonnes of Hydrogen, equivalent to 60 MWh of energy storage, about a one day of model village demand.
- The Dangerous Substances and Explosive Atmosphere Regulations 2002 sets out requirements for the use of equipment and protective systems in potentially hazardous environments, including those where Hydrogen is produced or stored.

3.4. Attracting investments

The new UK government has claimed it will invest in these green-energy advances, especially community projects that benefit villages [24]. A major priority for the government is increasing community ownership, with £3bn invested to be in local village projects as part of its initial £8.3bn contribution, which will be used to support private investors that will be the main source of funds for these new targets

The onshore Wind fund of £120M has been raised to £185M to accelerate onshore Wind installations.

But private investment must play a major role in getting village projects moving, because offshore Wind appears to be the main thrust of the new government at present, demanding large and expensive investments in expanding the grid, which is unnecessary for the local villages described in this paper.

Our concept is to establish a consortium of three UK villages, each with slightly different assets and expertise, to apply the principles of this paper to demonstrate and prove that profits can be achieved by moving towards Wind/Solar/Hydrogen principles.

The three villages must first define their annual energy demands, their grid bills, and the policies to make profit by replacing grid electricity, gas and petroleum products using Wind/Solar/Hydrogen. Typically, the savings will be around £6M/a, while the total CAPEX, OPEX for installation and commissioning will be about £20M. Payback should then be 3 to 4 years and profits near £60M over the following decade of operation. Each village should make its individual analysis by 2025, with plans to install and commission by 2026. Risk assessment is necessary, especially considering the investments, the planning issues, Hydrogen safety and potential failures of electrical equipment.

Investors will be sought meanwhile, with the Final Investment Decision in 2025.

3.5. Procurement and commissioning

Procuring and commissioning are vital tasks that are essential to establishing the necessary equipment and infrastructure links on the village site.

The first procurement needed is Private Wire. That is ownership of the electricity grid in the village, essential to install locally owned renewable power, so that profits can be made by reducing Grid electricity input [25]. This is a growing sensible idea but has to be well-informed, since penalties are applied if it goes wrong.

Equipment is the next issue. The UK is a good place to obtain key equipment such as electrolysers for production of green Hydrogen because ITM Power [26] has a Giga-Factory (**Figure 4**) building 5MW units in Sheffield, opened in 2021 with planned capacity of 1 GW/a from PEM (Polymer Electrolyte Membrane) electrolysers. A single PEM cell contains a thin 0.01 mm thick fluoro-sulfonic-acid polymer film that has a proprietary catalyst layer printed on each surface, one for the Hydrogen ion (proton) reaction and the other for the water to oxygen reaction. The two gases exit along channels in the interconnector plate, with Hydrogen at 35 bar going to a storage tank, while the oxygen is vented to atmosphere. The input electrical DC power flows through the interconnect to the next cell, utilizing about 1 Volt at each membrane, powering hundreds of electrolysis cells in the series stack. Many of these stacks fit into a container utilizing 5 MW, with about 80% efficiency. Pure water is fed in and used as coolant to extract the 1 MW of waste heat generated. PEM fuel cells effectively have similar structure but run backwards, creating electrons from the reaction of Hydrogen on the fuel electrode and air on the oxygen electrode, but the catalysts required are slightly different. Lifetimes are currently near 20 years for both PEM electrolysers and fuel cells.

The company is fully funded to build another facility, even bigger than the current one, with a higher degree of automation and a greater test capacity. ITM Power will proceed with this plan once the existing facility is ramped up to at least 60% of its capacity.

Large Hydrogen storage tanks for 2-ton capacity at 30 bar can be sourced locally at companies like Chesterfield Special Cylinders Ltd [27].

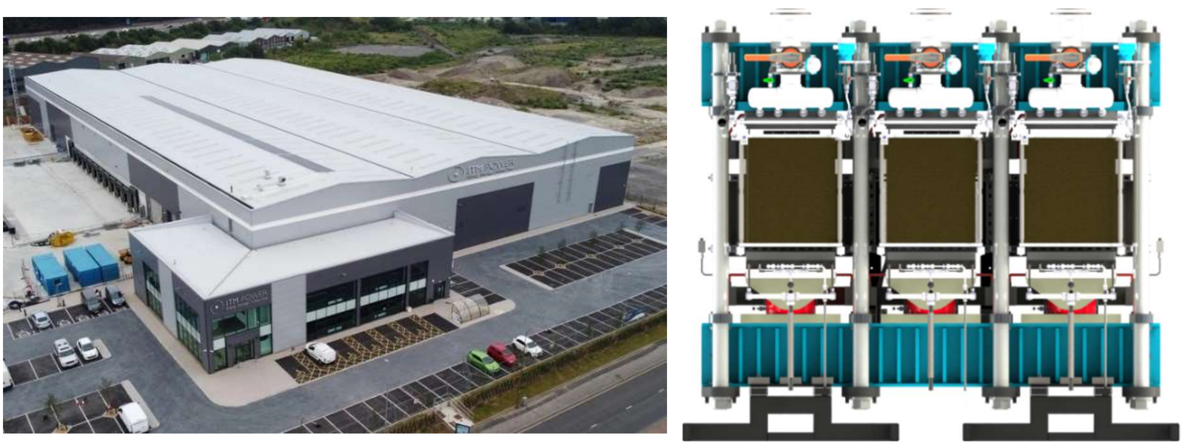
Hydrogen pipe systems are being installed increasingly now with suppliers like Swagelok providing the components for complete Hydrogen systems.

Onshore Wind turbines are available from several suppliers in Britain including Siemens, Enercon and Oersted.

Solar panels are not manufactured at scale in England, nor are large MWh batteries or fuel cell CHP systems, so these items are more difficult. But Battery Energy Storage Systems (BESS) are advancing rapidly while prices are dropping. BYD, the Chinese largest battery manufacturer worldwide has exported several to UK and some are operating on Wind/Solar sites, typically 1–2 MWh capacity and 1 MW power. Givenergy is a big battery company based in UK. No battery gigafactories exist in UK at present but this must change by 2030 when about 2 million car sales are planned to go electric.

To commission projects and run the installation, companies like Equans and Siemens have been active. Other companies like Adelan, Intelligent Energy and Ceres Power are now getting interested due to their long experience of Hydrogen and fuel cells. Until now, such companies have not found it easy to make profits in competition with fossil fuels.

Hydrogen for heating factories/buildings and refueling Hydrogen -fuel-cell vehicles is becoming increasingly popular though companies like Ryze and Element 2, though penetration still lags far behind China and Germany.



(**a**) (**b**)

Figure 4. (**a**) ITM Power gigafactory to manufacture electrolysers at Sheffield opened in 2021; (**b**): ITM Power product Trident stack made in Sheffield factory.

4. Results

No UK village has yet gone green by following the new proposals in this paper. As yet, there is no full experimental verification of the theoretical calculations described here, based on the 2022 evidence emerging from Keele [7]. Calculations of the reduced costs emerging from the 5 steps above have been published previously

[28]. The first results are expected in 2025, but many months experience of Wind and Solar will be needed to understand the overall performance.

5. Discussion

Information on potential success and profits emanating from Wind/Solar/Hydrogen application has been in short supply. For example, the paper describing Keele University's start-up in 2022 [7] does not mention the actual or potential savings made by going green with Wind/Solar/Hydrogen. There has been reticence about costs and prices across this field. Our objective is to make such data explicit and available to all.

The key point of this paper is that renewable energy (Wind and Solar) became more economic than fossil fuels like natural gas in 2017. Hence, transition of UK villages to green energy should now make profits by beating the Electric Utility Companies and the Grid. Other Grid problems can also be cut. The main benefit is stopping the ugly construction of 80,000 new UK pylons and overhead power cables. A further issue is the many GW of large UK Wind/Solar projects waiting for Grid connections, which can take 10 to 15 years to be granted because the Grid has little storage and modest capacity. Around 40% of such projects wait at least a year for grid approval [29]. That is why the grid connection for green villages should be for back-up only.

Profit from replacing expensive grid electricity is the priority goal, as indicated in **Table 2**. The main reason for proposing Green Villages is the extortionate high tariffs set by electricity companies in Britain, among the highest prices worldwide. This, together with the factor 3 increase in domestic prices (**Figure 2**) since 2019, has incentivized the introduction oi economic green power. The reasons for this are complex but stem from the monopolistic structure following British privatization of the Electricity Generating Board in 1990.

Natural Gas and petroleum products are much larger than electric energy because they are more competitive international markets. But gas and petrol are much cheaper than UK electricity, so deliver less revenues when replaced by Wind/Solar. Therefore, a longer-term plan is required to install Hydrogen vehicle refuelling stations. Replacing natural gas profitably with green Hydrogen is plausible if Combined Heat and Power (CHP) is used to convert the Hydrogen to half electricity and half heat. Burning the Hydrogen, as advised by previous governments, is not rational because Hydrogen value in electrical or transport applications is high, whereas heat is cheap.

Other long-term considerations include the expected increase in energy use as civilization extends internationally. Although UK electrical power usage has dropped by 25% since the Millennium as a result of efficient lighting and heating, more electrical applications are now arising such as Data Centres and Crypto-currencies, that are expected to double our power demand as we desire to live like Americans.

6. Conclusions

UK villages, comprising almost half the UK population at present, are paying large energy bills for electricity, gas and transport that can all be reduced by going green with Wind/Solar/Hydrogen. Five key steps have been identified to assist this process.

First, the size of the current grid bills for electricity, gas and petroleum products needs to be defined.

Then, the savings resulting from Wind/ Solar /Hydrogen installations must be calculated.

Thirdly, overcoming barriers like planning permissions for installing the new equipment and satisfying Hydrogen safety regulations must be prioritized because large delays can ensue [30].

Fourth is the attracting of investors to fund the village greening project.

Procurement and commissioning come fifth, with the needs to obtain Private Wire, order the Wind turbine, Solar farm, battery and electrolyser with Hydrogen storage tank and pipework essential.

Conflict of interest: The author declares no conflict of interest.

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