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Techniques of the GREEN Platform for Research Activities

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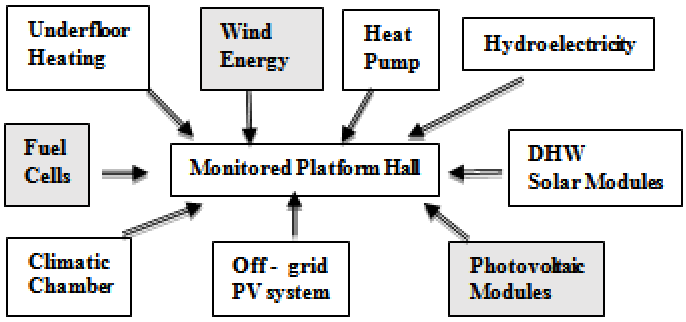
***Abstract**: The requirements of sustainable development encourage political, economic and scientific actors to seek solutions to decarbonise, make efficient production, distribution, storage, and increase the share of electricity from renewable sources. These objectives is coupled with the search for a reduction in the energy consumption of infrastructure and terminal equipment, in line with the quantities of energy produced from renewable sources.In this context the physics department of University Institute of Technology has decided to create a research laboratory, GREEN* platform, equipped with renewable energy technologies operating in real conditions in order to be able to model energy production for energy on demand. The platform scheme is represented below: only technologies in the grey box will be considered.*



**GREEN is a French abbreviation standing for Energy Resources Management & New Energies.*
***Keywords**: photovoltaic, wind power, fuel cells, Weibull*

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I. Introduction

University of Lorraine isequipped with a 200 m^2 designed GREEN platform where several renewable energy technologies are implemented for modeling, managing and optimisation of energy consumption. All technologies are monitored including real weather conditions data are recorded, processed and implemented on FPGA chips for prediction analysis. This article shows how models for energy output of renewable energy technologies in an urban zone have been determined based on data recorded on the GREEN platform. The models are then tested to forecast energy output.

The main monitoring hall is displayed in figure 1. This platform is located in the department of Physics Institute building at the University of Lorraine, Metz, France. This platform is structured and described as follows:

Polycristalline modules of SCHÜCO technologies are interconnected in series and mounted on the south vertical wall of the platform building. Each module has a peak power of 205 Wp, at tilt angle of 60°, low ventilation and connected to a SCHÜCO inverter for a power level up to 1 kW. **Amophous silicon modules** from SOPREMA is on the rooftop of the building. Soprema's modified roofing material, SopraSolar, powered by UNI-SOLAR, integrating their PV laminates into the waterproofing function. Each module has a peak power of 136 Wp, of nearly 5° inclination angle and connected to a

Figure 1. The main hall of the GREEN platform

1500T SCHÜCO inverter.Sizing off-grid PV systems and determination of technical and potential problems.Residential Skystream three blades 2.6 kW **horizontal axis wind turbine**, which is at 12 m above the ground level in an urban complex zone. An AREVA **Polymer Electrolyte Fuel Cells** (PEFC), converting hydrogen, or hydrogen-containing fuels, directly into electrical energy plus heat through the electrochemical reaction of hydrogen and oxygen into water. Generating simultaneously 1 kWth heat and 1kWe power. The goal is to study Fuel cell components and their impact on performance and automotive applications.Measuring overall efficiency of VIESSMANN solar technology, **flat-plate and vacuum tube collectors** for energy-efficient Domestic Heat Water (DHW) heating, central heating backup and power generation. New method for Coefficient of Performance (COP) determination of an STIEBEL-ELTRON air to water **heat pump**. Sizing and modeling a compact PELTON**hydoelectricity turbine** for a hydro project, requiring correct interfacing with the electrical, mechanical, hydraulic and civil aspects. Measuring and modeling heat transfer through new thermal insulating materials using a B.I.A **climatic chamber**.Thermal performances and properties determination through **underfloor heating experimental room**, aims to more efficiently heat homes by using occupancy sensing and occupancy prediction to automatically control home heating.**Simulating underfloor heating**, using REHAU software.Methods for accurate measurements of heat patterns, emissivity and temperature factors using different types of **thermal camera**.**Softwares for dynamic simulation**, design, yield for Photovoltaic, Solar Thermal and Heat Pump Systems as well as home heat loss simulating software. Li-ion cells modeling for battery management system (BMS), for electrical vehicle. New BMS around a heating/cooling system based on absorption thermodynamic cycle. Implementation of a low-power embedded system via FPGA reconfigurable circuit.

II. Photovoltaic System

The photovoltaic (PV) design of the GREEN lab is an on grid connected system. Polycrystalline [1] modules of SCHÜCO technologies are connected in a series wiring pattern and mounted on the south-south east vertical wall of the platform building as shown in figure 2. Each module has a peak power of 205 Wp, at tilt angle of 60°, low ventilation and connected to a SCHÜCO inverter for a power level up to 1 kWp. The two other modules respectively monocrystalline and polycrystalline on the right side of figure 2, are only for DC measurements for the same experimental real conditions.

Figure 2. Polycrystalline photovoltaic string of 1kWp

The electrical diagram of the PV system of the GREEN-lab is represented in figure 3, all electrical protecting system are not represented.Photovoltaics are effected by operating temperature [2,3] which is primarily a product of the ambient temperatures or module as well as the level of irradiation. The PV modules are therefore equipped with temperature and irradiation sensors.

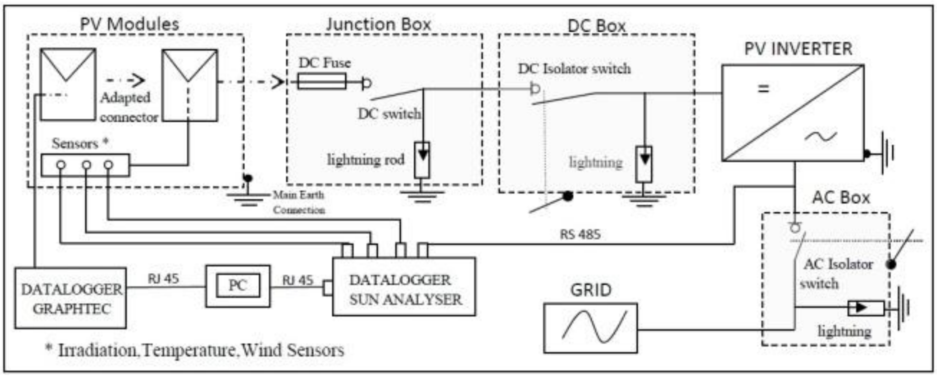


Figure 3. Electrical diagram of the polycrystalline system

III. Photovoltaic Weibull Model

On the GREEN-lab platform, we monitored and recorded data from year 2010 to 2019. We modeled daily then monthly mean location **Figure 3**. Electrical diagram of the polycrystalline system data through 7 years and involve calculations over one full year of 2014 which the middle year of studying period to predict the annual energy production.The Weibull function has been employed almost unanimously by researchers involved in wind speed analysis [4,5,6].We applied such analysis to PV system as this method involves understanding radiation behavior of the propose site and took also into consideration the life modules life time. The most general expression of the Weibull probability distribution function (pdf) is given mainly by the two-parameters Weibull distribution expression given by equation 1.

$$F(\varphi) = \frac{df}{d\varphi} = \frac{k}{A}\left(\frac{\varphi}{A}\right)^{k-1} \exp(-\frac{\varphi}{A})^{k} \quad (1)$$

Where A is the Weibull scale parameter in (W/m^2), k is the unitless shape parameter, φ is the irradiance (W/m^2). For the GREEN platform, k is known beforehand and is approximated to 2.Figure 4 gives the experimental image of the probability density distribution calculated from the Weibull function, for the month of October 2013 concerning polycrystalline modules of the GREEN platform.The thin dark line at 190W/m² is the most common irradiation for this month.

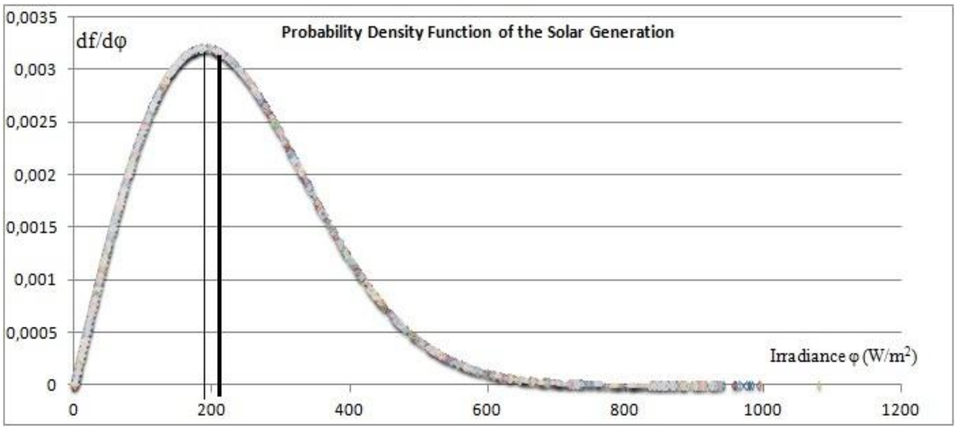


Figure 4. Weibull plot of a particular month of year 2013

The energy output is estimated on a monthly basis based on the Weibull-representative irradiation data for year 2013. The monthly calculated energy output using the Weibull-data, reprensented as $E_{Weibull}$ (kWh) is given by equation 2.

$$E_{Weibull}\ (kWh) \quad = \quad \sum_i^n P_{i,output} \left(\frac{df}{d\varphi}\right)_i . T_i \quad (2)$$

Where T_i is the number of hours of daily irradiation and n the number of days in a particular month and i to n is for the month number. The $P_{i,output}$ is determined by our another model [7] considering the back side temperature of PV modules in real conditions. The Pi,output is givean as in equation 3.

$$P_{output}\ (W) = \ A\ (\ 0{,}128\ \varphi\ -\ 0{,}239.10^{-3} T_{backside}\ )(3)$$

where A is the module surface area., T is the back side temperature of the module.
Table1 gives the monthly PV energy output for year 2014 by comparing the Weibull model and measured data in real experimental conditions.

Table 1. Comparing model and measured data

YEAR 2014		
Months	Weilbull data (kWh)	Recorded Data (kWh)
January	42,66	29,29
February	38,173	38,24
March	104,101	117,54
April	124,112	112,09
May	120,769	113,87
June	121,862	124,29
July	114,657	98,89
August	118,385	102,46
September	107,881	97,94
Octobre	79,872	53,63
November	25,01	22,96
December	12,926	9,23
Total (kWh)	1010,408	920,43

The recorded data of the month of December is due to a breakdown of the data logger for few days.
From table 2, we see that the total energy output of the Weibull model for each year 2013 and 2016 are closed to the measured data of the Green platform.

Table 2. Comparing model and measured data for different years

Méthodes	**Year**	**kWh**
Modèle Weibull	2013	1010,408
Measured data of GREEN Platform		920,430
Modèle Weibull		894,212
Measured data of GREEN Platform	2016	789,067

IV. Wind Power

The GREEN platform is equipped with a residential Skystream three blades 2.6 kW horizontal axis wind turbine, which is at 12 m above the ground level as represented in figure 5.

Figure 5. The 3 blades Wind power Skystream in an urban area.

The blades are constructed from two halves of compression molded fiberglass. The curve of the blade helps to more efficiently capture the energy in the wind and to reduce the sound of the the blades as they move through the air.The turbine is a downwind design so that the blades of the turbine are downstream from the nacelle, which is quieter and inherently better at finding the wind direction than upwind designs.Wind speed is measured by a 3-cup rotor anemometer at the same height as the wind power.

V. Weibull model of the wind turbine in an urban zone

The Weibull function is commonly used for fitting measured wind speed probability distribution but rarely applied for a wind turbine in an urban zone. In this section,we applied equation 1 to determine the most probable wind speed. The Weibull equation for the wind variable is given equation 4.

$$F(v) = \frac{df}{d\varphi} = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} \exp\left(\left(-\frac{v}{A}\right)^{k}\right) \qquad (4)$$

where v is the wind speed and k is the unitless shape parameter that had been determined accurately by equation (5), where σ is the standard deviation and v is the mean speed.

$$\mathrm{k} = \left(\frac{\sigma}{v}\right)^{-1.0983} \qquad (5)$$

Depending on the GREEN platform roughness coefficient we obtained k = 2,37.
A monthly wind speed for different years is given is figure 6.

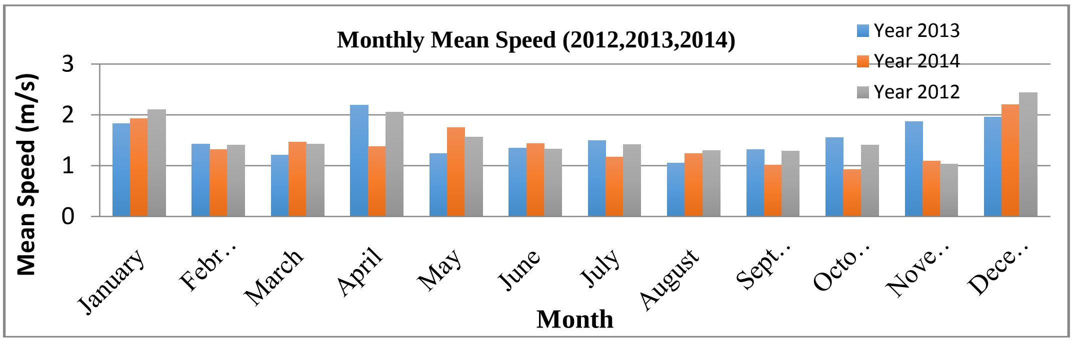
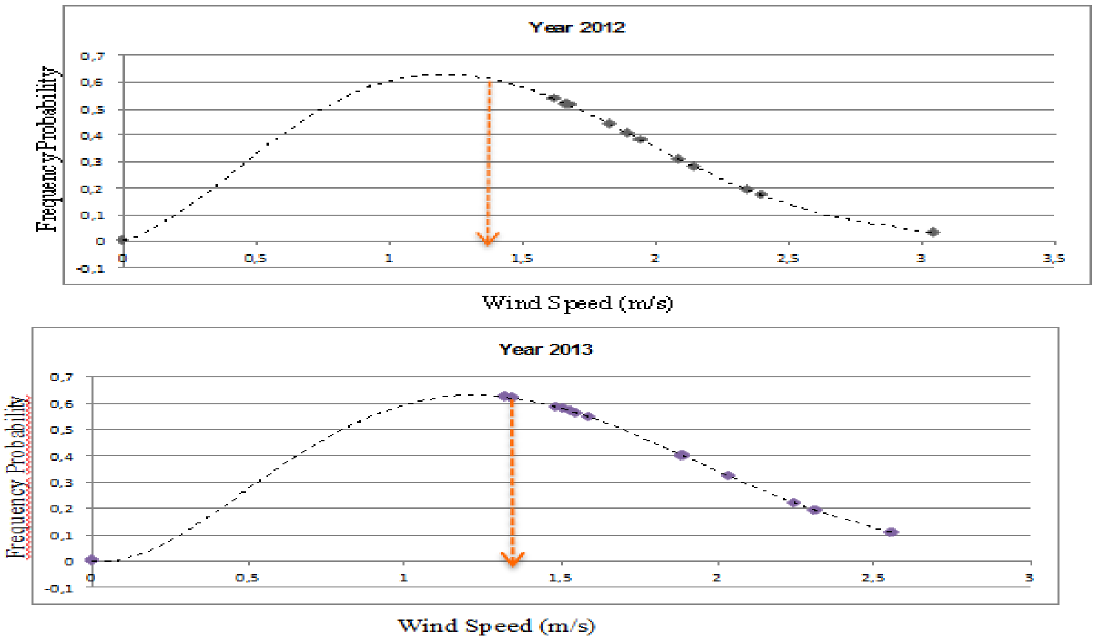


Figure 6. Monthly wind speed of the wind turbine of the GREEN platform

Figure 7 (a) to (e) is a comparisonof probability distribution function calculated from the Weibull function and the wind speed distribution based on data for the studied urban location, we see that the most probable wind speeds are close and lies between 1.3 and 1.4 m/s.



(a)

(b)

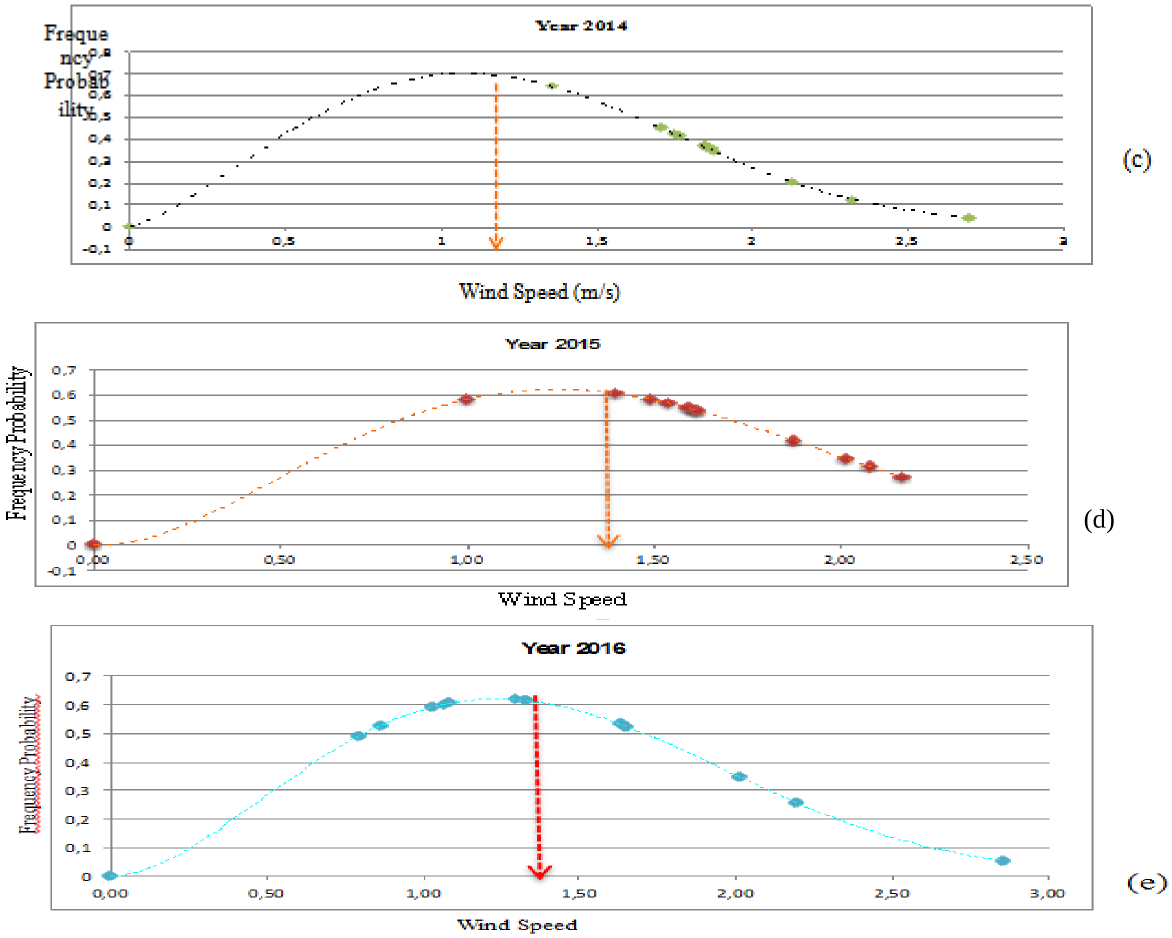


Figure 7. Weibull function versus wind speed upon 5 years with indicated years

VI. Power output of wind turbine

Output power from the wind is proportional to various parameters, as in equation 6,

$$P_{out} = \frac{1}{2}\, \rho\, S\, C_P\, V_{rmc}^3 \quad (6)$$

where S is the surface swept, P_{out} is wind power, V is the root mean squared speed,ρ is the mean air density which depends on altitude, air pressure and temperature and Cp, is the wind-turbine power coefficient.The latter is determined from measurements as represented in figure 8.

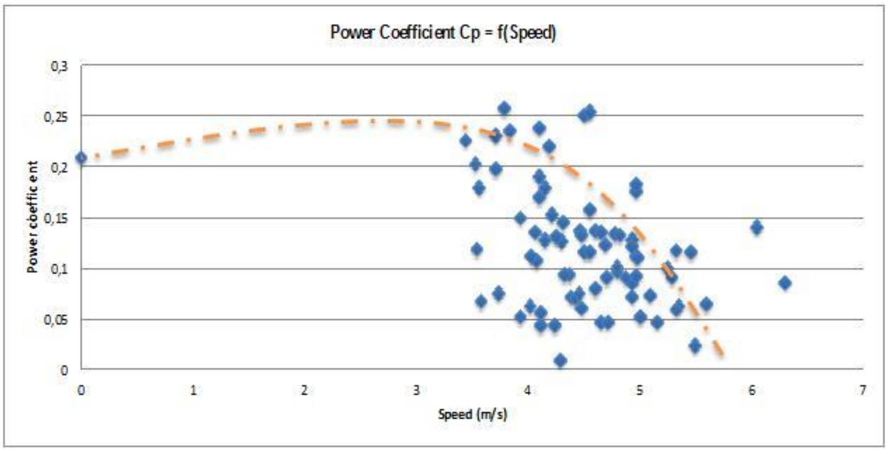


Figure 8. Experimental determination of Cp

The experimental Cp value for the GREEN platform is 0,25, that is 25%. The V_{rmc} is the root mean cube speed given by equation 7.

$$V_{rmc}^3 = A^3\Gamma\,(1 + 3/k) \qquad (7)$$

where Γ is the gamma function. Therefore equation 6 is modified and is given by equation 8.

$$P = \frac{1}{2}\,\rho\, S\, C_p A^3 \Gamma\,(1 + 3/k) \qquad (8)$$

The monthly calculated energy output using the Weibull-data, $E_{Weibull}$ (kWh) is given by equation 9.

$$E_{Weibull}\,(kWh) = \sum_i^n P_{i,output}\;F_i(v)\;\;T_i \qquad (9)$$

Table 3. Comparing model and measured data

Year	k	A (m/s)	Energy (kWh) (Weibull)	Measured Energy (kWh)
2012	2,37	2,03	372,77	279,83
2013	2,37	1,54	329,92	346,94
2014	2,37	1,41	311,36	297,14
2015	2,37	1,67	348,12	361,16
2016	2,37	1,48	314,16	295,17

Table 3, compares the energy output from Weibull model to the measured data for different years.The results of measurements and energy calculation shows a strong correlation.

VI.Fuel Cells

The GREEN platform is equipped with An AREVA Polymer Electrolyte Fuel Cells (PEFC), converting hydrogen, or hydrogen-containing fuels, directly into electrical energy plus heat through the electrochemical reaction of hydrogen and oxygen into water. Generating simultaneously 1 kWth heat and 1kWe power. The Fuel cell principle is given in figure 9.

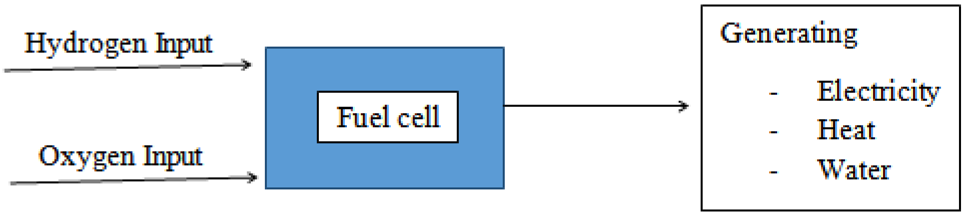


Figure 9. Fuel cell principle

At the anode of polymer electrolyte fuel cell, the hydrogen gas ionises, releasing electrons and creating H+ ions (or protons). The ionic equation at the anode is given in equation 10a.

$$2H_2 \rightarrow 4H^+ + 4e^- \quad (10a)$$

At the cathode, oxygen reacts with electrons taken from the electrode, and H+ ions from the electrolyte, to form water. The ionic equation at the anode is given in equation 10b.

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O(10b)$$

This reaction releases heat.

The final banalce equation if the sum of equations 10(a) and 10(b), given in euqation (10c)

$$2H_2 + O_2 \rightarrow 2H_20 \qquad (10c)$$

It should be noted that the electrolyte must only allow H+ ions to pass through it, and not electrons. Otherwise, the electrons would go through the electrolyte, not a round the external circuit, and all would be lost. The fuel cell of the GREEN platform is indicated in figure 10.

Figure10. Polymer Electrolyte fuel cell generating power of 1 kW and 1kW heat

The pressure and concentration of the reactants affects the Gibbs free energy, and thus the voltage. The Nernst equation, which can be given in many forms is gievn by equation 11, as a function of temperature and partial pressures of different gas.

$$E = E^0 + \frac{R\,T}{2\,F}\ln\left(\frac{P_{H2}^{1}P_{O2}^{1/2}}{P_{H2O}^{1}}\right) \qquad (11)$$

Where E° is the cell EMF at standard pressure et p is te partial pressure of the corresponding gas.In figure 12, we showed temperature effect on the ionic reactions at the electrodes. In figure 12a the red curve is the experimental curve at 30°C and the dark one is ideal curve of the PEFC. In figure 12b, we see that the experimental curve is close to the ideal one at a higher temperature of 70°C.

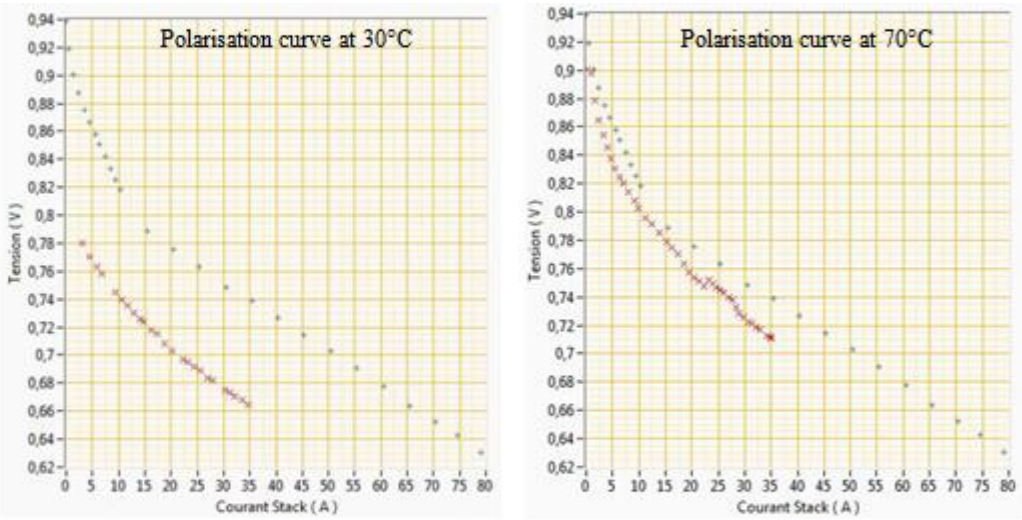


Figure 12. (a) PEFC at 30°C (b) Best working temperature is at 70°C

We then analysed the hydrogen rate given by equation 12.

$$Q_{H2} = \frac{I*60*\ V_{mol}\ *N_{cell}\ *\gamma_{H2}}{2\,F*\%\,H2}(\text{l/min}) \qquad (12)$$

Where V_{mol} is molar gas (22,4 l/mol), N cell is the number of cells, γ_{H2} is the stoechiometric ratio. The PEFC of the GREEN platform has 24 cells and we took γ_{H2} is equal to 2. The hydrogen rate as a function of fuel cell current is given in figure 13a

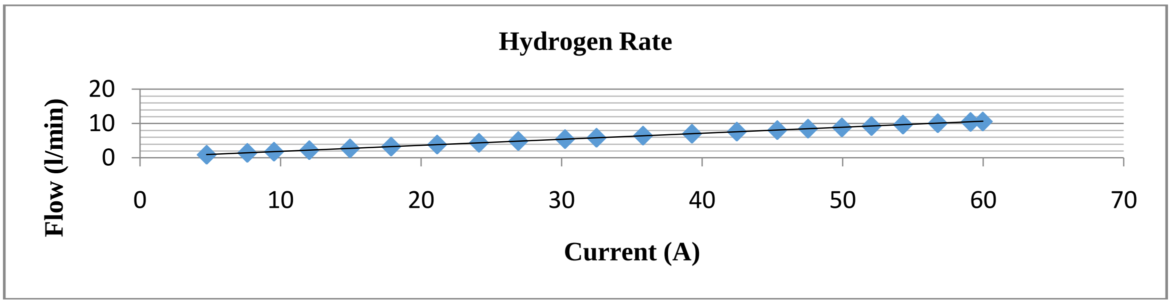


Figure 13a. Hydrogen rate of PEFC against current

We also studied the water rate as a function of current

$$Q_{water} = \frac{I * 60 * M_{wartermol} * N_{cell}}{2F} \text{ (g/min)} \qquad (13)$$

Where $M_{watermol}$ = 18g/mol

The water rate graph is given in figure 13b as function of current.

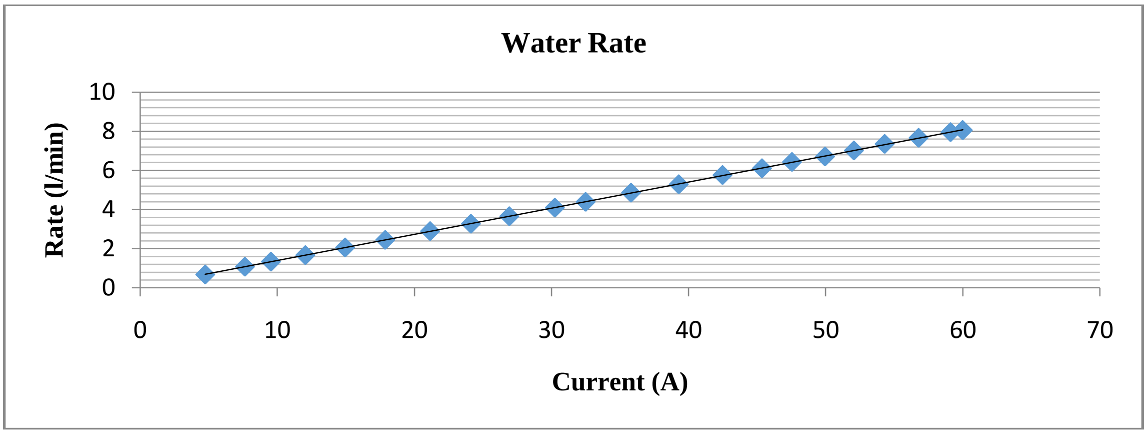


Figure 13b. Water rate of PEFC against current

The efficiency of a working hydrogen fuel cell can be found from the simple equation 14.

$$Efficiency = u_f \left(\frac{V}{1{,}48}\right) * 100\% \qquad (14)$$

where u_f is the fuel utilisation (typically about 0.95) and V is the voltage of a single cell within the fuel cell stack. The stack efficiency graph is given in figure 13 c as a function of current.

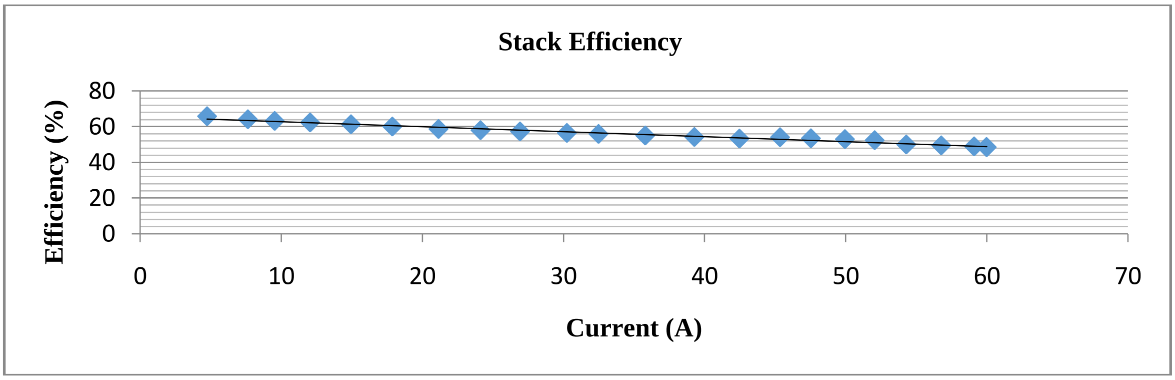


Figure 13c. Stack efficiency of PEFC against current

VII. Conclusion

The GREEN platform is equipped with several renewable energy technologies for modeling, managing and optimization of energy consumption. Only three technologies have been described mainly photovoltaic system, wind turbine and a PEFC fuel cell. The goal was to show that this platform has a strong potential to model energy output of new energy technologiesfor energy on demand.

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