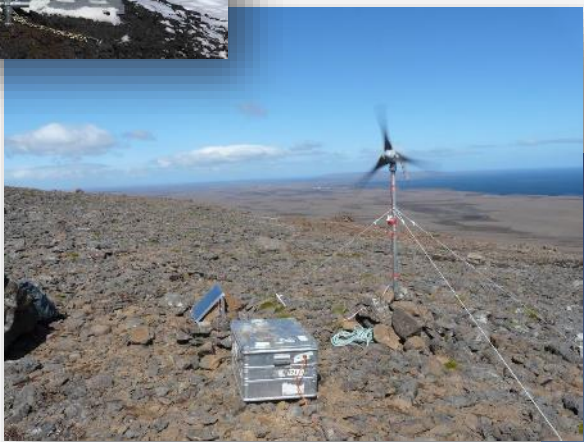
ENVRI+ European Horizon 2020 Project.
WP3.1, Deliverable 3.1: “Report on application of energy-unit in extreme environments”.

Energy for isolated scientific stations

A contribution to a shared knowledge

TOMO station from ANET network in Antarctica.
Credits : POLENET



Kerguelen « Monts de l'Atmosphère ».
Credits : IPGP

AGO Seismology station.
Credits : OPGC

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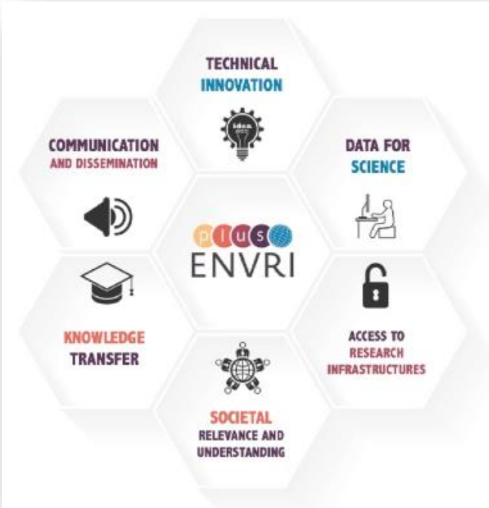
ENVRI+ WP3.1 project, energy for isolated scientific stations.



ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures (RIs), projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures (RIs) across Europe.

Environmental Research Infrastructures provide key tools and instruments for the researchers to address specific challenges within their own scientific fields. However, to tackle the grand challenges facing human society (for example climate change, extreme events, loss of biodiversity, etc.), scientific collaboration across the traditional fields is necessary. The Earth system is highly interlinked and the area of focus for environmental research is therefore our whole planet.

Collaboration within the ENVRIplus will enable the multidisciplinary Earth system science across the traditional scientific fields, which is so important in order to address today's global challenges. The cooperation will avoid the fragmentation and duplication of efforts, making the Research Infrastructures products and solutions easier to use with each other, improving their innovation potential and cost/benefit ratio of the Research Infrastructure operations.
Collaboration is the only way forward to address the Global Changes facing today's society.

The present report figure out how can cooperation will serve every RI on one of their common technical issue:

"Energy for isolated scientific stations".

Figure 1 - Weather station in Antarctica. Credit IGE, Laurent Arnaud.

Aims of this report:

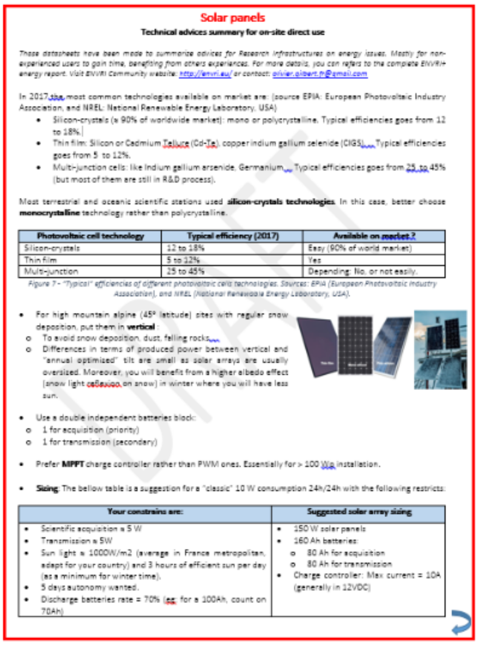
This report intend to provide **guidelines** and **technical advice** on operational solutions to powered remote isolated scientific measurement stations.

- This report aims at helping technical staff to choose most suitable solutions to bring energy to their autonomous sites with appropriate systems, to gain time.
- This report is not an ISO/AFNOR standard reviewing regarding energy efficiency on one or another power system. Evaluations have been made on-site: to ensure practical relevance of the document regarding Research Infrastructures (RIs) needs.

Structure of the document:

This report is composed of five stand-alone chapters:

Chapter A: A common knowledge on energy supplies for isolated stations
This chapter gives a quick overview of minimal useful knowledge on energy systems for isolated sites.
Chapter B: A catalogue of operational isolated stations
Thanks to the ENVRI+ RIs community within oceanography, biology, atmosphere, geology fields, this chapter gives examples of operational stations, their energy and data transmission. Contacts are provided for more required details.
Chapter C: Energy production systems evaluations
Regarding RIs needs and following the ENVRI+ survey, evaluations of the most used power systems are presented.
Chapter D: Energy storage systems evaluations
Regarding RIs needs and following the ENVRI+ survey, evaluations of the most used power storage systems (lead acid batteries) have been made.
Chapter E: Technical summary
Finally, all previous information has been summarized in technical data sheets for the direct on-site use. The data sheets are gathered in chapter E: Technical summary, ready to be printed.



Solar panels
Technical advices summary for on-site direct use

These datasheets have been made to summarize advices for Research Infrastructures on energy issues. Mostly for non-experienced users to gain time, benefiting from others experiences. For more details, you can refers to the complete ENVRI+ energy report. Visit ENVRI Community website: http://envri.eu/ or contact: olivier.gilbert.fr@gmail.com

In 2017 the most common technologies available on market are: (source EPIA: European Photovoltaic Industry Association, and NREL: National Renewable Energy Laboratory, USA)

- Silicon-crystals (≈ 90% of worldwide market): mono or polycrystalline. Typical efficiencies goes from 12 to 18%.
- Thin film: Silicon or Cadmium Tellure (Cd-Te), copper indium gallium selenide (CIGS)… Typical efficiencies goes from 5 to 12%.
- Multi-junction cells: like Indium gallium arsenide, Germanium… Typical efficiencies goes from 25 to 45% (but most of them are still in R&D process).

Most terrestrial and oceanic scientific stations used **silicon-crystals technologies**. In this case, better choose **monocrystalline** technology rather than polycrystalline.

Photovoltaic cell technology	Typical efficiency (2017)	Available on market ?
Silicon-crystals	12 to 18%	Easy (90% of world market)
Thin film	5 to 12%	Yes
Multi-junction	25 to 45%	Depending: No, or not easily.

Figure 7 - "Typical" efficiencies of different photovoltaic cells technologies. Sources: EPIA (European Photovoltaic Industry Association), and NREL (National Renewable Energy Laboratory, USA).

- For high mountain alpine (45° latitude) sites with regular snow deposition, put them in **vertical** :
  - To avoid snow deposition, dust, falling rocks…
  - Differences in terms of produced power between vertical and "annual optimized" tilt are small as solar arrays are usually oversized. Moreover, you will benefit from a higher albedo effect (snow light reflexion on snow) in winter where you will have less sun.
- Use a double independent batteries block:
  - 1 for acquisition (priority)
  - 1 for transmission (secondary)
- Prefer **MPPT** charge controller rather than PWM ones. Essentially for > 100 Wp installation.
- **Sizing**: The bellow table is a suggestion for a "classic" 10 W consumption 24h/24h with the following restricts:

Your constrains are:	Suggested solar array sizing
• Scientific acquisition ≈ 5 W • Transmission ≈ 5W • Sun light ≈ 1000W/m2 (average in France metropolitan, adapt for your country) and 3 hours of efficient sun per day (as a minimum for winter time). • 5 days autonomy wanted. • Discharge batteries rate = 70% (eg: for a 100Ah, count on 70Ah)	• 150 W solar panels • 160 Ah batteries: o 80 Ah for acquisition o 80 Ah for transmission • Charge controller: Max current = 10A (generally in 12VDC)

Figure 2 - Example of the technical datasheets for on-site direct use. Refers to chapter D.

Last but not least: every comment or additional knowledge will be welcome for updates to come.

➔ The more we share, the better we are.

Contact: olivier.gilbert.fr@gmail.com

A. Common knowledge on energy for autonomous sites

I. General information on energy

- **Definition:**

The scientific definition of energy is: "the energy is the physical quantity that characterizes a system state change". In others words: energy is the capacity to change the matter state. To move physical material from a place to another, to vaporize it, to make it move in a living body, to transform matter in heat, or to create light, etc…

- **Context and great challenge.**

Energy is everywhere, we need energy for everything. To build our house, to move our cars (burning an energy tank such as petroleum) to grow food (chemical energy coming from the ground, physical energy of the sun thanks to the photosynthesis), to warm rooms (thermal energy), to run our electrical devices (electrical energy), to make our muscles work (caloric energy).
That is why energy is by now one of the great challenges humanity has to face. Worldwide individual energy consumption has grown significantly in the last century (Figure 3). With the growth of population, the total consumption of energy developed as shown at Figure 4. Moreover, 80% of this energy results from burning fossil fuels made with carbon: Oil, Coal and Gas. Leading to an additional source of atmospheric CO_2, enhancing a global warming.

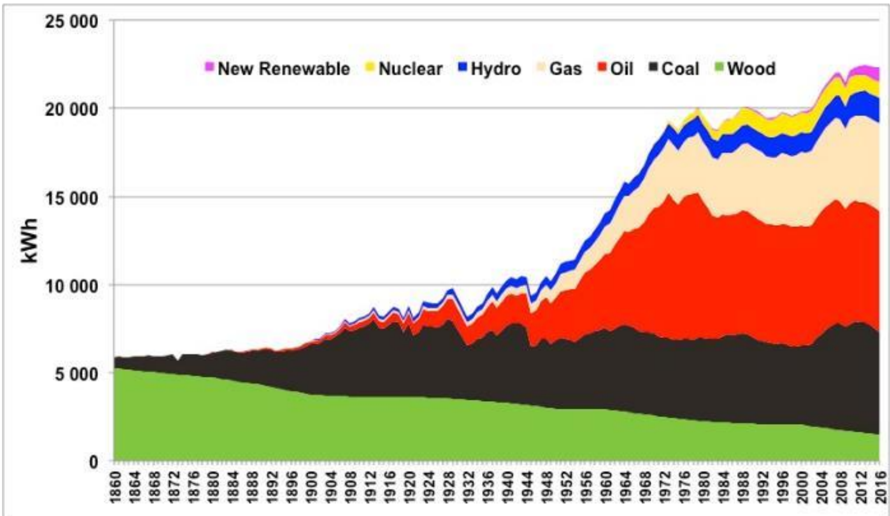


Figure 3 - Worldwide energy consumption average per person. Source: Jean Marc Jancovici, adaptation from Shilling et al. 1977, BP Statistical Review 2016, Smil 2016.

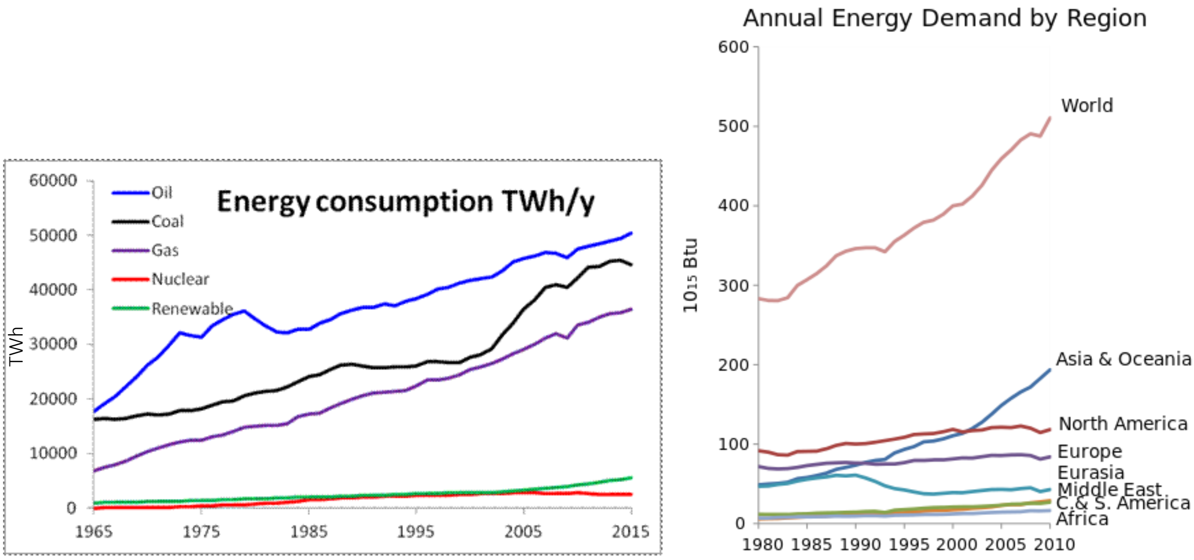


Figure 4 - World energy consumption by sources and region. Credit: BP Statistical Review of World Energy 2014 and International Energy Agency (IEA).

- **Units:**

The international system unit for energy (SI) is Joule: “J”. There also are many other useful units to express the appropriate quantity of energy in special domains, Table 1.

Unit name	Unit symbol	Joule equivalent (J)	Definition	Use example
Joule	J	1	Work done by a force of one Newton when its point of application moves through a distance of one meter in the direction of the force.	Mechanic
Calorie	Cal	4,1855	Heat quantity to increase the temperature of one kg of water per 1°C.	Food, biology
British Thermal Unit	BTU	1 054,50	Heat quantity to increase the temperature of one pound of water per 1°F.	Natural Gas
Kilowatt.Hour	kWh	$3,6.10^{6}$	Hourly consumption of energy by a 1000 W electric device.	Electricity
TNT ton	TNT ton	$4,184.10^{9}$	Energy resulted from the explosion of 1 ton of TNT.	Civil work
Ton Equivalent Petroleum	TEP	$4,186.10^{10}$	Calorific energy of 1 ton of crude petroleum.	Transportation
Electron Volt	eV	$1,602.10^{-19}$	Gain of kinetic energy from an accelerated electron, submitted to a voltage difference of 1 Volt.	Physics

Table 1 - Energy units. Source: ISTerre.

- **Differences between primary and final energy**

We rarely consume a cup of diesel as a breakfast, nor do we inject methane. Engine (or human work) consumes “primary” energy (wood, petroleum, radioactive fuels, wind, sun, water kinetic energy, coal,…) to produce the services we need, such as food, transportation services, heat, electricity, etc. As the final consumers, we use this “final” energy.

The difference between final and primary energy is the “intra-system loss”. At the global average, electrical loss in France from a production system (nuclear power plant) to a final user (as an electrical heat) is about 70% in the whole system[1]. Most of the energy loss happens inside power plants as thermal dissipation and mechanic loss (e.g: loss of mechanic work) and approximately 10% [2] of the total loss comes from energy transportation (Joule effect).

- **ENVRIplus isolated scientific stations and energy:**

Far away from the world energy issues and global consumption, isolated scientific stations are low players in terms of consumption. Typically, that is equivalent to or less than a light bulb, 2 to 100 W.

Still, without energy supply no measurements can be done. This is a critical issue for all scientific measurements and particularly for isolated sites, which are not connected to the national electrical networks.

In this report, as a common and usual language abuse, we will use the term of “energy” to designate “electric energy”, as we will only talk about the electric one (and not about thermal energy or energy of transportation).

[1] Source: BP statistical review and International Energy Agency. Data from 2010

[2] Sources: RTE (French electricity transportation network, ERDF (electricity network distribution France).

II. Energy production

To produce energy in an autonomous way to supply the isolated sites, you can either convert available natural energy flows to electricity, (sun, wind, water flooding), or you can choose to use primary energy stored in tanks, in the form of fuels (gas, alcohol, oïl, etc…) which are made of primary energy chemical compounds.
An important installation constrain is a minimum required maintenance of energy supply systems. If you are using fuels to obtain the energy, you will have to establish refueling logistics which can be complicated if your site is hard to access. In this sense, usage of natural energy flows is more beneficial, however, it can be complicated by their intermittence.

In this "energy production" chapter, we briefly describe the most common available natural energy flows used to produce electrical energy: sun, wind and water (e.g: contrary to thermal energy that often uses geothermal flows). After that we add a small paragraph about an emerging but still new technology (in 2017) represented by fuel-cells. We will focus on the methanol primary energy one. Stored in tanks so with refueling constrains but that can reach a long autonomy, typically from 2 to 6 months, for common ENVRI RIs needs that is 10 Watts consumption. (Describe in chapter B: ENVRI+ survey on energy "Who is using what?").

Note: Only the "common useful knowledge" (main technical specifications) is presented and discussed in this report. For users to have a quick global overview of each technology.

1. The sun: Photovoltaic (PV)

Figure 5 – Example of isolated scientific station powered with photovoltaic solar panels. Source: RESIF-GNSS network. ISTerre laboratory.

a) Operating principle

The device based on photovoltaic effects (solar panels) are using particle-energy proprieties in order to turn a striking photon into an electron, what happens if the radiating light energy is enough to overpass the energy barrier of an electron excitation in the atom. At this moment, an electron is "freed" out of the atomic structure.
If a voltage difference is applied to the conductor matter, an electrical current coming from electron movement will appear, as represented in the Figure 6.- Illustration of the photovoltaic effects. Copyright University of Calgary.

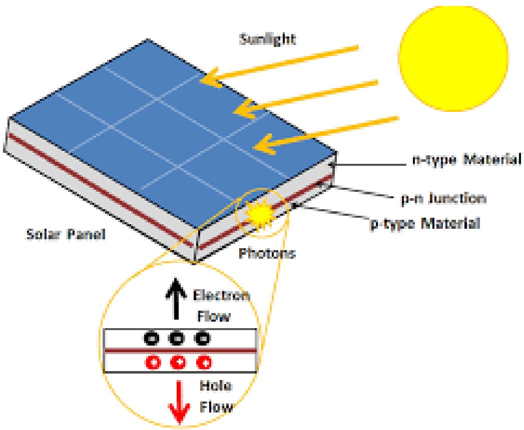


Figure 6 - Illustration of the photovoltaic effects. Copyright University of Calgary.

b) Some technologies

Different technologies can differ in terms of efficiency of electricity production versus light irradiation. (Available sun-light spectrum),
Figure 7 shows the efficiency of some common photovoltaic technologies at 0 to 1200 nm wavelength range.

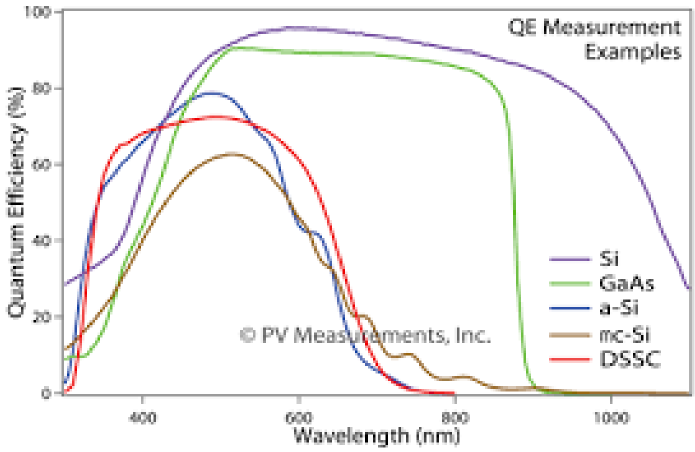


Figure 7 - some common photovoltaic technologies efficiency for a 0 to 1200 nm wavelength range. Source: PV Measurements, Inc. 2014.

Si	Mono crystalline silicon
GaAs	Gallium arsenide junction
a-Si	Amorphous silicon
mc-Si	Multi crystalline silicon (also named Polycrystalline)
DSSC	Dye sensitized solar cells

There are others technologies, like cadmium-telluride (CdTe), Heterojunction with Intrinsic Thin-layer (HIT), etc… "Si", as Silicon technology is currently the most developed, affordable, and used solar cells technology. Widely used as a solar source for scientific stations, we will only discuss this technology in this report.

Photovoltaic silicon technology is developed in three different ways: it can be represented by monocrystalline or polycrystalline solar panels, or as thin film amorphous solar panels (deposited without any crystalline structure). A representation of visible differences is displayed in the Figure 8.

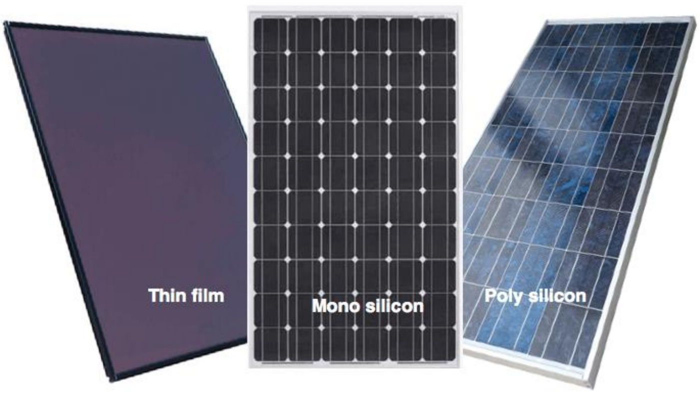


Figure 8 – Representation of visible differences from mono, poly and thin film (amorphous silicon) solar panels. Source: newsouthernenergy.com

Thin film deposition (made like with a paper printer) offers the possibility for flexible solar panels.

There are also others emerging technologies: Multi-junction cells, dye sensitized cells, organic and inorganic cells, quantum dots cells, but they are less abundant and do not take a large part of the worldwide market in 2017 (Figure 9).

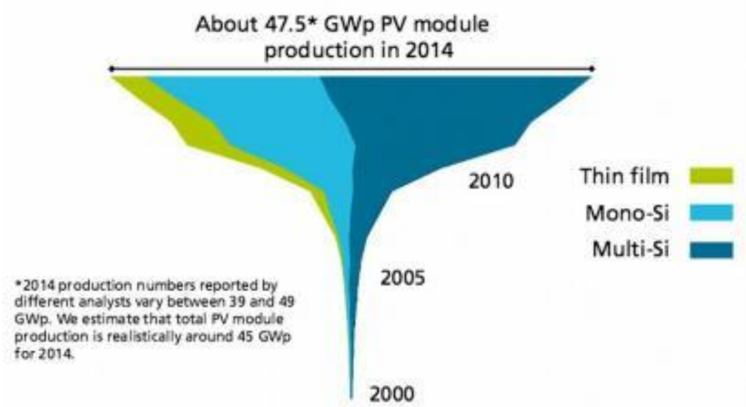


Figure 9 - PV production 2014 per technology. Source: Fraunhofer ISE, Photovoltaics Report. Adapted by www.photovoltaique.info

c) Technical specifications for fieldwork use

For photovoltaic solar panels, the following specifications are important for on-site applications:

- Efficiency
- Energy production
- Influence of orientation (to the south) and tilt (above the horizon)
- Temperature effects
- Installation sizing
- Effects of snow deposition

• Efficiency

The solar energy industry may be (2017) one of the most dynamic in the world in terms of Research and Development (R&D). As a consequence, there are strong differences between market products and the highest efficiencies rates in R&D.
In 2017, the most common technologies available on market (source EPIA: European Photovoltaic Industry Association, and NREL: National Renewable Energy Laboratory, USA) are:

- Silicon-crystals (≈ 90% of worldwide market): mono or polycrystalline. Typical efficiencies goes from 12 to 18%.
- Thin film: Silicon or Cadmium Tellure (Cd-Te), copper indium gallium selenide (CIGS). Typical efficiencies goes from 5 to 12%.
- Multi-junction cells: like Indium gallium arsenide, Germanium. Typical efficiencies goes from 25 to 45%.(but most of them are still in R&D process).

Most terrestrial and oceanic scientific stations use **silicon-crystal technologies**. Monocrystalline technology has certain advantages upon polycrystalline version.

Photovoltaic cell technology	Typical efficiency of commercial[3] solutions (2017)	Market availability
Silicon-crystals	12 to 18%	Easy (90% of world market)
Thin film	5 to 12%	Yes
Multi-junction	25 to 45%	Depending: No, or not easily.

Table 2 - "Typical" efficiencies of different photovoltaic cells technologies. Sources: EPIA (European Photovoltaic Industry Association), and NREL (National Renewable Energy Laboratory, USA).

Figure 10, produced by the NREL (National Renewable Energy Laboratory, USA) displays the evolution of efficiency of several existing solar photovoltaic technologies through the last decades. This information can be used as a reference to help technical staff to choose solar panels for very shadowed sites, if only few hours of sun are available. As can be seen, efficiency of discussed technological solutions matters, but many of these solutions are not yet standard commercial products.

[3] Data for R&D cells are of course upper. Refers to next page with the NREL graphic.

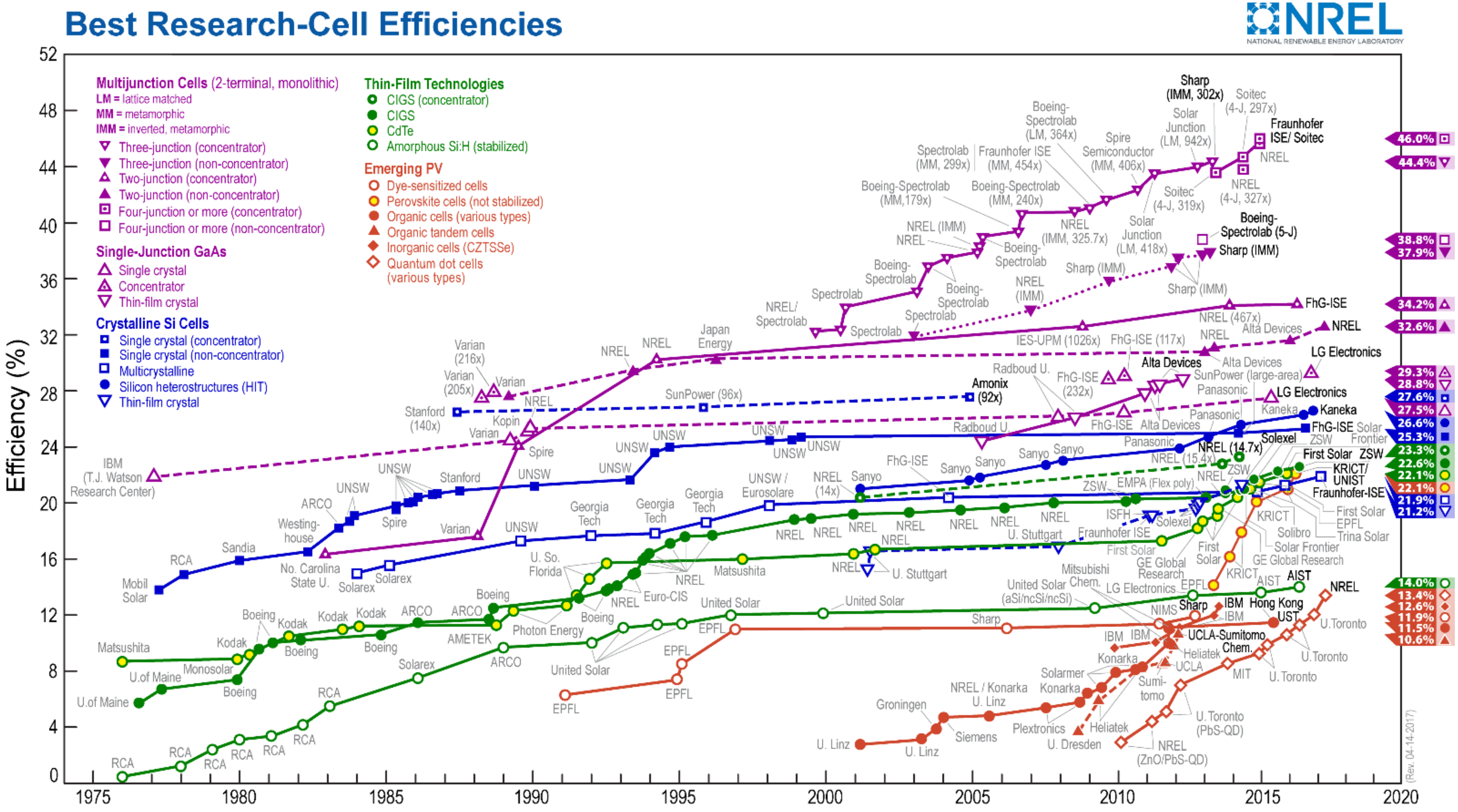


Figure 10 - Best research cells efficiencies. Source NREL. https://www.nrel.gov/pv/

- ## Energy production:

Produced current I(A) from solar panels will of course be highly influenced by incoming solar energy (irradiance), as can be seen in the Figure 11. Voltage will also be influenced but not at the same extent as produced current. The Maximum Power Point (named MPP) represents the optimum ratio between voltage and current as follows the Power P in Watts (W) is to equal to their product:

$$P(W) = U(V).I(A)$$

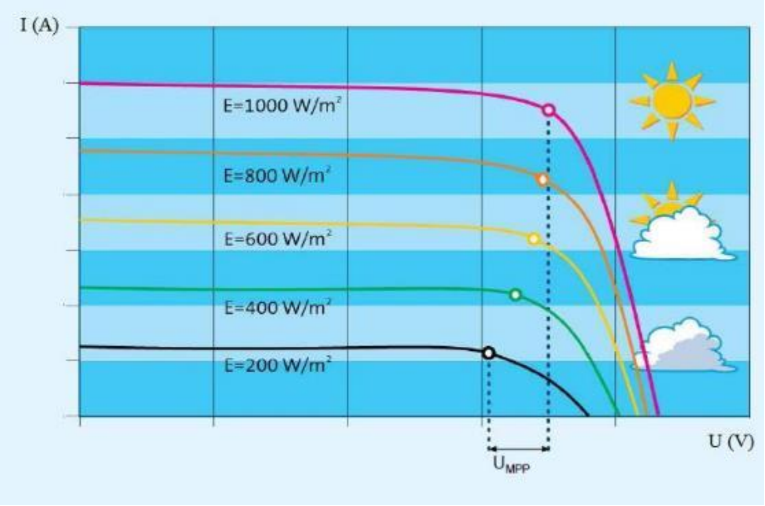


Figure 11 - Influence of light on solar panels voltage and current. Place of the MPP - Credits: http://www.photovoltaique.guidenr.fr/III_2_effet-eclairement-module-photovoltaique.php

The total produced power will be influenced by:

- Orientation to the south.
- Tilt (angle) above the horizon.
- Internal temperature: efficiency decreases with increasing temperatures.
- Dirt (dust or snow)
- Quality of the manufacturing

- ## Influence of orientation (to the south) and tilt (above the horizon)

Orientation to the south and tilt angle (above the horizon) have a great influence on production, as shown on the Figure 12. The blue circle represents the optimum (maximum = 100% production) for a 45° latitude site for the annual production. In this case that mean that a tilt of ≈ 30° (23 to 37) will be the annual optimum. In winter time, it is better to increase tilt (closer to 90° = vertical), as the sun is lower.

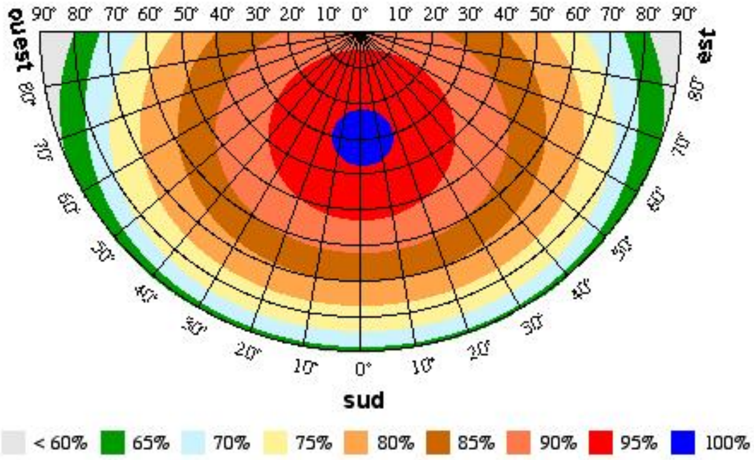


Figure 12 - Effects of south and tilt deviation (above the horizontal) on solar panel efficiency. Source: dualsun.fr

- ## Tracking technology

Solar panels can also be mounted on a tracker that provides a great possibility to track the sun location and follow it all day long.

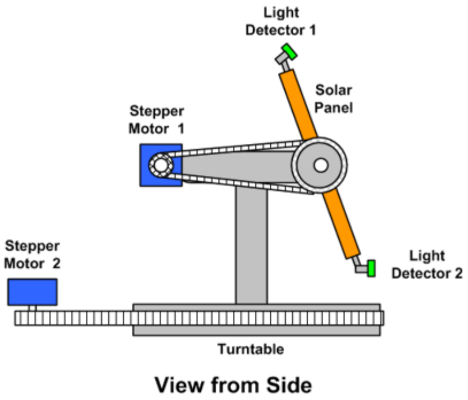


Figure 13 - Illustration of solar tracker systems.

Figure 14 - Illustration of solar tracker systems.

Theoretically, such solar panels (with trackers) will produce more energy as photovoltaic surfaces will always be perpendicular to the coming solar radiation, as displayed on the graph Figure 15.

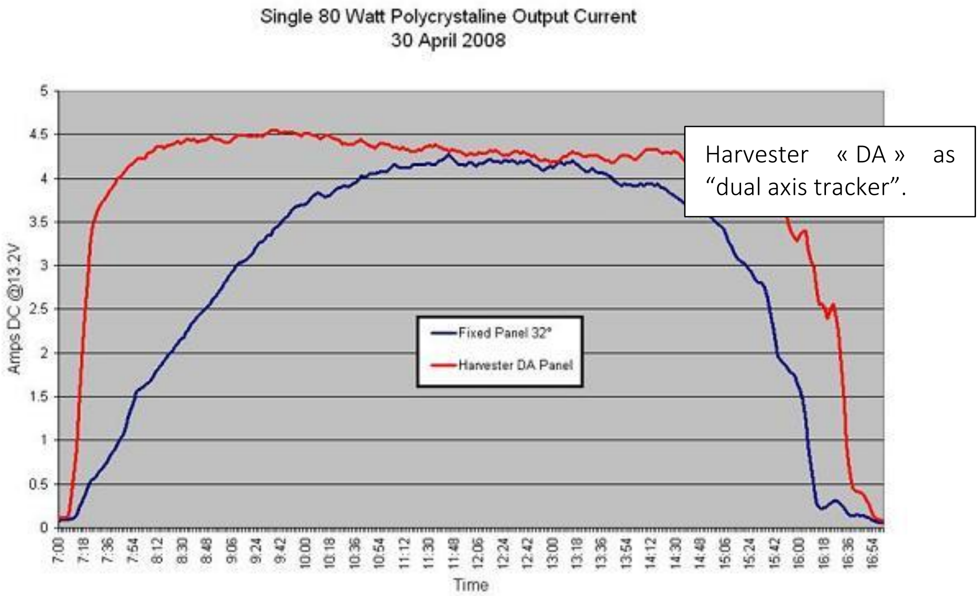


Figure 15 - Comparative production of solar tracking system and fixed solar panels in Australia. Source: www.solarchoice.net

On the other hand, trackers will also consume a part of the energy produced by solar panels to move-on. For important solar arrays, as “solar farm”, the whole gain in terms of produced power can be interesting. One shall take in account that the more technically sophisticated installations, will be a sources of additional technical failures .

Thus, such installations can be inconvenient for RIs intended use because of:

- Weaknesses to face strong winds.
- General weaknesses of construction due to the large amount of details.

Moreover, for most of the ENVRI RIs on-site cases, fixed solar arrays are so oversized to prevent from cloudy days and allowed autonomy that they do not need for more yield optimization.
Not a single example of tracker use had been collected through the ENVRI community. As this technology do not fits RIs uses, it will not be develop in this report.

- ## Temperature effects

A solar cell works better in cold than in high temperatures. Indeed, power production will drop when temperature increase, as can be seen in the following Figure 16. The temperature will influence the voltage more than the current.

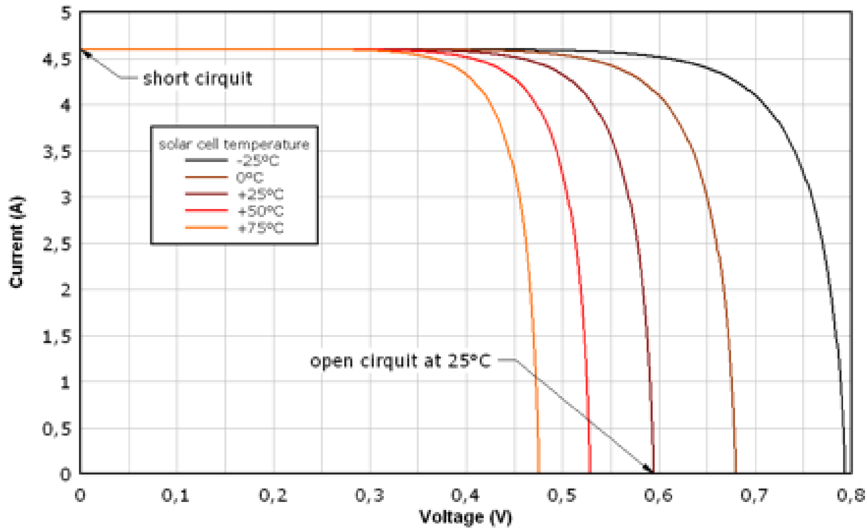


Figure 16 - Solar cell characteristics temperature dependency. Source: pvresources.com

- ## Solar photovoltaic array sizing

An appropriate sizing of the solar installation is important for the following primary reasons:

- Size will depend on your site's solar average potential.
- Logistics constrains such as weight and space would be crucial.
- To adapt batteries capacity with an appropriate charge current (refers to paragraph A.III for more details on batteries) and wanted autonomy, if no sun.

In order to help users going for an appropriate sizing, the two following inputs will be develop:
1. How to estimate your site solar potential.
2. How to estimate energy storage (batteries) regarding worst period without sun.

1. Solar potential estimation:

One of the most used tool is the European JRC (Join Research Center) webpage called "PVGIS"as PhotoVoltaic Geographical Information System. It helps to evaluate the solar potential for a special site (latitude/longitude).
Link: http://re.jrc.ec.europa.eu/pvgis/
It will give you an estimation of average irradiance for a special latitude and longitude coordinates. This model will not be able to take into account potential shadows coming from natural relief (mountains), trees, or buildings.
Available hours of sun on site will so have to be independently estimated on-site. Especially for the annual worst period: winter time or solstice: 21th of December for the northern hemisphere, 21th of June in the southern.

Another useful tool we can mention comes from the French National Institute on Solar Energy (INES).
The INES educational set-up a website to estimate power potential on a site (latitude/longitude).
Link: http://ines.solaire.free.fr/index.php.
This model can also estimate the albedo effect on the monthly production regarding your solar array tilt. As an illustration of the importance of the ground reflection for a snowy mountain site: With a 36° tilt above the horizon production is lower in winter time, were albedo is high and sun is low, than with a 70° tilt (refers to chapter C.III.1 Evaluation results, photovoltaic for more details).

2. **Solar array (and battery) sizing:**

Created in the Institute of Earth Sciences in Grenoble (ISTerre) for their own application, M. Mickaël LANGLAIS aggregated a step by step methodology that easily determine:

- Needs in production (W): PV installation sizing.
- Needs in storage (Ah): Batteries sizing.

Using the following inputs:

- Total installation energy consumption (W).
- Wanted autonomy (Days).
- Worst available irradiation (daily hours of efficient irradiance average).

Advice on solar array sizing: if possible, **oversize** your power system (solar panels and batteries).

d) Effect of snow deposition:

As PV cells are connected in series in a solar panel, it is important to anticipate possible snow deposition and to think about the way you will install your solar panel, with electrical connections lines parallel or perpendicular to the potential snow accumulation. Effects on production are major, as represented on Figure 17 . If a single cell is shadowed, all the others, even if they are perfectly lighted, will have the same passing low current as the shadowed one (like a pinch on a garden hose).

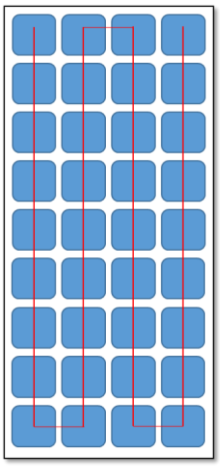
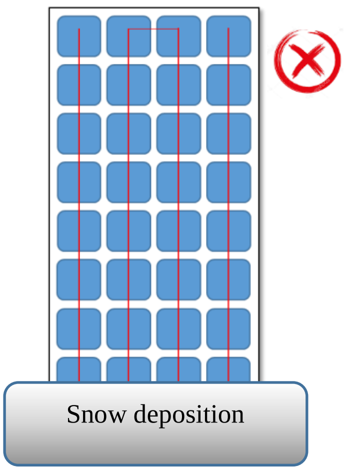
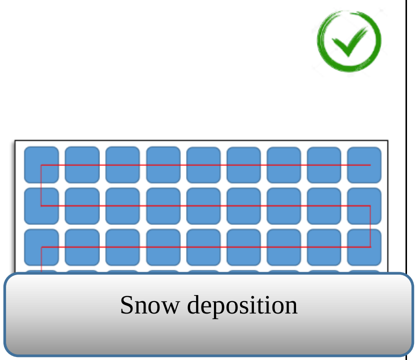
Single solar panel	Not efficient disposition	More efficient disposition
		
Electrical connections in red	All the circuit is cut	Only ¼ circuit is cut

Figure 17 - Effects of snow deposition regarding photovoltaic cells electrical connections. Source: ISTerre

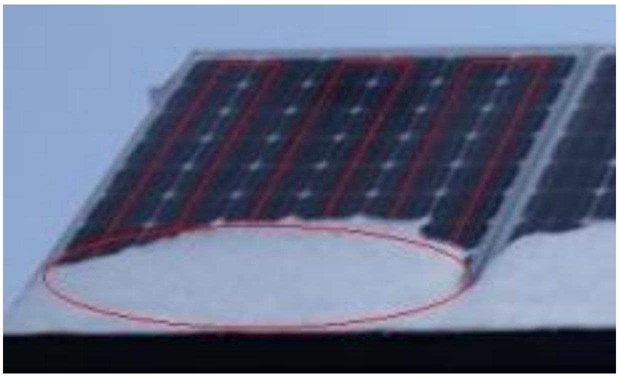


Figure 18 - effects of snow deposition on electrical cells connection. Source: Norusk.com.

By-pass diodes are often inserted in the cells sub-circuit to shunt a potential shadowed part of the solar panel.

e) Advantages & disadvantages of photovoltaic solar panels[4].

Advantages	Disadvantages
Mechanically strong	Intermittence, only with sun !
$1m^2 \approx 100$ Wp	$1m^2 \approx 100$ Wp
Very low needed maintenance	great surfaces = sails to winds
Works better un cold than warm environments	Works better un cold than warm environments
Easy to use	

Table 3 - Advantages & disadvantages of photovoltaic solar panels

[4] Non-exhaustive list.

2. The wind: Wind turbines

a) Operating principle

Wind turbines (WT) use electro-mechanic engines to transform mechanical energy (rotating axis) into an electric energy, through the use of rotor and stator: rotating magnet versus a fixed one coupled to a conductor coil.
It produces alternative current (AC) that is needed, for most of our applications, to be redressed as a direct current (DC). This is made by a rectifier and regulator that is usually inside the WT. Most of modern and efficient small WT use neodymium magnet, while blades are made with a mix of plastics (for flexibility) and carbon fibers (for rigidity and lightness).

Extracting power (P) from a wind turbine is proportional to the cube of the wind speed, as:

$$P = \frac{1}{2} C.\rho.A.(W_s)^3$$

With :

- C: power coefficient
- ρ: Air density
- A: Rotor swept area
- W_s: Wind speed

This equation highlight the critical aspects of the place and the height of the WT emplacement. Which is for most scientific sites not a primary parameter for site selection.

b) Some technologies

“Classic” wind turbines uses horizontal axis. For small wind turbines (e.g 10 to 1000W production) vertical axis already exist (Figure 19).

Horizontal axis	Vertical axis
	

Figure 19 - Examples of small horizontal and vertical axis wind turbines.

Three WT have been evaluated on-site during this project:

- 2 vertical axis: “VAWT A” for Vertical Axis Wind Turbine, and “VAWT B”.
- 1 horizontal axis: HAWT for Horizontal Axis Wind Turbine.

Only important facts to keep in mind for on-site uses will be summarize here.

It also exist vertical twisted WT (Figure 20), that are supposed to be more efficient than non-twisted WT facing turbulent winds. We did not try some during this project.

Figure 20 - Example of a twisted vertical axis wind turbine.

c) Technical specifications

“Nominal” power with laminar winds in laboratory’s tunnel test, versus on-site turbulent winds.

Reality is far different from laboratory wind tunnels evaluations. Technically, “theoretical “ power characteristics are usually different from the on-site produced power, especially for vertical axis. As in laboratory wind tunnels wind are laminar, they come perpendicularly to the WT, with an equal speed in the stream and a constant flux through its height.

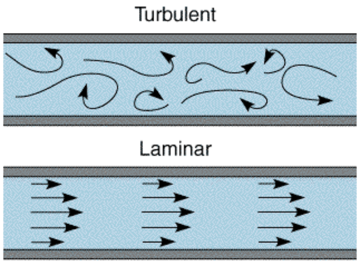


Figure 21 - Representation of laminar and turbulent winds. Source: University of Liverpool

On site, particularly in mountain regions, winds are usually turbulent, not laminar. This mean that the wind is sometimes coming with an important tilt to the WT. This factor is more crucial for vertical axis than for horizontal ones.
Vertical axis on-site electricity production can dramatically drop compare to the attended power. Those wind turbines are deemed to be more useful on ships, where they inevitably face laminar winds.
For horizontal axis WTs, a turbulent wind is still well absorbed and used thanks to long and sometimes twisted blades.

Mounting:
Fixation of the wind turbines is crucial on an isolated site, particularly in polar regions and high mountains, as winds can be violent and maintenance infrequent.
Horizontal axis are obviously “pole mounted”: on the top of a mast.
Vertical axis can also be “side mounted”, like a staple, grabbed both on the top and the bottom of it. This position necessarily induces a loss of power as the wind is blocked on a side (by a wall, a rock, the side of a mast), but it also greatly strengthens it as it avoid from vibrations, and as it will still not change production so much during strong winds events.

- ⇨ Be careful that you check horizontal and vertical axis, for all mechanic parts to works in their appropriate way. This is important.

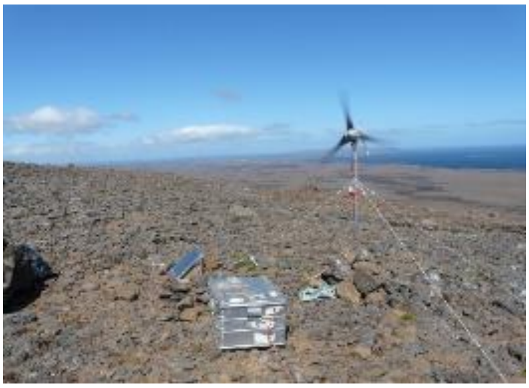
Example of side mounting vertical axis wind turbines (GPS in Antarctica)	Example of polar mounting horizontal axis wind turbine (atmosphere on Kerguelen Island)
	

Table 4. - Examples of used wind turbines . Sources: POLENET/UNAVCO and IPGP

a) Advantages & disadvantages of small wind-turbines[5].

Advantages	Disadvantages
Can provide energy where sun is not present.	Mechanically weak especially facing cold temperatures, salty atmosphere and very strong turbulent winds.
In windy area: regular source of energy	Better choice for coastal regions with regular laminar winds.
Can be an additional source to solar panels.	Need regular maintenance (typically a month) to check every screw and global positioning (possible changes due to vibrations).
Easy to use.	Horizontal and vertical axis must be strictly installed with a spirit level, to avoid premature wear.

Table 5 - Advantages & disadvantages of small wind-turbines

[5] Non-exhaustive list.

3. The water: hydro-turbines

Very few examples of scientific stations use hydroelectricity within the ENVRI+ RIs. However, some micro hydro turbines could be used in special conditions. The Figure 22 displays a global overview of such existing systems.

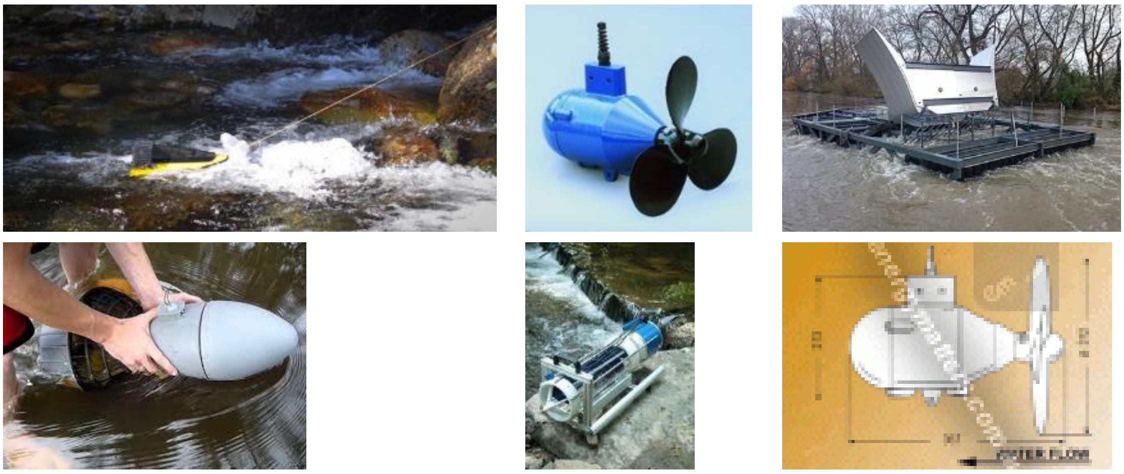


Figure 22 - Examples of several micro hydro turbines.

As an example, the French Guyana CNRS/ANAEE "Nouragues" (station for tropical ecology research) use a 10 kW hydroelectric "pelton" turbine, similar to the one bellow (Figure 23).
Website for more information: http://www.nouragues.cnrs.fr/spip.php?rubrique4

Figure 23 - Example of a 10 kW hydro turbine at CNRS ANAEE Nouragues station.

Others, as small as 100 W hydro turbines (Figure 24) can constantly power small devices, as long as flowing water is available.

Figure 24 - Example of a micro ≈ 100 W hydro turbine. Source:

4. The chemistry: fuel cells

a) Operating principle

Fuel cells produce electricity without combustion but with electrolysis: gathering molecule separation energy. Several technologies are existing, among them two are enough advanced to be commercialized:

- Hydrogen: H_2
- Methanol: CH_3OH

Figure 25 - Example of a methanol fuel-cell. Source: EFOY

Fuel cells technology is still a relatively new technology (at report date, 2017) which shows a great dynamics in research and development. Indeed, fuel cells gathered few interesting advantages for the needs of scientific research sites.

b) Technical specifications

Here is an example of technical specifications of a methanol fuel cell.

Input	
Power IN	12.5 – 15 V DC / 4 A / max. 60 W (mains adapter, 12 V – car charging cable, solar panel)
Fuel Cell IN	11.0 – 13.8 V DC / max. 10 A
Output	
240 V OUT	240 V AC / 400 W (max. 600 W) / 50 Hz Pure sinus voltage
12 V OUT	12 V DC / 10 A
USB OUT	2x 5 V DC / 2.1 A
Temperature range and General information	
Operating temperature: Charging	0 °C to +40 °C
Operating temperature: Discharching	-10 °C to +40 °C
Recommended storage temperature	+10 °C to +30 °C Do not store at temperatures below +1 °C
Inclination	Continuous: 35 ° Temporary: 45 °
Storage time	Charge every 6 months
Weight	5.8 kg
Dimensions (L x W x H)	28.6 x 18.6 x 20.1 cm
Certifications	CE, UN 38.3, ECE-R10

Table 6 - example of technical specifications of a methanol fuel cell. Source: EFOY.

c) Examples of applications

Previous evaluations (on-site use) had been done by technical staff from laboratories, on a methanol fuel cells. Some feed backs are:

- Water vapor emitted:

That made the set ups to switch to the safe mode when temperature dropped under 0°C. That is inappropriate for mountain outdoor scientific stations.

In these cases an insulated and warmed adaptation should be evaluated being currently available on the market.

- Emission of CO_2 :

Such conditions do not fit for GHG measurements and they have to be placed in ventilated place for personnel safety.

Caution: Methanol can be a hazardous liquid/gas for logistic operations. Toxicity is relatively high, precautions have to be taken.

Autonomy:

One major positive fact for the methanol fuel cell system is its autonomy: 2 months with a 10L tank, for a ≈ 8 W (≈700 mA consumption at 12 VDC).

Methanol tank does exist in 5, 10, 28 and 60 Liters capacity. That can theoretically allow up to ≈ 6 months autonomy.

Figure 26 - Example of a methanol fuel cell.

The manufacturer now sell adapted warm and insulated boxes, with large enough fuel tank to supply both warming and battery/direct consumption. We did not evaluate yet those solutions (2017). such models are supposed to run down to -40°C.

Hybrid systems:

This fuel-cell can contain lead-acid or Lithium $FePO_4$ batteries, and can be linked with solar panels.

Charge controllers can be located inside. A wind turbine can also be attached.

d) Advantages & disadvantages of methanol fuel-cells[6].

Advantages	Disadvantages
Constant: Provide current all day long, 24/24. No intermittence as from the wind or the sun.	Rejects gases: H_2O and CO_2 Impossible to be use for some atmospheric measurement. Ice can appears under 0°C. Must be placed in a ventilated site.
Relative long autonomy for small electrical consumption needs (W). Typically 1 L of Methanol for 1 000 Wh produced = 100 hours for a 10W consumption.	Fuel can be hazardous for transportation: ➔ H_2 ➔ Methanol: CH_3OH Precautions for its manipulation.
Where there are no others energy sources. Light and compact system.	Much more expensive than solar panels
	Limited running hours because of internal membranes state of health.

Table 7 - Advantages & disadvantages of methanol fuel-cells.

[6] Non-exhaustive list

III. Energy storage

Electricity has to be stored for unproductive periods: night, no wind, no fuel... Batteries are the most used technology to directly store produced electricity, compared to others physical secondary storages like water tank - using the gravity potential energy power - , chemical compounds like H_2, pressurized air, etc. This is the only storage technology that will be discussed here.

There are two major families of batteries:

- **Non rechargeable** batteries: known as "primary" batteries.
- **Rechargeable** batteries, known as "secondary" batteries.

We will mainly describe the most used by scientific research laboratories: the "secondary" rechargeable ones: [7]

1. Lead-acid batteries
2. Lithium-ion batteries.

Few words will be finally added regarding the primary non rechargeable batteries.

Note: Only the "common useful knowledge" (main technical specifications) is presented and discussed in this report. For users to have a quick global overview of each technology.

1. Lead-acid batteries

a) Operating principle

A lead-acid battery is composed of lead (negative pole) and lead-oxide plates (positive pole) joined together by an electrolyte prepared from a mix of sulfuric-acid and water (Figure 27). This set up represents a single battery cell. Its nominal voltage is about 2,1 to 2,2 Volts. A "12 V" battery is made with six cells in series that produce a nominal voltage of **12,6 to 13,2 volts**.
If a cell voltage drop under 2 V, the battery has to be recharged. Thus for 12V batteries, if voltage drop under 12V it has to be recharged.

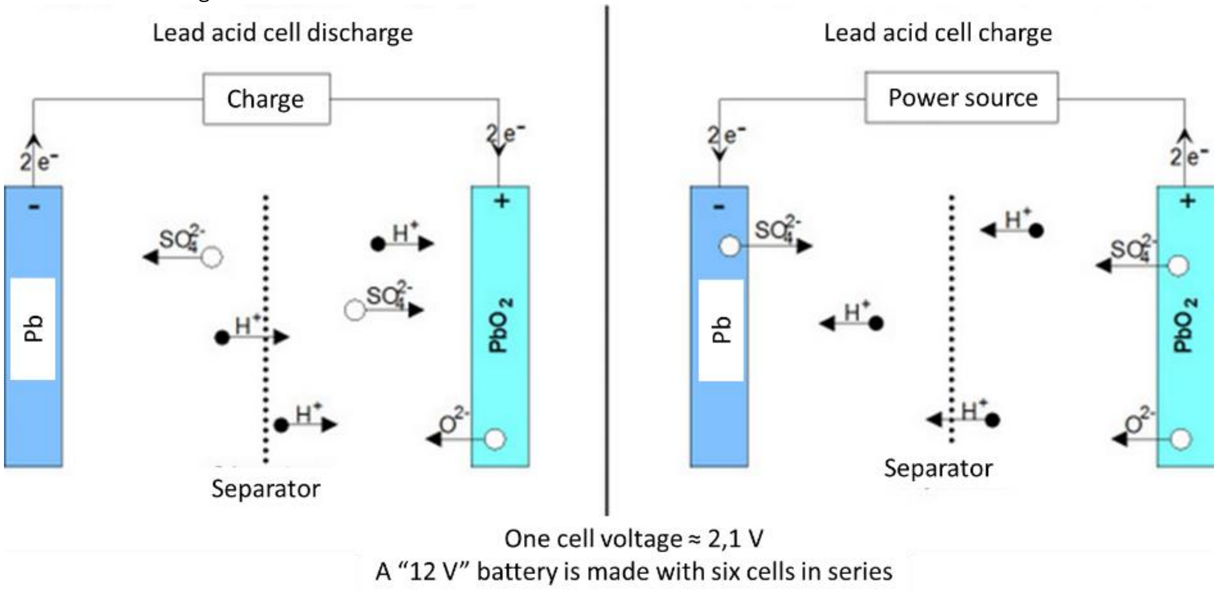


Figure 27 - Lead acid battery operating principle. Source: Batterie-solaire.com

[7] Note that oceanic studies use mainly primary lithium non rechargeable batteries. Contact IFREMER at http://wwz.ifremer.fr/ for more information.

There actually exist three major technologies for lead-acid batteries:

1. Open liquid: sulfuric acid + water
2. Sealed with AGM (Absorbent Glass Mat)
3. Sealed with Gel inside

The sealed batteries are called VRLA as “Valve-Regulated Lead-Acid”. They are the most used batteries by scientific research infrastructures. We will discuss them in the following paragraphs.

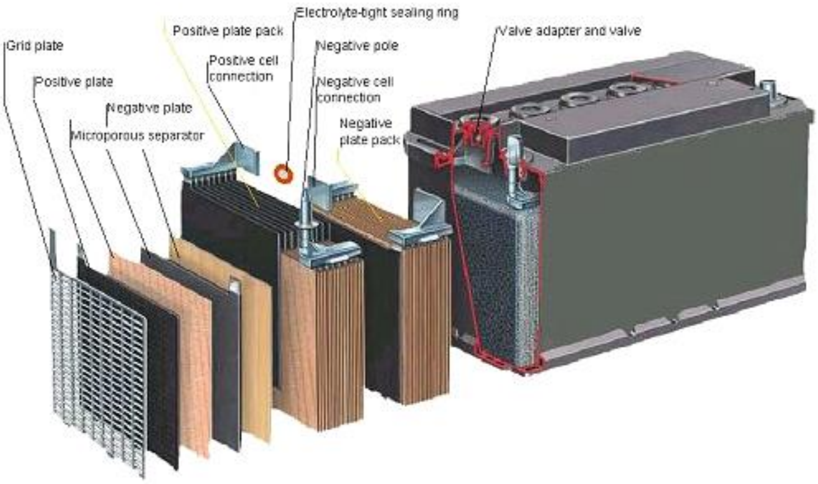


Figure 28 - Schematic of a typical lead-acid VRLA battery. Source: http://barden-uk.com/info/

The open liquid batteries were used in cars for a while, but nowadays they are replaced by VRLA ones. Major photovoltaic solar arrays still use tall open liquid batteries for two reasons: 1: they can provide higher current, and 2: they will not be removed from the energy storage building.

b) Valve Regulated Lead-Acid (VRLA) batteries.

The sealed batteries are called VRLA as “Valve-Regulated Lead-Acid” batteries as their closed box is secured with pressure valves. They can run in an inclined position, and do not need a regular maintenance, in contrast to the open ones that regularly need to be refueled with water that slowly evaporates within charges and discharges cycles.

Gel or AGM are two different technologies made to store the acid and water mixed electrolyte. Their characteristics will differ, depending on how they were built and with which purpose: high current for cars, high cycles available, etc.

For most global scientific requirements (isolated, solar panel charge, low current consumption), it is important to notify your seller about the intended, “typical” use:

- Low currents consumption: Approximately 1 Ampere.
- Charge with photovoltaic solar panels, so needs a high number of available cycles (sometimes called “cycling batteries”).

As an example, for the YUASA batteries, cycling batteries are the REC and NRC product range, they are AGM VRLA batteries. Gel was reputed at the beginning of its technology (that is newer to AGM) to better runs in cold conditions. It looks that new AGM manufacturing, improving quality of the glass material, made this difference lower. Once again, **it is important to clearly explain your need to batteries sellers: low current and solar charge**.

Another technology, less known and much more expensive (e.g: 330 € for a 50 Ah battery, in contrast to an approximate 150€ for typical VRLA AGM or GEL) is the thin plate pure lead: TPPL.
This technology is expected to have longer life and to run in lower temperatures. A case study of an Antarctic station for seismology measurement is displayed in chapter B II “catalogue of operational isolated stations” (a station set-up by the French Institute of Earth Globe Physics in Strasbourg). This technology will not be discussed in this report, but should be investigated for the polar installations.

c) Technical specifications

- #### Capacity

The capacity represents the amount of electricity the battery is able to store. It is expressed in Amper.hour: Ah. As an example, a 50 Ah battery is supposed to be able to supply 5 A during 10 hours, 2 A during 25 hours, 10 A during 5 hours.

A lead-acid battery is able to send more current with a lower amperage than with a higher one. E.g: delivering 100 mA current will increase the nominal battery capacity rather than using a 10 A current, where the battery capacity will seriously drop. This is why nominal battery capacity is usually expressed as the optimum current for a 20 hours discharge, that is noticed as "**C20**".

C20 = X Ah = battery capacity if you constantly consume a X/20 Ampere current.
As an example:
C20 = 50 Ah: With a 50/20 = 2,5 A current, continuously pull out from the battery during 20 hours.
We can also found C10 or C100 written on batteries. C100 = current for a 100 hours use. C10 = current for a 10 hours use. If C20 = 50Ah, C10 will be < 50 Ah, as C100 will be higher.

- #### Charge

A battery capacity will depends with the way you charge it. Indeed, it is more efficient to use a charge current from **10% to 25% of nominal capacity (at C20)** than lower one. (Upper one will damage it with too high temperatures). As an example, if C20 = 50 Ah: use a 5 to 12,5 A charging current.

Furthermore, it is better to charge your battery with a "multiple steps" charge process. Usually found with 3 steps, you can also use chargers using 7 or 8 steps. Each step will make the voltage and the current change regarding the battery state of charge. If the battery is very low, high current will be used with an upper voltage. This step is called the "**bulk**" step. When the battery reach its nominal charge, current will be dropped at the "**floating**" step level. Between both, it is the "absorption" step, as represented on the Figure 29.

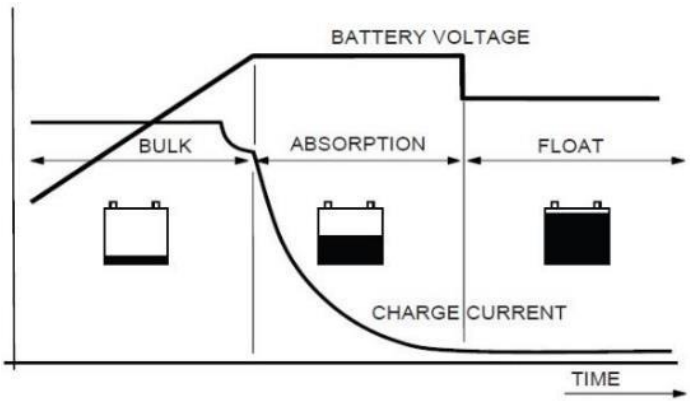


Figure 29 - Ideal 3 steps battery charge. Source: Batterie-solaire.com

Battery "internal" chargers made to be used in offices, normally offers this multi-steps technology. This is not always the case with cheap solar chargers, used in isolated stations.

Too high charge voltages and currents will result in hydrogen formation. Valve regulated (VRLA) system will drop gas off down to threshold pressure. Such scenario has to be prevented and avoided. In addition, charging room shall be correctly ventilated.

- #### Discharge.

Usually an explanation from the manufacturers can be seen: Do not drop under 1,8V per cell. That means that 12V

battery shall not be **discharged under 10,8 V**. Under this threshold, water is more present in the electrolyte (sulfuric acid + water mix). It will enhance formation of sulfur crystals that will make the potential (voltage) and so electricity storage capacity decrease.

It is recommended not to use the battery more than **50% of its nominal capacity**. That means that for an 80 Ah battery, scheduled sizing as if it was a 40 Ah one. The less you will discharge it for each cycle (a cycle = one charge + one discharge), the longer your battery will last.

Mentioned advices refer to an optimal use of battery, and making them last longer. For very remote sites, were you really need each available Ah, it make sense to use more of the total capacity battery even if you have to change it every three years instead of six.

<u>Internal self-discharge:</u>
When batteries are not used and stored, they also undergo an internal self-discharge occurring through the time. Globally, it is **better to store them in a fresh (and ventilated) room** to slow down this process. On the Figure 30, the lead-acid battery lost 0.07 V per cell in 6 months at +40°C (that means ≈ 0.5 V for a classical 12 V battery made with 6 cells in series), while it lost the same voltage in 48 months at +10°C. This tendency has been also confirmed by another battery manufacturer (YUASA).

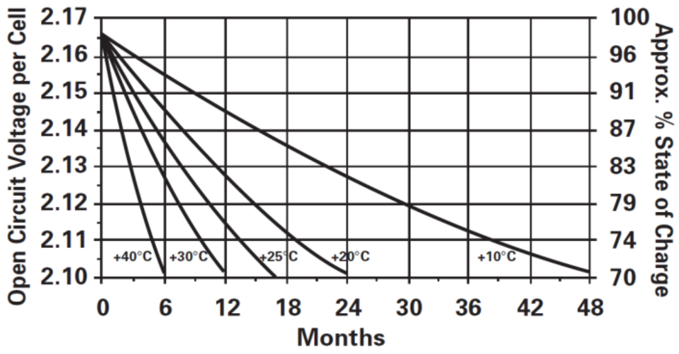


Figure 30 - Example of self-discharge rate for a range of temperature. Source: EnerSys-emea.com

- Others additional information :

Storage when batteries are not used:
Batteries need to be recharged when voltage U < 12 V, or every 6 months.
A discharge battery contains more water in its electrolyte. This will promote sulfate crystals growth that will create an irreversible deposition on lead plates, and so drop down battery capacity dramatically.

Capacity and temperature:
The effective capacity of a battery varies in reverse proportion to temperature:

Temperature (°C)	Capacity (%)
-10	80
10	92
15	95
20	100
25	103
30	105

Table 8 - Example of a battery capacity for different temperatures. Source: Victron "Energy Unlimited".

Capacities under -10°C are less known and cannot easily be found in literature, but these are usual cases for scientific measurements performed by the Grenoble laboratories community, working in high mountains and/or polar regions. This is why tests have been made using a climate chamber, where temperatures can be drop down to -50°C. Those results are presented in chapter D “In laboratory climate chamber, energy storage (batteries) evaluation.”

- ### A quick test for batteries state of health.

As previously mentioned, sulfate crystals will appear with water in the electrolyte during too deep and too long discharges, seriously damaging the nominal battery capacity. Checking voltage when the battery is running will tell you about its state of charge, but not about its internal SoH.

If you fully charge an empty battery, then few second after you will have disconnect the charger, a voltmeter will surely display you an approximatively 13V voltage. That could say that the battery is in a good health. But you will have to wait at least two hours after the end of charge (let's wait for four if possible) to check its "true" voltage. This will be in correlation with the internal battery SoH (refers to chapter D for more details).

As a several-times-tested and validated protocol during this project, here is a quick empirical battery test coming from YUASA manufacturer and that can be used as a good approximation for internal battery SoH.
Note that an impedance-meter will offer you a more precise diagnostic thanks to the impedance Z(Ω) measurement, but those devices are quite expensive for "just batteries users", and similar results can be achieved , using just an affordable regular voltmeter.

<u>Protocol:</u> (Ideally, everything is done at temperature of 20°C)

1. **Fully charged the battery**
2. **Wait for 4 hours after disconnecting the charger.**
3. **Measure voltage U(V), refers to the bellow table.**
   Option : If you can : also check the impedance (Z in Ω)
4. **Note U(V) (and Z as an option) on its label, added on the battery.**

U(V)	Battery State of Health (%)	Comments
≥ 13,0 V	100%	Ok for fieldwork use.
12,5 V	50%	Temporary use only
12,0 V	0%	End of life

Table 9 - Table of results for quick battery SoH evaluate.

Date	Voltage (V) after charge + 4h00 rest
01/2015	13,2
06/2015	13,1
04/2017	12,6
≥ 13,0 V = 100% of SoH	
12,5 V = 50% of SoH	
≤ 12,0 V = 0% of SoH	

Figure 31 - Example of battery label for a SoH following. Source: ISTerre laboratory

Precisions on Impedance Z(Ω): If double = battery end of life occurred. Figure 32.
Rough estimate of nominal new lead-acid batteries impedance ≈ 5 to 10 mΩ

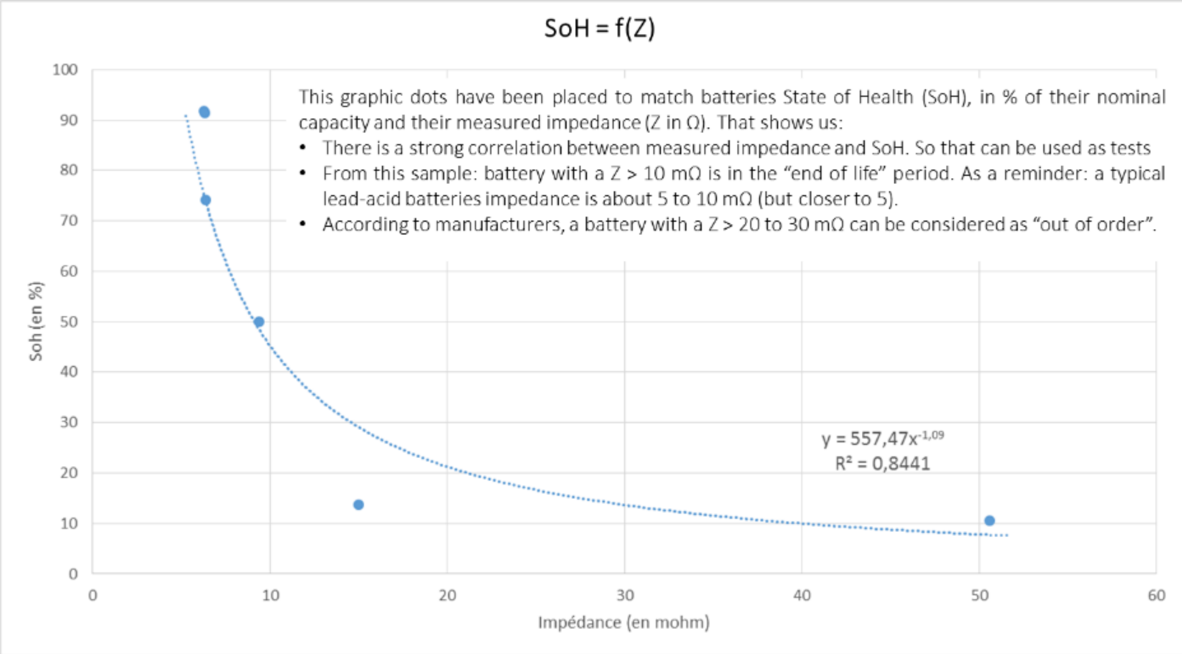


Figure 32 - Link between battery impedance (Z) and State of Health (SoH).

2. Lithium batteries

a) Some technologies

There are currently (in 2017) three main families of Lithium batteries:

- Lithium-metal batteries: non rechargeable (primary batteries)

They use Lithium plate as anode, and another metal as the cathode. As an example a Li (anode) and MnO_2 (cathode) battery, Figure 33.

Example of lithium button cell battery
 *Figure 33 - CR2032 lithium button cell battery. Source: https://en.wikipedia.org/wiki/Lithium_battery*

Some oceanic domain Research Infrastructures use primary Lithium-metal batteries.
Specific energy: 150-800 W·h/kg

- Lithium-ion batteries (Li-ion): rechargeable

Lithium Ions move in a liquid electrolyte from the negative to the positive pole during discharge, and vice-versa during charge.
Specific energy: 100–300 W·h/kg

Example of a ≈ 1,5 Ah Lithium-ion battery	Example of a 60 Ah Lithium-ion battery
 *Figure 34 - Example of a 1,5 Ah Li-ion battery. Source: https://en.wikipedia.org/wiki/Lithium-ion_battery*	 *Figure 35 - Example of a 60 Ah Lithium-ion battery used by a research infrastructure*

- Lithium-polymer batteries (Li-Po): rechargeable

They use a polymer electrolyte instead of a liquid one (Li-ion). Specific energy: 100–300 W·h/kg

Example of a ≈ 1,5 Ah Lithium-polymer batteries
 *Figure 36 - A lithium-ion polymer battery used to power a mobile phone. Source: https://en.wikipedia.org/wiki/Lithium_polymer_battery*

From the ENVRI+ point of view: Lithium batteries are mainly used in the oceanic domain (see Figure 37), in buoys or deep ocean profiling float, such as the Lithium Sulfuryl Chloride cell. Primary lithium batteries will be set-in at launch time, and changed when the device returns.

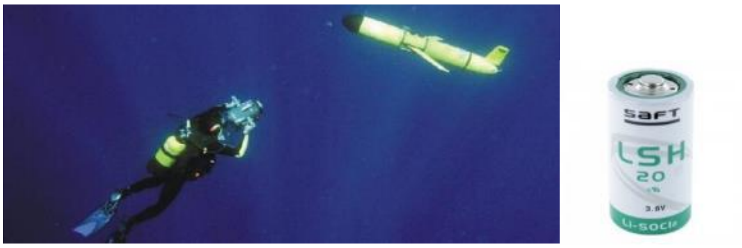


Figure 37 - An example of use Lithium Sulfuryl Chloride (primary non rechargeable) cell in oceanic domain, RI's feedbacks in survey.

Of course Lithium-ion or Lithium Polymer batteries are the most used for mobile devices such as laptops, smartphones, tablets, etc.

b) Advantages & disadvantage of Lithium batteries regarding lead-acid ones.

Non exhaustive list.

Advantages	Disadvantages
Density energy: • Wh/kg: ≈ 10 times more than lead acid • Wh/L: ≈ 3 times more than lead acid Rough estimate. Do not include battery capsule that can make the difference smaller (eg: electronic management in some high capacity Lithium batteries).	Running temperatures are not going down as low as lead-acid batteries. They cannot charge below 0°C. That is a major problem. But for aware users, this could be fixed. As an example in Greenland in summer 2016, for a scientific mission, a Li-$FePO_4$ battery had been used and put on a dark tarpaulin to be rewarmed by sun. Users were satisfied with its service: charging computer, phones, etc.
Speed charge: can go 5 times (average) faster than lead-acid battery charge.	Logistic, transportation, especially in airplanes, can be complicated.
Smaller self-discharge: from less than 5% for Li-ion to 5-15% for lead-acid batteries. For equal environmental conditions (temperature, humidity).	Need others special chargers than “common” lead-acid ones. Voltage and current variation (minimum and maximum) are different, such as charging steps.
Li-$FePO_4$ is one of the safer Li-ion technology: avoiding problems of fire and explosion. This is one of the most appropriate technology for scientific station use. It fits low current requirements	
High cycling rate. Can throughput 5 times more Ah than lead acid batteries (average). Typically 1000-2000 cycles for Li-$FePO_4$ battery, in comparison with hundreds to a thousand for higher rates “cycling” lead-acid ones.	

Table 10 - Advantages & disadvantage of Lithium batteries regarding lead-acid batteries.

3. Others batteries technologies.

There are other battery technologies that could be used for some specific installations. We will not describe them in this report as they are not representative of the most used for isolated scientific stations.

Some of them are:

- Alkaline batteries: Zn/MnO2
- Lithium metal battery (Lithium bouton cell, non-rechargeable)
- Ni-Cd, Ni-MH

As current Research and Development (R&D) axis, we can also mention:

- Sodium-ion batteries (develop by CNRS/CEA in 2016)
- Lithium-air batteries
- Pb/Li

As a summary, the Figure 38 presents main differences between the most used battery technologies:

				Li-Ion		
Specifications	**Lead-Acid**	**NiCd**	**NiMH**	**Cobalt**	**Manganese**	**Phosphate**
Specific energy density (Wh/kg)	30 – 50	45 – 80	60 – 120	150 – 190	100 – 135	90 – 120
Internal resistance (mΩ/V)	<8.3	17 – 33	33 – 50	21 – 42	6.6 – 20	7.6 – 15.0
Cycle life (80% discharge)	200 – 300	1,000	300 – 500	500 – 1,000	500 – 1,000	1,000 – 2,000
Fast-charge time (hrs.)	8 – 16	1 typical	2 – 4	2 – 4	1 or less	1 or less
Overcharge tolerance	High	Moderate	Low	Low	Low	Low
Self-discharge/month (room temp.)	5 – 15%	20%	30%	<5%	<5%	<5%
Cell voltage	2.0	1.2	1.2	3.6	3.8	3.3
Charge cutoff voltage (V/cell)	2.40 (2.25 float)	Full charge indicated by voltage signature	Full charge indicated by voltage signature	4.2	4.2	3.6
Discharge cutoff volts (V/cell, 1C*)	1.75	1	1	2.5 – 3.0	2.5 – 3.0	2.8
Peak load current**	5C	20C	5C	> 3C	> 30C	> 30C
Peak load current* (best result)	0.2C	1C	0.5C	<1C	< 10C	< 10C
Charge temperature	-20 – 50°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C
Discharge temperature	-20 – 50°C	-20 – 65°C	-20 – 65°C	-20 – 60°C	-20 – 60°C	-20 – 60°C
Maintenance requirement	3 – 6 months (equalization)	30 – 60 days (discharge)	60 – 90 days (discharge)	None	None	None
Safety requirements	Thermally stable	Thermally stable, fuses common		Protection circuit mandatory		
Time durability				>10 years	>10 years	>10 years
In use since	1881	1950	1990	1991	1996	1999
Toxicity	High	High	Low	Low	Low	Low

Source: batteryuniversity.com. The table values are generic, specific batteries may differ.
*"C" refers to battery capacity, and this unit is used when specifying charge or discharge rates. For example: 0.5C for a 100 Ah battery = 50 A.
**Peak load current = maximum possible momentary discharge current, which could permanently damage a battery.

Figure 38 - Batteries technologies comparison - Source: homepower.com

Global differences in terms of energy density (Wh/L or Wh/kg) are presented in Figure 39.

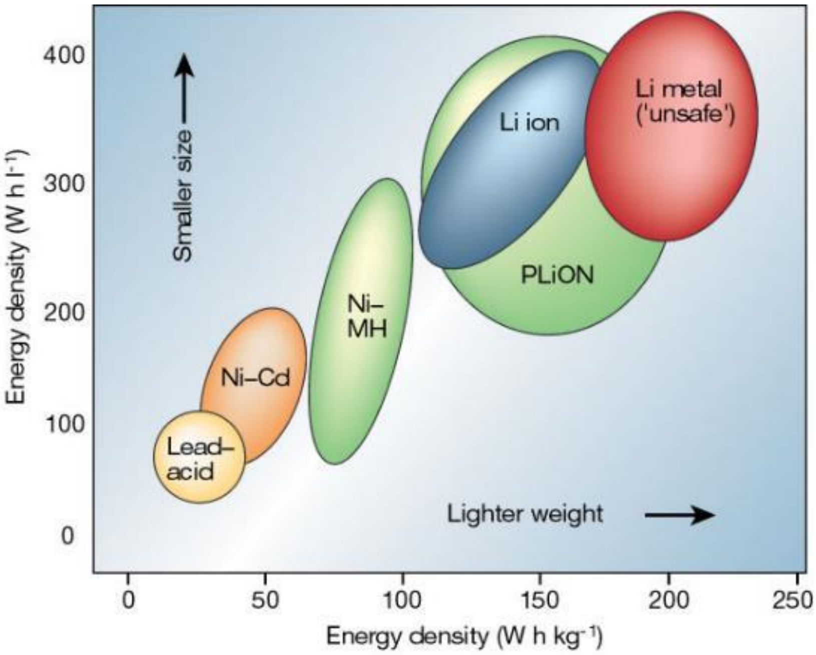


Figure 39 - Energy density comparison - Sources: JM Tarascon & M Armand, http://www.nature.com

"Comparison of the different battery technologies in terms of volumetric and gravimetric energy density. The share of worldwide sales for Ni–Cd, Ni–MeH and Li-ion portable ion batteries is 24, 14 and 63%, respectively. The use of Pb–acid batteries is restricted mainly to SLI (starting, lighting, ignition) in automobiles or standby applications, whereas Ni–Cd batteries remain the most suitable technologies for high-power applications (for example, power tools)."
Nature · December 2001 ; Michel Armand & JM Tarascon. Université de Picardie Jules Verne.

IV. Power regulation/control

Note: Only the "common useful knowledge" (main technical specifications) is presented and discussed in this report. For users to have a quick global overview of each technology.

1. General concepts

Between production and storage systems, a suitable current regulation is needed to maximize efficiency.
For example in a car, from an engine generator, the current regulation is made by the alternator. It produces direct current (DC) through a regulator for 12V batteries and electric devices. Primary energy comes from the engine's circular mechanic force and an alternative current (AC) produced.

Electric regulation is needed as production systems can sometimes provide very different voltages from the ones needed. As an example a wind turbine usually gives a 3 phases alternatives current (AC) that has to be transformed into a direct current (DC), to fit typical electronic 9-36 VDC devices. For industrial wind turbines things are different: they produce AC that "just" has to be adapted to the electric network voltage, for example, from 400 000 VAC for long distance transportation to a final distributed 220-240 VAC .

Regarding solar panels, DC produced voltage also has to be modified in order to fit uses: charging batteries or making devices running. Both are supposed to be set at the appropriate voltage not to damage them, depending on the number of photovoltaic cells that compose the solar panel. Voltage usually ranges from 20 to 40 VDC with maximum irradiance, so it has to be adapted to fit the generic 12 VDC (or 9-36 VDC for typical industrial uses).

Remark for very isolated polar stations:
In very remote areas, some laboratories use only Zener diodes as solar charge controller to cut-off over-voltage in order to minimize its internal consumption during winter time (when a single mA counts). As they know that during the sunny period, they will have enough time to recharge batteries, even if the sun is low and weak, and even if power regulation is not at its highest efficiency. Furthermore, they try to minimize as much as possible all electronic use as they are the weakest parts under -50°C.

2. Special cases for solar panels: PWM or MPPT

For solar power regulation, there are two main power controller systems:

- PWM as Pulse Width Modulation.
- MPPT as Most Power Point Tracking.

A PWM charge controller can be compared to a switch that connects solar panels to the battery. It will pull down the panel voltage close to the battery voltage to charge it without damage. Pulsation in time will make the current adapt to the battery.
A MPPT charge controller will constantly try to target the most efficient ratio between voltage and current in order to maximize battery charge.

For scientific applications, especially for isolated unmanned stations, we recommend to use MPPT, especially for high power solar panels[8]. A 250 Wp solar panel is composed with 60 photovoltaic cells of 0,5 V each, so it will reach approximatively 30 VDC. A PWM charger will pull down this voltage just up to the battery one, e.g 14 V for a 12 V battery. It results in an important loss of efficiency as P(W)=U(V).I(A).
Contrary, a MPPT charge controller will constantly adapt the total power using the "Most Power Point" solar panel value, as explain on the Figure 40 and Figure 41, to maximize available current.

[8] Last update: following winter 2017-2018 MPPT versus PWM evaluations, we strongly recommend to systematically use MPPT ones, even for "small" (e.g 50 to 100 Wp) solar panels. See details in chapter C.III.3.

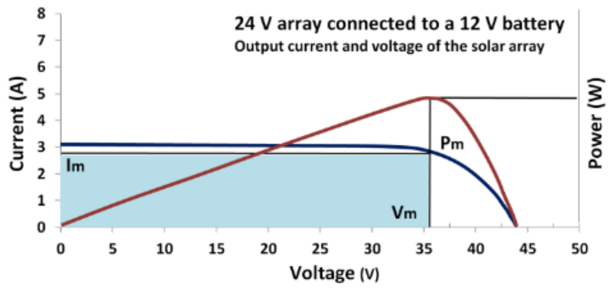


Figure 40 - Example of a large number of cells wired in series to produce 36 volts. Source: Victron energy.

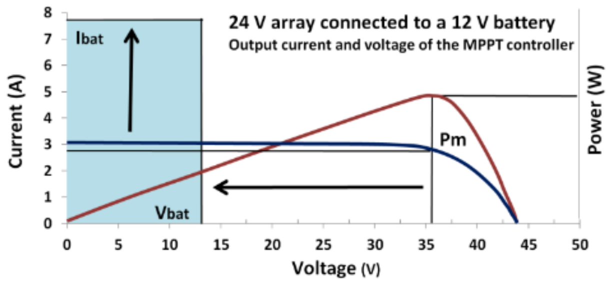


Figure 41 - Graphical representation of the DC to DC transformation as performed by an MPPT controller. Source: Victron energy

Moreover, a MPPT regulator will optimize solar panel performance when cell temperature is too low or too high, and when irradiation is low. That is indeed a strong advantage for low sun places that RIs can sometime face.

Additionally, we also suggest to have a “duo” regulator or a battery separator system that can manage two battery racks: one for the scientific acquisition, the other for the data tele transmissions. The first one should be prioritized in case of low enough current to charge both at the same time, to secure scientific recording data. So splitting the communication parts, that often consume a lot (≈5W) in comparison with data acquisition (also ≈5W).

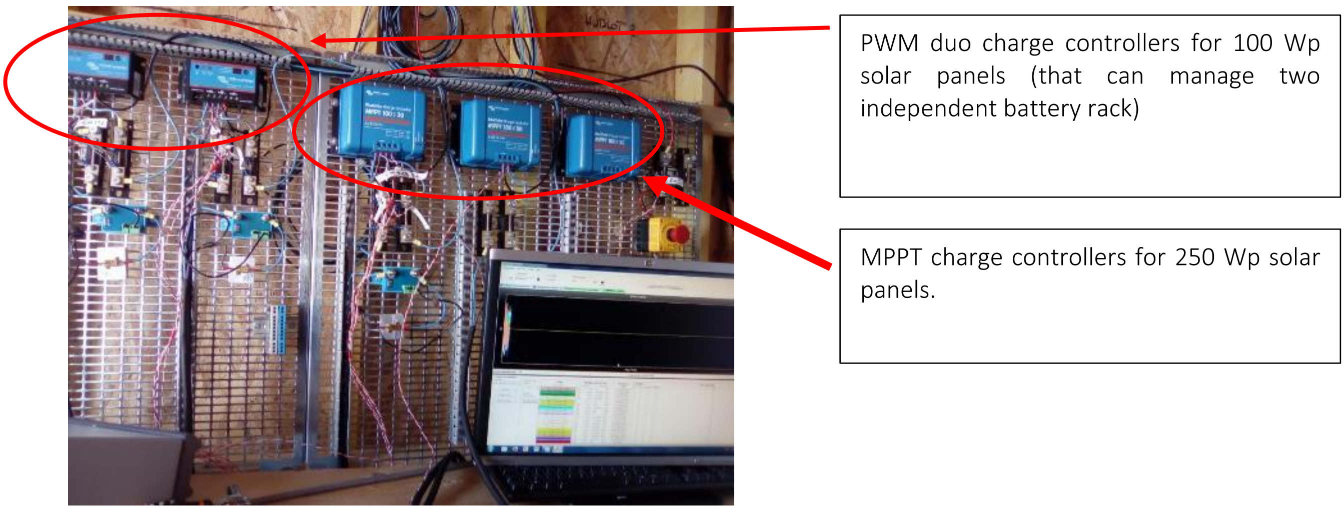


Figure 42 - examples of adapted current regulators for solar panels. Source: ENVRI+ WP3.1 bench test at the Col du Lautaret (refers to chapter C).

3. From production to storage: importance of wires

As wires have their own Ohmic resistance, depending mainly on the section size, you will need to take care of which wires to use regarding voltage, current, and length.

Power loss is due to the Joule effect (Joule Heating)

$$Power \ = \ R * I^2 = \frac{U^2}{R} = U * I$$

Where:

- I = Electric current through the wire (A)
- R = total electrical resistance of the wire (ohm).
- Power (lost, in this case) in Watts (W)

The wire resistance, results from its:

- L: Length (m)
- S: Cross section (m)
- ρ: Material resistivity in Ω.m

As:

$$R = \ \rho * L/S$$

For a same material (e.g same ρ) and same Length (L), it results that a bigger cross section will reduces Joule losses. As few examples of material resistivity:

Material	Resistivity ($\times 10^{-8}$ Ω.m)
Copper	1,7
Iron	10
Carbon	3500

Table 11 - Some material resistivity. Source: ISTerre.

Usually solar and battery system for isolated scientific stations are using 12 V devices. Remember that a higher voltage will allow you to reduce cable cross section (for a same power) or to increase current with same cables. Figure 43 (French for metric system and English for AVG correlations) shows maximum available power or current as function of wires lengths and cross sections.

Puissance max en fonction de la longueur et de la section des câbles (12V)										
Câble (mm2)	Longueur des 2 câbles (AR)									
	2	4	6	8	10	12	14	16	18	20
1,5	103	51	34	26	21	17	15	13	11	10
2,5	171	86	57	43	34	29	24	21	19	17
4	274	137	91	69	55	46	39	34	30	27
6	411	206	137	103	82	69	59	51	46	41
10	686	343	229	171	137	114	98	86	76	69
16	1097	549	366	274	219	183	157	137	122	110
25	1714	857	571	429	343	286	245	214	190	171
35	2400	1200	800	600	480	400	343	300	267	240
50	3429	1714	1143	857	686	571	490	429	381	343
70	4800	2400	1600	1200	960	800	686	600	533	480
90	6171	3086	2057	1543	1234	1029	882	771	686	617

Wire Gauge and Current Limit Table						
AWG gauge	Diameter Inches	Diameter mm	Ohms per 1000 ft	Ohms per km	Maximum amps for chassis wiring	Maximum amps for power transmission
0	0.325	8.2525	0.098	0.3224	245	150
1	0.289	7.3482	0.124	0.4064	211	119
4	0.204	5.1892	0.249	0.8151	135	60
6	0.162	4.1148	0.395	1.2959	101	37
8	0.129	3.2639	0.628	2.0605	73	24
10	0.102	2.5883	0.999	3.2764	55	15
12	0.081	2.0523	1.588	5.2086	41	9.3
14	0.064	1.6281	2.525	8.2820	32	5.9
16	0.051	1.2903	4.016	13.1725	22	3.7
18	0.040	1.0236	6.385	20.9428	16	2.3
20	0.032	0.8128	10.150	33.2920	11	1.5
22	0.025	0.6452	16.140	52.9392	7	0.92
24	0.020	0.5105	25.670	84.1976	3.5	0.577
26	0.016	0.4039	40.810	133.8568	2.2	0.361
28	0.013	0.3201	64.900	212.8720	1.4	0.226
30	0.010	0.2540	103.200	338.4960	0.86	0.142

Figure 43 - Suggested wire cross section and length as a function of power (W)

B. ENVRI+ Survey on energy: A catalogue of operational isolated stations

Purpose:

The purpose of the ENVRI+ (WP3.1) survey was to know who is using which solution in terms of energy to power their isolated stations. It had been conducted from March to June 2016 and gathered (at date of this report) approximatively 25 examples of operational isolated stations from very different scientific domains: oceanography, biology, atmosphere, geology... Those stations are representative of larger networks and so representative of more.

This chapter reports on the survey results, as they were presented in the ENVRI+ MS9 report.

It is composed by two mains chapters:

- The survey itself "Who is using what ?" that aggregate statistics on the answers provided by RIs.
- The catalogue of operational solutions, based on the outcome of the survey.

I. The Survey on energy : "Who is using what ?.

1. Construction

a) Purpose

Title: **"Energy and data transmissions for isolated scientific stations: Who is using what?"**

The aim of this questionnaire (and so of the constructed database - catalogue -) was to aggregate as many as possible examples of site conditions regarding energy and data transmission systems, coming from all over the world and different scientific domains (solid earth, atmosphere, oceanic, ...).
A general thread that motivate this report, that you should keep in mind as a guideline is:

"the more we share, the better we are"

This quote particularly applies for isolated technical installations in extreme conditions. Only general information was asked regarding the technologies that are used for energy and data transmission systems in their isolated scientific stations. To see directly operational solutions and case studies for energy and data transmission: please refer to the catalogue (second part).

b) Asked Questions

Talking about one isolated station per answer, questions asked in the ENVRI+WP3 questionnaire, were:

On energy:

- What is its approximatively total energy consumption? (total: sensors + communication + heating + alarm + ...)
  - <10W
  - 10W < X < 100 W
  - 100 W < X < 1000 W
  - > 1000 W
- Which technology are you using to provide the energy you need ?
  - Photovoltaic
  - Wind turbine
  - Fuel Cell
  - Hydroelectric turbine
  - Fuel generator (diesel, gasoline,...)
  - Other:
- Could you please specify the model you are using ?
  - Example: 3 mono-crystalline solar panels "Name of the brand" of 80 W, Vertical axis Wind Turbine model "XXXXX", methanol fuel-cell with a 3 months tank
  - Free text
- What is the theoretical power of your (production) system ? (in Watts: W)
  - Example: 250
- What is the total capacity of your batteries? (in Ampere.hours: Ah)
  - <100 Ah
  - 100 Ah < X < 500 Ah
  - >500 Ah
- Which kind of batteries are you using?
  - Lead-acid
  - Lithium-ion
  - Ni-Cd
  - Ni-Mh
  - Other:
- What is the model (brand, specifications) of those batteries?
  - Free text

On data-transmission:

- What technology are you using for data transmission ?
    - Exemple: 3G, GPRS, GSM, WIFi, WiMax, Satellite, etc...
- What is the modem model you are using ? (brand and model)
    - Free text
- Why did you choose this technical solution ? (for data transmission)
    - Example: We just don't have the choice: from where we are, only satellite works. We have several remote stations on this site, we build a WIFI "bridge" network, etc...

And general information:

- Could you please shortly describe your station ?
    - Example: Seismological station in the Alps, powered with 200 W of solar panels, Lead-acid batteries, 3G communication. CO2 measurement in forest, powered with lithium batteries design to last for a minimum of 1 month.
- email for contact (if agreed)
- Name of your station and research infrastructure:
    - Example: ARGG from RESIF, XXXX from ACTRIS, etc...

Figure 44 - Illustration of the ENVRI+ WP3.1 Survey: "Energy and data transmissions for isolated scientific stations: Who is using what ?"

Calendar:

A first general questionnaire was sent and available from February to June 2016. A second one, simpler and shorter (the one describe in this report), had been put online starting from June 2016, and is still running
To users: Please share it (link for numerical version of the report):
Survey: Energy and data transmission from isolated scientific stations: "who is using what ?"

1.1.1. Standard legal information

The questionnaire aims at providing technical information (energy and data transmission for remote stations) on European public Research Infrastructures (RI): Answering the questionnaire is voluntary. You have been selected to answer the questionnaire as your professional capacity as the representative of the RI you are working with. All data will be stored securely on servers of the University Grenoble Alps (France, WP3 leader) and will only be used within the framework of the ENVRIplus project. The questionnaire technical results and conclusions deducted from the results can be published within the ENVRIplus project deliverables, reports and documentation, however no personal information will be published in any form. All questionnaire answers will be deleted at the end of the ENVRIplus project. If you leave your contact information, you can also request to be informed on the reports and documents generated from the information collected in this questionnaire.

2. General results

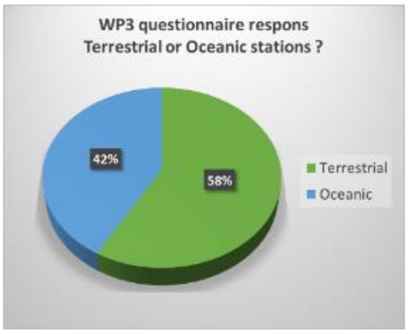
After consolidation, 24 responses were recorded in the database, presenting 24 different isolated stations from all over the world (see below) and from different scientific domain:

Scientific domain	Answers to questionnaire
Ocean	10
Atmosphere	3
Biodiversity-ecosystem	1
Solid Earth	10
TOTAL	24

Table 12 - Scientific domain of the RIs that answered to the energy survey. Source: ISTerre

Talking about energy systems and data transmissions, it is important to keep in mind that some technical solutions could be available for terrestrial application, as they couldn't be for oceanic ones. Thus, we decided to separate them for a more relevant comparison.

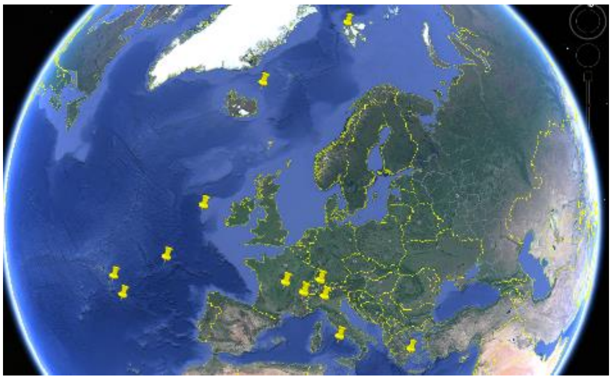
Oceanic or Terrestrial sites	Answers to questionnaire
Oceanic	10
Terrestrial	14



Glaciology (polar stations in this case), was mentioned under "Solid Earth" designation (as GPS references stations are usually put on surrounding rocks).

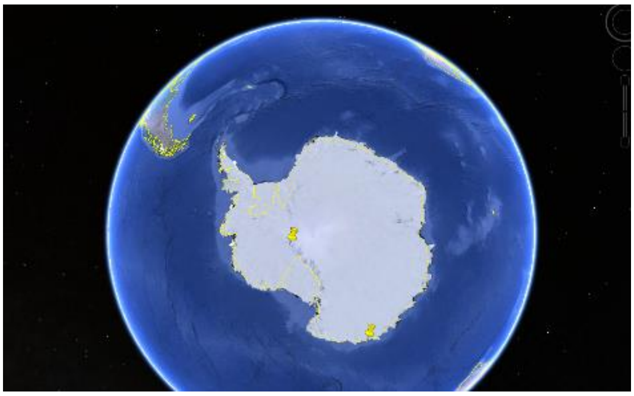
Where are recorded stations located?

Stations locations had voluntary been displayed in a wide area. The following maps only presents their global situation to help users finding the most appropriate ones (depending on their needs: oceanic, polar, forest,…).



ENVRI+ 3.1 Survey's stations: Sixteen in Europe

ENVRI+ 3.1 Survey's stations: One in South America



ENVRI+ 3.1 Survey's stations: Two in Antarctica

ENVRI+ 3.1 Survey's stations: Two in Southern Ocean

ENVRI+ 3.1 Survey's stations: Three in Northern Ocean, Arctic

Figure 45 - ENVRI+ Survey stations localization. Maps powered by Google Earth

3. Details on energy systems

► Question: What is approximate total energy consumption of the isolated measurement station? (total: sensors + communication + heating + alarm + ...)

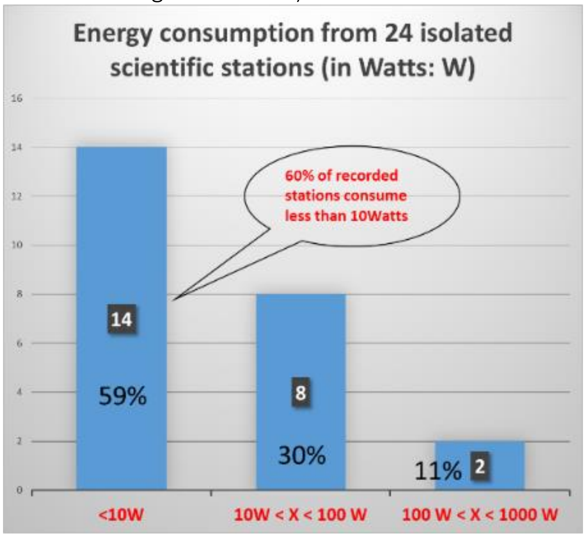


Figure 46 – Survey: Energy consumption from 24 isolated scientific stations. Source: ISTerre

One of the most useful returns we obtain from this questionnaire, in order to help us working on common solutions, is that 60% of isolated scientific stations consume less than <u>10 Watts</u>.
The questionnaire did not try to highlight others categories up to 1kW of electricity consumption. We considered (and knew) that for upper levels of energy needs, most of scientific stations are supplied in this case by gasoline power engine, that are not well designed regarding unmanned restrictions.

<u>Oceanic Versus Terrestrial:</u>
Obviously, there are attended differences between oceanic and terrestrial use, Figure 47.

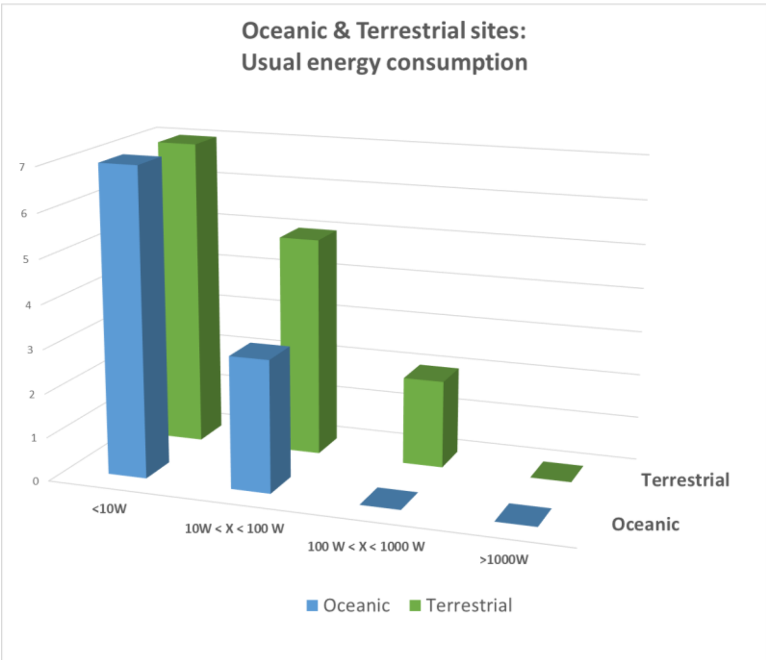


Figure 47 - Survey: Oceanic Vs Terrestrial energy typical consumption. Source: ISTerre

Oceanic stations usually have lower consumption than terrestrial ones. Indeed, the energy source issue is even more critical when you are under-water.

► Question: Which technology are you using to provide the energy you need?

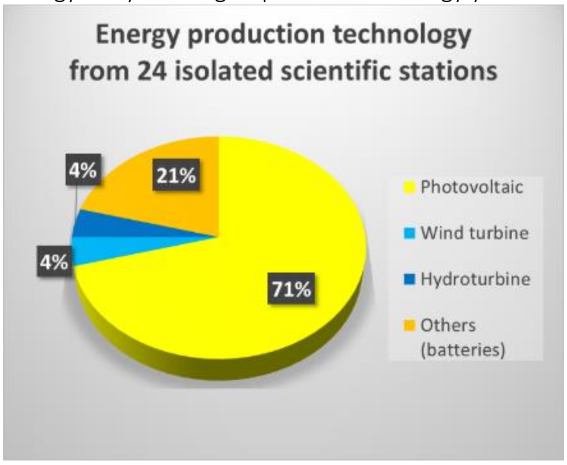


Figure 48 - Survey: Energy production technology used in 24 isolated scientific stations. Source: ISTerre

Photovoltaic is, by far, the first electrical source of energy used in isolated scientific stations. => More than 70% of recorded isolated scientific stations use solar panels. Indeed, this technology does not require regular and complex onsite maintenance, contrary to wind turbines which are more sensitive to cold temperature (because of oil and mechanic parts). For illustration and case studies, please refer to the catalogue (second part).
We didn't have feedback with the use of fuel cells. That could be interesting hence they are more and more (2017) frequently used as energy source on isolated sites (fuel cell using H_2 made from methanol or H_2O). If you have know such examples, please contact us using questionnaire or email (olivier.gilbert@univ-grenoble-alpes.fr).
Otherwise, we can mention as an interesting (but of course expected) result that most of the oceanic applications only use batteries to be regularly changed, without energy production source. That is obvious for underwater profilers, in contrary of surface buoys (that generally use small photovoltaic solar panels).

► Survey: Global summary on energy production:

Name of your station and research infrastructure:	What is its approximative total energy consumption ? (total: sensors + communication + heating + alarm + ...)	Which technology are you using to provide the energy you need ?	Could you please specify the model you are using ?	What is the theoretical power of your system ? (in Watts: W)
AGO	<10W	Photovoltaic	2 mono-crystalline solar panels Victron of 30W SPM30	60
Autonomous open-seas hydrophones	<10W	Others	nc	na
station stereoscopique	10W < X < 100 W	Photovoltaic	2 mono-crystalline solar panels FVG36-125 100Wc	200
SBLM	10W < X < 100 W	Photovoltaic	4 poly-crystalline solar panel "sun modules" of 185Wc each	740
CIS	<10W	Others	mixed - alcaline/lithium	na
Poseidon System, HCMR	10W < X < 100 W	Photovoltaic	SOLARA SM 80M/S	92
EMSO Azores Relay buoy (BOREL)	<10W	Photovoltaic	8 mono-crystalline solar panels of 20 W	160
ACTRIS	<10W	Photovoltaic	50w kyocera	50
E2M3A from INOGS - TRIESTE	10W < X < 100 W	Photovoltaic	4 mono-crystalline solar panels Enipower - Eurosolare model MN5/53	200
DELOS A	10W < X < 100 W	Others	Alkaline batteries, size D	na
EMSO Azores surface buoy	<10W	Photovoltaic	4 mono-crystalline solar panels of 20 W	80
Kerguelen Monts de l'Atmosphère	100 W < X < 1000 W	Wind turbine	AIR-X 400	400

Agassiz Ice Cap summit Ellesmere Island	<10W	Photovoltaic	For solar panels 10W MSX10 or 20W MSX20 from Campbell Scientific with CH150 power regulator	60
NALPS from SED	<10W	Photovoltaic	2 Sun-Peak PN-SPR of 100W	200
PREO from SED	10W < X < 100 W	Photovoltaic	2 x Sun Peak PN-SPR of 100W	200
TOMO from ANET network in Antarctica	<10W	Photovoltaic	2 Sharp 80 Watt monocrystalline solar modules model NE-80JEA plus two Forgen vertical axis wind turbines model 500LT	160 W (solar) plus wind (variable)
RIPLE	<10W	Photovoltaic	1 poly-crystalline 100Wc 12V	100
EMSO-LSFSW	<10W	Others	Lithium Sulfuryl Chloride chemistry DD cells	na
NOC-PAP1 observatory	<10W	Photovoltaic	nc	210
LEEISA	100 W < X < 1000 W	Others	Inselberg: hydro turbine + solar panels / Saut Pararé: Generator + solar panels	>20 kW
EuroArgo - profiling floats:	<10W	Others	non rechargeable batteries	na
EPOS_OMIV - RUI	10W < X < 100 W	Photovoltaic	nc	320
RAP-OGFO	10W < X < 100 W	Photovoltaic	nc	300
GPS in Antarctica	<10W	Photovoltaic	Kyocera Solar panels 60 cm x 40 cm 21 W (KC21T02)	42

Table 13 - ENVRI+ WP3.1 Survey : summary on energy production. Source: ISTerre.

► Question: Which kind of batteries are you using ?

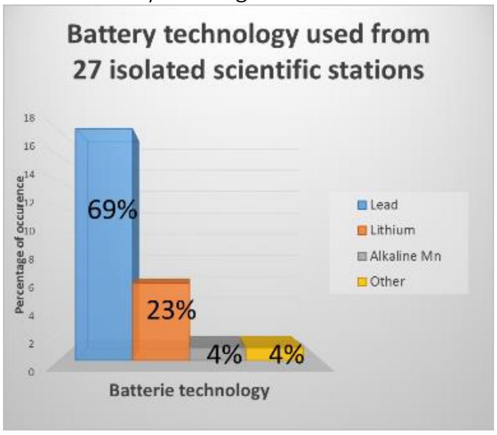


Figure 49 - Survey: Battery technologies used from 24 isolated scientific stations. Source: ISTerre

=> Lead-acid batteries are still (2017) the most used technologies for energy saving in isolated scientific stations. Lithium batteries are also used (from what has been recorded in the questionnaire), most of them for oceanic underwater applications. No drones applications have been recorded as isolated scientific station, as it is known that lighter batteries are used for them.

Last but not least, note that:

1. Regarding the actual state of the art of this technology, lithium batteries runs less good than lead-acid facing cold conditions.
2. Lithium is still a problem for logistical transportation, even if some technologies (as $FePO_4$) really improved safety issues.

For illustration and case studies, please refer to the catalogue (second part).

► Question: What is the model (brand, specifications) of those batteries ?

Name of your station and research infrastructure:	Which kind of batteries are you using ?	What is the model (brand, specifications) of those batteries ?
AGO	Lead-acid	nc
Autonomous open-seas hydrophones	lithium	nc
station stereoscopique	Lead-acid	nc
SBLM	Lead-acid	nc
CIS	Lihium-ion	Saft
Poseidon System, HCMR	Lead-acid	Power Safe 12V62F)
EMSO Azores Relay buoy (BOREL)	Lead-acid	Sonnenschein Solar S12/41A
ACTRIS	Lead-acid	SONNENSCHEIN dryfit
E2M3A from INOGS - TRIESTE	Lead-acid	HAZE HYZ-EV12-110
DELOS A	Mn 1300	Duracell Procell, size D 1.5V LR20 (multiple units welded together)
EMSO Azores surface buoy	Lead-acid	nc
Kerguelen Monts de l'Atmosphère	Lead-acid	Battery Deep Discharge
Agassiz Ice Cap summit Ellesmere Island	Lead-acid	BP20, from Campbell Scientific
NALPS from SED	Lead-acid	Swiss Solar Compact96
PREO from SED	Lead-acid	SWISSsolar compact 240Ah
TOMO from ANET network in Antarctica	Lead-acid	East Penn Deka model 8G31ST 98 A-hr
RIPLE	Lead-acid	Sonnenschein Dryfit SB12/100
EMSO-LSFSW	Lithium Sulfuryl Chloride chemistry DD cells	Lithium Sulfuryl Chloride chemistry DD cells
NOC-PAP1 observatory	Lead-acid and lithium batteries	nc
LEEISA	Lead-acid	nc
EuroArgo - profiling floats	Primary lithium batteries	nc
EPOS_OMIV - RUI	Lead-acid	nc
RAP-OGFO	Lead-acid	nc
GPS in Antarctica	Lead-acid	Batterie plomb gel étanche A512-60G6

Table 14 - ENVRI+ WP3.1 Survey : summary on energy storage. Source: ISTerre.

4. Details on data-transmission systems

► Question: What technology are you using for data transmission ?

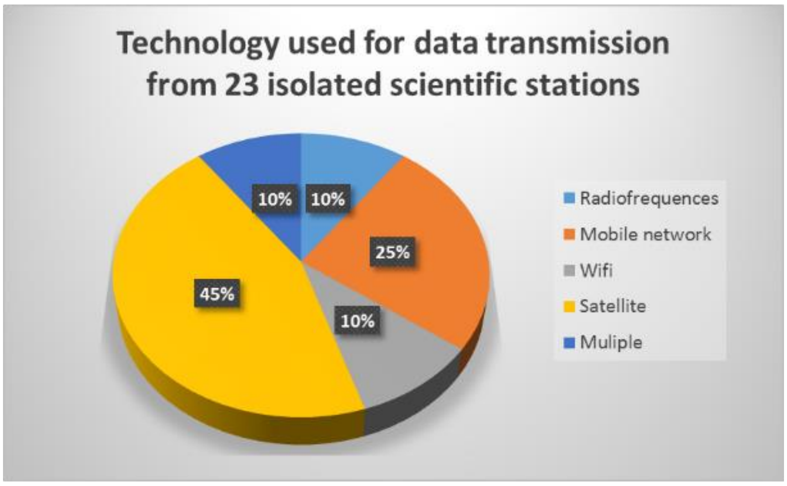


Figure 50 - Survey: Technologies used for data transmission, from 24 isolated scientific stations. Source: ISTerre.

Satellite communication is the most used data transmission systems for isolated sites. Indeed, satellite constellation as Iridium is the only system that covers polar regions.
However, satellites systems are quite expensive. That is the reason for mobile network (GSM, GPRS, 3G, EDGE, 4G,…) to come in the second position for data transmission (if, of course, available on site). Data throughput is also more important than coming from satellites connection, and antenna usually more stable facing strong winds.

Of course, we can still observe that there are differences between terrestrial and oceanic requirement: Satellite systems are of course the most used technologies for oceanic connections.

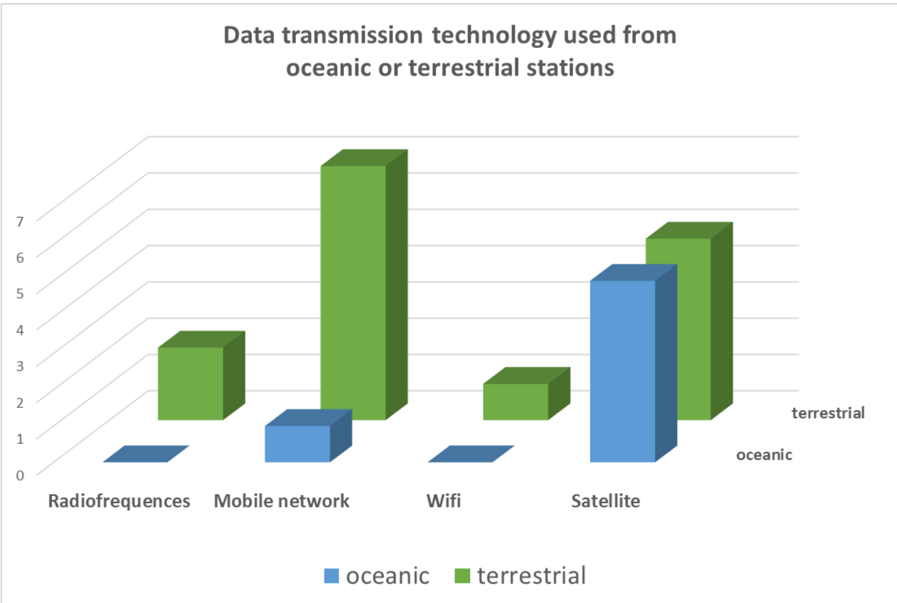


Figure 51 - Survey: Data transmissions, differences between Oceanic and Terrestrial stations

WiFi as a local multiple points network (many measurement stations in a defined area) are regularly used for data transmission, working with a parallel mobile network modem installed to aggregate all station’s data and to send them to datacenters.
For illustration and case studies, please refer to the catalogue (second part).

Data transmission summary:

Scientific domain	What technology are you using for data transmission ?	What technology are you using for data transmission ?	What is the modem model you are using ? (brand and model)	Why did you choose this technical solution ? (for data transmission)	Could you please shortly describe your station ?
Atmosphere	3G	Mobile network	siera wireless ls300	easyest solution	Weather station
Atmosphere	GSM, Satellite	Mobile network + Satellite	nc	nc	Atmospheric measurement aboard air crafts
Atmosphere	none	NA	none	No available cheap network	Atmospheric measurement in Kerguelen Island
Atmosphere	Iridium Satellite System	Satellite	or 9602 depending on data volumes	In the polar regions this is the only system available	Meteorology/climatology station in Greenland
Biodiversity-ecosystem	Satellite + Radio	Satellite + Radiofrequences	nc	nc	Biodiversity measurement in French Guyane
Oceanic	GSM	Mobile network	Siemens, MC35i	Cost effective	Oceanic wave measurement (buoy)
Oceanic	NA	NA	NA	NA	Oceanic hydrophone measurement (ocean sound monitoring)
Oceanic	NA	NA	NA	NA	Deep oceanic measurement (multiparameters)
Oceanic	Iridium	Satellite	nc	miniaturized GPS/Iridium modules are offered that allow or position	Ocean hydrography measurement
Oceanic	Iridium Rudics	Satellite	Nal research A3LADG	Bandwith/Cost compromise	
Oceanic	Satellite	Satellite	Qualcomm GSP-1620	We just don't have the choice: from where we are, only satellite works	Surface oceanic buoy measurement
Oceanic	Satellite (Iridium RUDICS)	Satellite	Nal Research A3LADG	Global coverage, low cost, correct baudrate (2400 bits/sec)	Surface oceanic buoy measurement
Oceanic	Satellite	Satellite	nc	nc	nc
Oceanic	Argos2, Argos3, Iridium	Satellite	nc	nc	nc
Solid earth	3G (UMTS)	Mobile network	Cabtronix AnyRover	and reliable plus we can control the modem via SMS if everything else fails.	Seismological station in the Alps mountain
Solid earth	LTE	Mobile network	Cabtronix AnyRover	control the modem by SMS is everything else fails.	Seismological station in the Switzerland
Solid earth	3G	Mobile network	NetModule NB1600	3G available, low energy consumption	Landslide in the Alps mountain (France, Grenoble)
Solid earth	3G	Mobile network	NetModule NB1600	3G available, low energy consumption	Seismological station in the Alps mountain (France, Grenoble)
Solid earth	UHF	Radiofrequences	ultracom TUR5/TUW5	Low power consumption and 35 km wide.	Seismological station in Auvergne (France)
Solid earth	VSAT Ku band	Satellite	Nanometrics Cygnus205	VSAT technology for resilence in case of big Earthquake.	Seismological station (unknown location)
Solid earth	satellite (Iridium)	Satellite	Xeos 9522B	Iridium is only system that will work at this latitude (75 degrees south)	GPS measurement in Antarctica
Solid earth	WIFI	Wifi	ubiquiti rocket m5	we don't have choice because the network have been already created	Volcanology in Indonesia (stereo stations)

Table 15 - ENVRI+ WP3.1 Survey : summary on data transmission. Source: ISTerre.

II. The ENVRI+ catalogue of operational isolated stations

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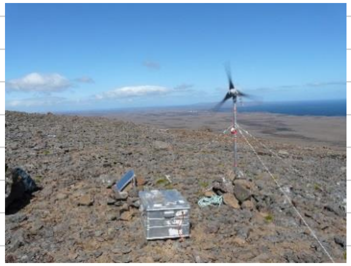
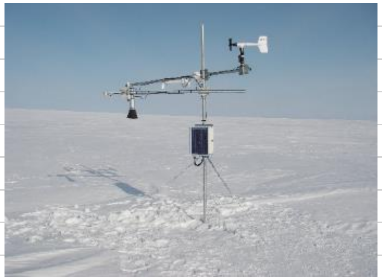
The catalogue presents both terrestrial and oceanic stations. 1 page = 1 existing (2017) station.
The catalogue is available in an independent pdf format on the ENVRI Community website: http://envri.eu/

1. Terrestrial stations

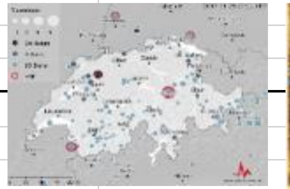
General informations:	
Name of the scientific station:	Kerguelen Monts de l'Atmosphère
Research infrastructure/laboratory :	IPGP
Measured parameters:	Atmospheric iron, cobalt, aluminium and dust
Localization :	Kerguelen Island (sub antarctic)
Contact (email):	losno@ipgp.fr
Website:	http://www.ipgp.fr
Energy supply:	
Energy consumption:	nc
Energy production:	Wind turbine, 400W (peak)
	AIR-X 400
Energy storage:	Lead-acid batteries
	4 batteries of 75Ah each
	Batterie Deep Discharge (type traction)
Telecommunication:	
Network architecture:	No automatic data transmissions.
	No available cheap network (Kerguelen)
Modem:	NA
Others informations:	Direct measurements of atmospheric iron, cobalt and aluminium-derived dust deposition at Kerguelen Islands Cette centrale électrique a permis une disponibilité de l'ordre de 70-80% avec une consommation continue de 120 W, soit plus de 10 A en continu. L'alimentation était coupée pour une tension <11V et ne revenait qu'à bonne charge des batteries (~12.5 V).Update 2017: the wind turbine brokes. Probalbly due both by a very hard storm, and salt atmosphere. The owner was thinking to test the marine one.

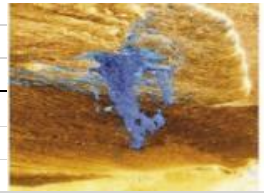


General informations:		
Name of the scientific station:	AGO	
Research infrastructure/laboratory :	OPGC	
Measured parameters:	Seismology	
Localization :	Auvergne, France	
Contact (email):	j.m.douchain@opgc.fr	
Website:	http://www.opgc.univ-bpclermont.fr/opgc/index.php	
Energy supply:		
Energy consumption:	<10W	
Energy production:	Photovoltaic, 60W	
	2 mono-cristallyne solar panels Victron of 30W SPM30	
Energy storage:	<100 Ah	
	Lead-acid	
Telecommunication:		
Network architecture:	UHF	
Modem:	ultracom TUR5/TUW5	
	Low power consumption and 35 km wide.	
Others informations:	Seismological station in Auvergne, powered with 60W solar pannels	
	Lead-Acid batteries, UHF communication	

General informations:		
Name of the scientific station:	Agassiz Ice Cap summit Ellesmere Island	
Research infrastructure/laboratory :	Campbell Scientific Canada	
Measured parameters:	Meteorolgical station	
Localization :	North Canada	
Contact (email):	claude@campbellsci.ca	
Website:	https://www.campbellsci.fr/	
Energy supply:		 
Energy consumption:	<10W	
Energy production:	200W	
	2 Sun-Peak PN-SPR of 100W	
Energy storage:	100 Ah < X < 500 Ah	
	Lead-acid	
	BP20, from Campbell Scientific	
Telecommunication:		
Network architecture:	Iridium Satellite System	
	In the polar regions this is the only system available	
Modem:	Campbell Scientific 9522B or 9602 depending on data volumes	
Others informations:	A meteorology/climatology station on summit of Agassiz Ice Cap in continuous operation since 1988. Solar recharged power systems is designed to live through 3 months of darkness (no charging) and at the coldest temperatures of polar night.	

General informations:	
Name of the scientific station:	NALPS from SED
Research infrastructure/laboratory :	EPOS/ Swiss Seismological Service (SED)
Measured parameters:	Seismic
Localization :	Alps mountain
Contact (email):	lukas.heiniger@sed.ethz.ch
Website:	http://www.seismo.ethz.ch/en/home/
Energy supply:	
Energy consumption:	<10W
Energy production:	Photovoltaic, 200Wp
	2 Sun-Peak PN-SPR of 100W
Energy storage:	Lead-acid
	100 Ah < X < 500 Ah
	Swiss Solar Compact96
Telecommunication:	
Network architecture:	Mobile network
Modem:	Cabtronix AnyRover
	Communication is reasonably fast, affordable and reliable plus we can control the modem via SMS if everything else fails.
Others informations:	Seismological station in the Alps, powered with 200 W of solar pannels, Lead-acid batteries, 3G communication.





General informations:	
Name of the scientific station:	Stereoscopic station, Merapi Vocano (Indonesia)
Research infrastructure/laboratory :	LMV-OPGC
Measured parameters:	pression,temperature,humidity measurement,digital single-lens reflex camera,webcam,thermal camera.
Localization :	Indonesia
Contact (email):	K.Kelfoun@opgc.univ-bpclermont.fr
Website:	http://lmv.univ-bpclermont.fr/kelfoun-karim-2/

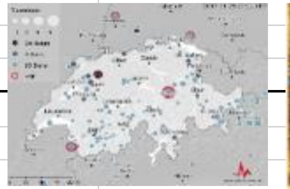

Energy supply:	
Energy consumption:	10W < X < 100 W
Energy production:	Photovoltaic, 200Wp
	2 mono-cristallyne solar panels FVG36-125 100Wc
Energy storage:	100 Ah < X < 500 Ah
	Lead-acid

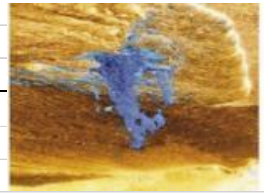

Telecommunication:	
Network architecture:	Wifi
Modem:	ubiquiti rocket m5
	The distance between the station and the server is nearly 20 km.
	Wi-Fi B (IEEE 802.11b), Wi-Fi G (IEEE 802.11g), Wi-Fi N 150 Mbps (IEEE 802.11n)


Others informations:	2, Stereo stations at the summit (3000m) of merapi volcano (indonesia) , powered with 6 solar panel, each panels 80 w, 3 lead-acid batteries,wifi communication, pression,temperature,humidity measurement,digital single-lens reflex camera,webcam,thermal camera.The station takes photos, thermal image e 8 time per day and takes video webcam every hours and send data to server . There 2 same stations at the bottom of the volcano. The distance between the station and the server is nearly 20 km.

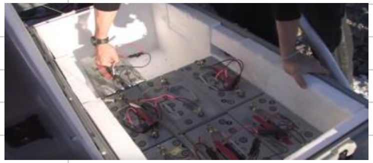
General informations:		
Name of the scientific station:	SBLM	
Research infrastructure/laboratory :	nc	
Measured parameters:	nc	
Localization :	nc	
Contact (email):	nc	
Website:	nc	
Energy supply:		
Energy consumption:	10W < X < 100 W	
Energy production:	Photovoltaic	
	4 poly crystalin solar panel "sun modules" of 185Wc each	
	740 Wc	
Energy storage:	100 Ah < X < 500 Ah	
	Lead-acid	
Telecommunication:		
Network architecture:	Satellite	 
	VSAT Ku band	
Modem:	Nanometrics Cygnus205	
	VSAT technology for resilence in case of big Earthquake.	
Others informations:	seismic station (BB velocity, acceleration , GNSS)	

General informations:	
Name of the scientific station:	NALPS from SED
Research infrastructure/laboratory :	EPOS/ Swiss Seismological Service (SED)
Measured parameters:	Seismic
Localization :	Alps mountain
Contact (email):	lukas.heiniger@sed.ethz.ch
Website:	http://www.seismo.ethz.ch/en/home/
Energy supply:	
Energy consumption:	<10W
Energy production:	Photovoltaic, 200Wp
	2 Sun-Peak PN-SPR of 100W
Energy storage:	Lead-acid
	100 Ah < X < 500 Ah
	Swiss Solar Compact96
Telecommunication:	
Network architecture:	Mobile network
Modem:	Cabtronix AnyRover
	Communication is reasonably fast, affordable and reliable plus we can control the modem via SMS if everything else fails.
Others informations:	Seismological station in the Alps, powered with 200 W of solar pannels, Lead-acid batteries, 3G communication.





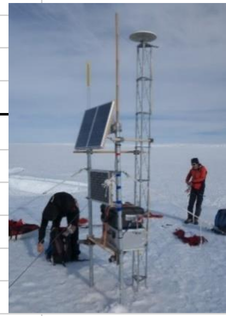
General informations:	
Name of the scientific station:	TOMO from ANET network in Antarctica
Research infrastructure/laboratory :	POLNET
Measured parameters:	GPS
Localization :	Antarctica
Contact (email):	kendrick.42@osu.edu
Website:	http://polenet.org/?page_id=176
Energy supply:	
Energy consumption:	<10W
Energy production:	Photovoltaic
	2 Sharp 80 Watt monocrystalline solar modules model NE-80JEA plus two Forgen vertical axis wind turbines model 500LT
Energy storage:	Lead-acid
	>500 Ah
	East Penn Deka model 8G31ST 98 A-hr
Telecommunication:	
Network architecture:	Satellite
Modem:	Xeos 9522B
	Iridium is only system that will work at this latitude (75 degrees south)
Others informations:	GPS station in Antarctica powered by two 80 W solar panels and two Forgen vertical-axis wind turbines. Has 22 lead acid batteries to last through the winter darkness. Station also transmits meteorological data.

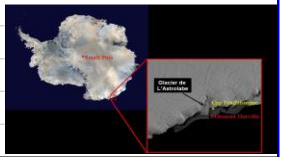


General informations:	
Name of the scientific station:	RAP-OGFO
Research infrastructure/laboratory :	EPOS/RESIF/RAP/ISTerre
Measured parameters:	seismic
Localization :	French alps, Near Grenoble
Contact (email):	isabelle.douste-bacque@ujf-grenoble.fr
Website:	http://rap.resif.fr/
Energy supply:	 
Energy consumption:	10W < X < 100 W
Energy production:	Photovoltaic
	300 Wp
Energy storage:	Lead acid batteries
	710 Ah
Telecommunication:	 
Network architecture:	Mobile network
Modem:	NetModule NB1600
	3G available, low energy consumption
Others informations:	Seismic station in the Alps.

General informations:		
Name of the scientific station:	Automatic weather station	
Research infrastructure/laboratory :	ACTRIS	
Measured parameters:	Meteorological parameters (P, T, U, wind)	
Localization :	Antarctica	
Contact (email):	luc.piard@ujf-grenbole.fr	
Website:	http://www.ige-grenoble.fr/	
Energy supply:		 
Energy consumption:	<10W	
Energy production:	Photovoltaic	
Energy storage:	Lead-acid	
	<100 Ah	
	SONNENSCHEIN dryfit	
Telecommunication:		
Network architecture:	Mobile network	
	easyest solution	
Modem:	siera wireless ls300	
Others informations:	Automatique weather station	

General informations:	
Name of the scientific station:	GPS in Antarctica
Research infrastructure/laboratory :	IGE (Institute of External Geosciences) Grenoble, France
Measured parameters:	Ice shield, through GPS
Localization :	Antarctica
Contact (email):	emmanuel.lemeur@univ-grenoble-alpes.fr
Website:	http://www-lgge.obs.ujf-grenoble.fr/personnels/lemeur_emmanuel/
Energy supply:	
Energy consumption:	<10W
Energy production:	Photovoltaic
	Kyocera solar pannels 60 cm x 40 cm 21 W (KC21T02)
	2 x 21 W (2 solar pannels)
Energy storage:	Lead-acid
	100 Ah < X < 500 Ah
	Sonnenschein Lead acid Gel A512-60G6
Telecommunication:	
Network architecture:	no more real time transmission. RAdio modem transmission before giving up
Modem:	ATIM (small society close to Grenoble) radio serial + ethernet Modem 868 MHz (500 mW) + 433 MHz (150mW)
	remote place ... 9 station were transmitting to a relay (433 MHz) and then the relay was transmitting to the narby (20 km) Antarctic base (868 MHz, directionnal Antennae)
Others informations:	GPS beacon comprising : 1 netR9 Trimble GPS receiver + Geodetic Zephir antenna, 2 Kyocera KC21T02 solar pannels, 1 charge controller (Sunsaver) and 3 60 A.h gel lead batteries

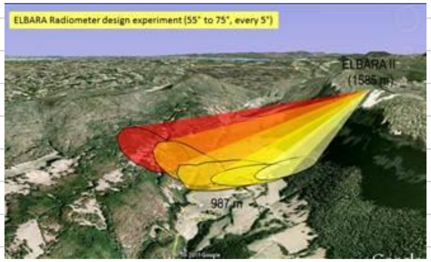




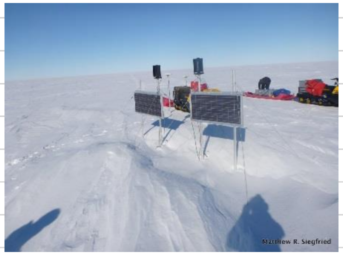
General informations:	
Name of the scientific station:	RIPLE
Research infrastructure/laboratory :	IGE (Institute of External Geosciences, Grenoble, France)
Measured parameters:	2 turbidimeters, 1 hydrophone, 2 radars (water level and speed), conductivity probe, echo sounde
Localization :	
Contact (email):	yoann.michielin@gmail.com
Website:	
Energy supply:	
Energy consumption:	<10W
Energy production:	Photovoltaic
	1 polycristallin 100Wc 12V
Energy storage:	Lead-acid
	100 Ah < X < 500 Ah
	Sonnenschein Dryfit SB12/100
Telecommunication:	
Network architecture:	Mobile network (3G)
Modem:	Erco & Gener Genpro 325e
	low cost, standard, large network coverage
Others informations:	Platform for sediments and water fluxes monitoring, installed in the Alps (Bourg d'Oisans). Integrating 2 cameras, 1 pump, 2 turbidimeters, 1 hydrophone, 2 radars (water level and speed), conductivity probe, echo sounder. Energy consumption

General informations:		
Name of the scientific station:	Nouragues Station. (Two sites 8 km apart Inselberg / Saut Pararé Amazonie	
Research infrastructure/laboratory :	Laboratoire Ecologie Environnement Interactions des Systèmes Amazoniens	
Measured parameters:	nc	
Localization :	Amazonie, French Guyana	
Contact (email):	philippe.gaucher@cnrs.fr	
Website:	http://www.nouragues.cnrs.fr/	
Energy supply:		
Energy consumption:	<10W	
Energy production:	Inselberg: hydroturbine + solar panels / Saut Pararé: Generator + solar panels	
	Solar panels	
Energy storage:	1420 A.h	
	Solar lead batteries	
Telecommunication:		
Network architecture:	Satellite + Radiofrequences	
Modem:		
Others informations:	Biodiversity/Ecosystem station in French Guyana (Amazonian Forest)	

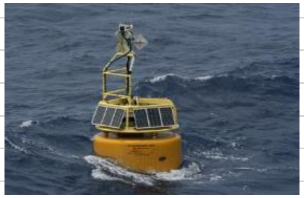
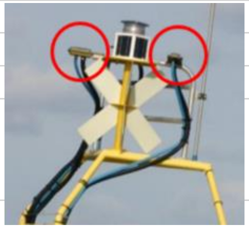
General informations:	
Name of the scientific station:	ELBARA
Research infrastructure/laboratory :	IGE
Measured parameters:	Sol humidity with radiometer measurements
Localization :	Vercors mountain
Contact (email):	bernard.mercier@univ-grenoble-alpes.fr
Website:	http://pp.ige-grenoble.fr/pageperso/pellarin/Radiometrie_montagne.htm
Energy supply:	
Energy consumption:	100W < X < 1000 W
Energy production:	Photovoltaic solar panels
	DEIKKO DKJM 1580x807 mono-cristalyne: 2xDKJM160 + 1xDKJM175 totalisant 495Wc
	Peak power :240W Mean power : 120W
Energy storage:	100 Ah < X < 500 Ah
	Lead-acid batteries
	EnerSol250 (12V 250Ah x2 in serie)
Telecommunication:	
Network architecture:	No tele transmissions. To go on site to dowload them.
Modem:	
Others informations:	Sol humidity with radiometer measurements



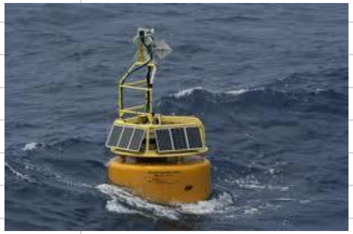
General informations:	
Name of the scientific station:	S2 from NIVO-IPEV-IGE
Research infrastructure/laboratory :	IGE
Measured parameters:	Meteo
Localization :	Antarctica, eastern plateau
Contact (email):	laurent.arnaud@univ-grenoble-alpes.fr
Website:	eric.lefebvre@univ-grenoble-alpes.fr
Energy supply:	
Energy consumption:	<10W
Energy production:	Photovoltaic
	2 multi-crystalline cells (encapsulation between 2 sheets of glass) PWX100 Photowatt of 12 Wc.
	24 W
Energy storage:	
	100 Ah < X < 500 Ah
	Lead-acid, Sonnenschein A512 65 Ah * 6
Telecommunication:	
Network architecture:	ARGOS
Modem:	ST21 - Campbell Scientific
	Only 2 choices Iridium SBD or ARGOS for high latitude (> 75°). We use both solutions, but ARGOS for S2.
Others informations:	Meteorological and snow temperature profiles stations. Set up between Concordia and Vostok stations on the East Antarctic Plateau, one of the coldest place on earth: annual average temperature -55°C and temperature fall below -80° during the winter. No sun for 4 months (batteries capacity > 360 Ah). 2 10 Watts solar panels are north oriented but a little bit west for one, and east for the other. They power the meteorological station (through lead-acid batteries). The third solar panel power a fan for the temperature sensor box.

General informations:	SUBGLACIAL ANTARCTIC LAKES SCIENTIFIC ACCESS
Name of the scientific station:	WISSARD
Research infrastructure/laboratory :	SALSA (Subglacial Antarctic Lakes Scientific Access)
Measured parameters:	
Localization :	
Contact (email):	matthew.siegfried.phd@gmail.com
Website:	https://salsa-antarctica.org/subglacial-hydrology-2/
	brad_lipovsky@g.harvard.edu
Energy supply:	
Energy consumption:	5 W
Energy production:	2 by 80 W solar panels, installed to face north
	Plus Two forgen Antarctic Wind turbines vertical axes
	6 by 100 Ah lead acid batteries
Energy storage:	
Telecommunication:	
Network architecture:	nc
Modem:	nc
Others informations:	The wind turbines provide inconsistent and high voltage, so they are not sufficient to keep power through the winter---instead they are used primarily to heat heating pads within the electronics box to maintain a relatively warm internal temperature for the receiver and power system. Both solar and turbine use charge controllers made by Flexcharge
	The Subglacial Antarctic Lakes Scientific Access (SALSA) project aims to uncover new knowledge about this newly explored biome through an integrative study of subglacial geobiology, water column and sedimentary organic carbon, and geobiological processes in one of the largest subglacial lakes in West Antarctica

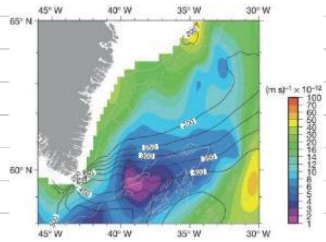
2. Oceanic stations

General informations:		
Name of the scientific station:	EMSO Azores Relay buoy (BOREL)	
Research infrastructure/laboratory :	EMSO/IFREMER	
Measured parameters:	nc	
Localization :	Oceanic, Azores	
Contact (email):	julien.legrand@ifremer.fr	
Website:	http://www.emso-fr.org/EMSO-Azores/Infrastructure	
Energy supply:		
Energy consumption:	<10W	
Energy production:	Photovoltaic, 80W	
	4 mono-cristallyne solar panels of 20 W = 80 W	
Energy storage:	<100 Ah	
	Lead-acid	
Telecommunication:		
Network architecture:	Satellite (Iridium RUDICS)	
	Global coverage, low cost, correct baudrate (2400 bits/sec)	
Modem:	Nal Research A3LADG	 
	Iridium antenna is mounted at the top of the BOREL superstructure. The electronic unit is placed inside the UGB (Buoy Electronic Management Unit). There is no central data storage available on the buoy.	
Others informations:	Data relay buoy of the EMSO Azores observatory on Lucky Strike vent field.	
	Borel is the surface buoy, relaying bi-directionally measurement data or commands between seabed and shore, through underwater acoustics and satellite. Borel holds a geodetic Global Positioning System and can host near surface ocean sensors.	

General informations:	
Name of the scientific station:	EMSO-LSFSW
Research infrastructure/laboratory :	EMSO
Measured parameters:	nc
Localization :	Ocean buoy
Contact (email):	crawford@ipgp.fr
Website:	http://www.ipgp.fr/fr
	http://www.emso-eu.org/site/
Energy supply:	
Energy consumption:	<10W
Energy production:	No production, only non rechargeable batteries.
Energy storage:	Electrochem CSC93 Lithium/Sulfur Chloride DD cells
	Electrochem BCX-93 Lithium/Bromine Chloride DD cells
	Tadiran TL-5937 Lithium/Thionyl Chloride DD cells
	>500 Ah
Telecommunication:	
Network architecture:	na
Modem:	na
Others informations:	nc



Lithium cells

General informations:		
Name of the scientific station:	CIS - Central Irminger Sea	
Research infrastructure/laboratory :	GEOMAR	
Measured parameters:	hydrography: Temperature, Salinity, Fluorescence,oxygen	
Localization :	Greenland	
Contact (email):	jkarstensen@geomar.de	
Website:	http://www.geomar.de/en/	
Energy supply:		
Energy consumption:	<10W	
Energy production:	None, only batteries	
Energy storage:	mixed - alcaline/lithium <100 Ah	
Telecommunication:		
Network architecture:	Iridium data volume, two-way communication, miniaturized GPS/Iridium modules are offered that allow our position	
Modem:		
Others informations:	hydrography in the Central Irminger Sea, Telemetry system MISAT I & II from company	

General informations:	
Name of the scientific station:	Poseidon System, HCMR
Research infrastructure/laboratory :	HCMR
Measured parameters:	temperature, salinity, waves
Localization :	Hellenic sea
Contact (email):	mntou@hcmr.gr
Website:	http://www.hcmr.gr/en/

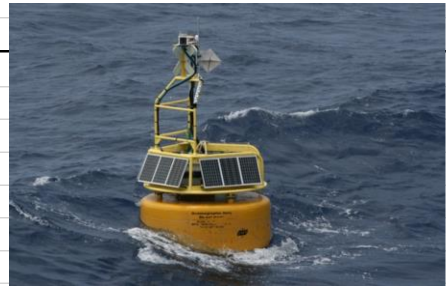
Energy supply:	
Energy consumption:	10W < X < 100 W
Energy production:	Photovoltaic, 92W
	SOLARA SM 80M/S
Energy storage:	100 Ah < X < 500 Ah
	Lead-acid
	Power Safe 12V62F)

Telecommunication:	
Network architecture:	GSM
Modem:	Siemens, MC35i

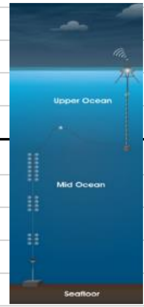
Others informations:	
	Wavescan buoy - wave directional buoy measuring wave-, meteorology- and environmental parameters. The buoy has several options regarding sensors and equipment. Data can be stored on board on hard disk. The buoy can be powered by a lithium battery packs or by a solar cell charged battery pack. The buoy can be equipped with position systems like GPS (Global Positioning System) to prevent loss of buoy. Different sensors options exist, e. g. air humidity, water current sensors of profiling or single point type. Even customer specific sensors can be installed to meet special requirements.

General informations:		
Name of the scientific station:	E2M3A from INOGS - TRIESTE	ISTITUTO NAZIONALE DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE
Research infrastructure/laboratory :	INOGS, Italy	
Measured parameters:	meteorological data, Radiance and Infrared in air, CTD, Ph, PcO2	
Localization :	Ocean	
Contact (email):	pmansutti@inogs.it	
Website:	http://www.ogs.trieste.it/en	
Energy supply:		
Energy consumption:	10W < X < 100 W	
Energy production:	Photovoltaic 200Wp	
	4 mono-cristallyne solar panels Enipower - Eurosolare model MN5/53	
Energy storage:	Lead-acid, back-up alkaline batteries	
	100 Ah < X < 500 Ah	
Telecommunication:		
Network architecture:	Satellite	
Modem:	Qualcomm GSP-1620	
	We just don't have the choice: from where we are, only satellite works	
Others informations:	Oceanographic buoy, powered with 200W of solar pannels, Lead-acid batteries, back-up alkaline batteries. Satellite communication. Measurement of meteorological data, Radiance and Infrared in air, CTD, Ph, PcO2 at 2m depth.	

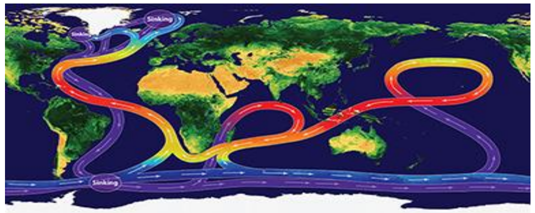
General informations:	
Name of the scientific station:	DELOS A (Deep-ocean Environmental Long-term Observatory System)
Research infrastructure/laboratory :	DELOS
Measured parameters:	sonar, hydrophone, oxygen sensor, conductivity sensor, pressure sensor, current meter, fluorometer and turbidity sensor, ADCP, 2x digita
Localization :	Ocean, Angola
Contact (email):	jessica.craig@abdn.ac.uk
Website:	http://www.delos-project.org/
Energy supply:	
Energy consumption:	10W < X < 100 W
Energy production:	No production, only batteries
Energy storage:	Alkaline batteries, size D, Mn 1300, replaced annualy
	100 Ah < X < 500 Ah
	Duracell Procell, size D 1.5V LR20 (multiple units welded together)
Telecommunication:	
Network architecture:	No teletransmission
	manually downloading once a year
Modem:	
Others informations:	Autonomous Deep-ocean Environmental Long-term Observatory System (DELOS) located at 1500 m depth off the coast of Angola in the oil

General informations:		
Name of the scientific station:	EMSO Azores surface buoy	
Research infrastructure/laboratory :	EMSO/IFREMER	
Measured parameters:	communication relay for oceanic stations	
Localization :	ocean, azores	
Contact (email):	julien.legrand@ifremer.fr	
Website:	http://www.emso-eu.org/site/	
Energy supply:		
Energy consumption:	<10W	
Energy production:	Photovoltaic	
	4 mono-cristallyne solar panels of 20 W, total = 80Wc	
Energy storage:	Lead-acid	
	<100 Ah	
Telecommunication:		
Network architecture:	Satellite	
Modem:	Nal Research A3LADG	
	Global coverage, low cost, correct baudrate (2400 bits/sec)	
Others informations:	Data relay buoy of the EMSO Azores observatory on Lucky Strike vent field. Date are transmitted acoustically from 2 seabed stations to the buoy. Borel is the surface buoy, relaying bi-directionally measurement data or commands between seabed and shore, through underwater acoustics and satellite. Borel holds a geodetic Global Positioning System and can host near surface ocean sensors.	

General informations:	
Name of the scientific station:	NOC-PAP1 observatory
Research infrastructure/laboratory :	National Oceanography Center
Measured parameters:	nc
Localization :	Northeast Atlantic, buoy
Contact (email):	migcha@noc.ac.uk
Website:	http://projects.noc.ac.uk/pap/
Energy supply:	
Energy consumption:	<10W
Energy production:	Photovoltaic
	210 Wp
Energy storage:	>500 Ah
	The PAP buoy has 6 batteries of 12V and 180Ah. 3 of them are used by the Met office and 3
Telecommunication:	
Network architecture:	Satellite
Modem:	nc
Others informations:	The PAP buoy has 6 batteries of 12V and 180Ah. 3 of them are used by the Met office and 3 by us.We also have a battery housing for a pH sensor of 266Ah. In addition we have batteries in an underwater housing as follow: - 3*200Ah lithium D-cell battery housings - Up to 3*120Ah alkaline D-cell battery housings - 1*50Ah battery pack - Internal sensor batteries (specific for each sensor)



General informations:	
Name of the scientific station:	EuroArgo - profiling floats: Arvor, Provor, Deep-Arvor
Research infrastructure/laboratory :	EuroArgo/IFREMER
Measured parameters:	Salinity, temperature, pressure
Localization :	Oceanic
Contact (email):	serge.le.reste@ifremer.fr
Website:	http://www.euro-argo.eu/
Energy supply:	
Energy consumption:	<10W
Energy production:	none (only batteries)
Energy storage:	Non rechargeable bateries Primary lithium batteries 96 to 192A.h, depending on profiling float type
Telecommunication:	
Network architecture:	Satellite
Modem:	
Others informations:	



C. On-site evaluations of energy production systems.

I. Aim.

The purpose of the ENVRI+ on-site energy bench-test is to evaluate several commercially available systems in order to optimize them regarding RIs needs. Especially on terrestrial extreme conditions as scientific stations can face in high mountain or polar regions:

- Cold.
- Snow.
- Strong and turbulent winds.
- Period with very low, or no.

For those reasons, the Station Alpine Joseph Fourrier site (Col du Lautaret, 2100 m high in the Alps) has been chosen. It is briefly described in the first paragraph (C.I.1).

Adaptation and learning evaluated technologies for RI use is the matter. Advising technical staff with **recommendations for on-site use, is the aim**.

With respects to the ENVRI+ energy survey (WP3.1, refers to chapter B), we focused on the most common power supply technologies from RIs:

- Solar panels :
  - Two main commercialized technologies: Monocrystalline vs Polycrystalline.
  - Tilt angle: vertical (to avoid snow deposition or with very low sun in polar regions) or 36° (optimum for 45° latitude sites).
  - Bifacial (Est-West oriented) Vs Monofacial (South oriented).
- Wind turbines:
  - To evaluate and optimize some small wind turbines models regarding RI needs.
    - Two vertical axis model.
    - One horizontal axis model.
- Solar charge controllers: MPPT or PWM technologies.
- Lead-acid batteries: AGM or GEL technologies. (Further in-laboratory test have been conducted and reported in chapter D).

The protocol was to compare total produced power (Wh) from each energy system, as :

$$P(W) = U(V).I(A)$$

➔ So to monitor U(V) and I(A).

Not only electrical characteristics have been checked, but also mechanics resistivity, weight, obstruction place, constraints on transportations, as well as needed maintenance. As all those factors matter for isolated stations where you can sometimes only access by walk.

Technical specifications of the bench test are described in chapter C.II.2 and results are displayed in C.II.3.

Remark: What those evaluations are not.
The following evaluations are not ISO Standards tests for characterization. Therefore, it is not the purpose to conclude on one or another technology's efficiency. ISO Standard test are made in laboratory with standard conditions and protocol. e.g: 25°C, 1000 W/m^2, laminar wind, etc…
Our evaluations have been realized in order to help RIs for a better understanding and use of systems there are familiar with, so to optimize them regarding their very special needs.
For solar panels: The aim was to compare different solutions facing same environmental conditions, but not to calculate their absolute efficiency. That is the reason why no radiometer has been used.

II. Evaluation protocol: SAJF site and ENVRI+ bench test.

1. The Alpine Station Jospeh Fourrier (SAJF) test site.

The **Alpine Station Jospeh Fourrier** (SAJF) is located in the French alps at the “col du Lautaret”. 2100 m high and less than two hours drive from Grenoble city, or 30 minutes from Briançon (Figure 52). The SAJF takes care of 100 years old Alpine garden heritage, and offers a technical platform facility in high mountain conditions: the TETRA (TEst Technologiques pour la Recherche Alpine) Hut.
More available informations at: https://www.jardinalpindulautaret.fr

Figure 52 - Station Alpine Joseph Fourrier (SAJF) geographical location and vue. Source: SAJF.

The TETRA Hut:

The TETRA hut (Figure 53) was installed by the ENVRI+ SAJF partner as a test and measurement facility for technical solutions or scientific measurements in high mountain conditions. It is composed by a 10m² wood hut with 220 V AC available and mobile internet connection. A wired internet connection (University network) is planned for 2018. Logistic: Cars and trucks can access the site during summer. Parking is 100 meters below the site during winter. All required accommodations are available to work in pleasant conditions (dormitories, kitchen, warm refuge).


Figure 53 - The TETRA hut and the ENVRI+ bench test for high mountain conditions. Source: SAJF.

2. The ENVRI+ bench-test.

Thanks to the SAJF facilities, we installed our bench test in order to evaluate the following energetic production systems:

a. Photovoltaic solar panels
b. Wind turbines
c. PWM or MPPT solar charge controllers

With the:

d. Acquisition system

a) Photovoltaic solar panels

The following devices have been use for photovoltaic evaluations:

- Solar panels:
  - Two 100 Wp monocrystalline
  - Two 100 Wp polycrystalline
  - One 240 Wp monocrystalline bifacial
  - One 250 Wp monocrystalline monofacial (same technology as bifacial one)
- Regulators:
  - Same PWM duo for all 100 Wp panels
  - An additional MPPT to compare to PWM (all others equipements equal)
  - Same new MPPT for 250 and 240 Wp panels
- Batteries:
  - Same single 90 A.h gel lead-acid batterie.

Solar photovoltaic (PV) panels had been evaluated in order to compare for our special use cases:

1. Impact of tilt angle: vertical (to avoid snow accumulation) Vs appropriate tilted [9].
2. The two major commercialized technologies: Monocrystalline Vs Polycrystalline (silicon). Is there a significant difference in our case ?
3. Bifacial Est-West oriented Vs Monofacial south oriented. That can be interesting in polar regions where sun turns around in circle, in a lower angle above the horizon

The two first evaluations (vertical Vs tilted and Poly Vs Monocrystalline, Figure 54) have been gathered as solar panels have similar nominal power of 100Wp (Watt peak).

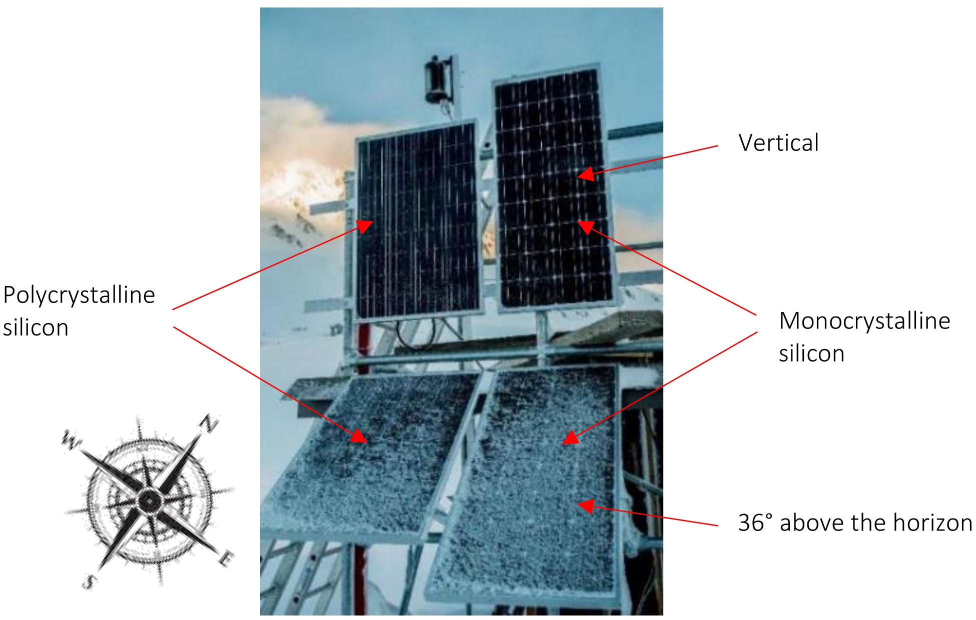


Figure 54 - The four 100 Wp evaluated solar panels. Source: ISTerre.

[9] 36° above the horizon for a 45° latitude to maximize the annual production, or 78° to maximize winter production.

4. Bifacial East-West oriented Vs Monofacial South oriented (Figure 55 and Figure 56):

Est-West oriented: the maximum of production is at sun-set and sun rise

Figure 55 - The 270Wp bifacial evaluated solar panel Source: ISTerre.

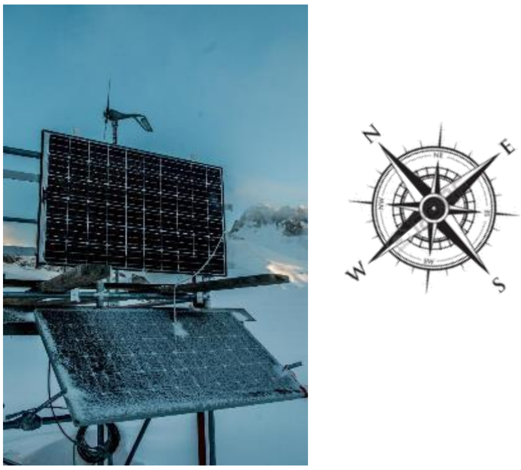


Figure 56 - Two monofacial 250Wp evaluated solar panels (here during installation). Source: ISTerre.

For the following discussion, we will refers to those solar panels using the abbreviations:

Solar panel	Used abbreviation	Certificated power (from manufacturer) in W [10]
Polycrystalline 36° tilted	PV_poly_36	100.3360
Polycrystalline vertically tilted	PV_poly_vertic	100.3360
Monocrystalline 36° tilted	PV_mono_36	100.3360
Monocrystalline vertically tilted	PV_mono_vertic	100.3360
Bifacial 270Wp	Bifacial	Nc
Monofacial 250 Wp	Monofacial	nc

Table 16 - Evaluated solar panels system. Source: ISTerre.

[10] Standard conditions : Irradiance = 1000 W/m² ; T = 25,0°C ; Air Mass coefficient = 1,5

b) Wind turbines

Three wind turbines had been evaluated for our special use cases

➔ Two vertical axiss of 20 Wp and 70 Wp, that are respectively be name as:
- VAWT A: Vertical Axis Wind turbine “A”: 30 Wp
- VAWT B: Vertical Axis Wind turbine “B”: 70 Wp

➔ One horizontal axis of 400 Wp:
- HAWT : Horizontal Axis Wind turbine: 400 Wp

Technical specifications:

VAWT “A”:

Technical specifications

Rotor Diameter	**200 mm**
Vane height	**310 mm**
Output voltage	**Suitable for 12VDC or 24VDC**
Start-up wind speed	**Approximately 3~3.5ms^{-1} (5.82~7.82 knots)**
Cut-in wind speed	**Approximately 4ms^{-1} (8.95 knots)**
Generator	**Protected Three Phase permanent magnet**
Noise Level	**Less than 5dB, 5m from unit**
Coating	**All exposed parts powder coated Aluminium, centre shaft cold ano-dised**
Bearing	**Low temperature, fully sealed**
Temperature range	**-50°c to +50°c**
Wire	**10 metres 2 core wire (options available)**
Mounting option	**Side mount (included)**
Weight	**7 Kgs**
Installation	**Easy and simple**
Warranty	**2 years**

Table 17 - Vertical VAWT “A”, wind turbine. Source: FORGEN, adaptation ISTerre

Powering (Figure 57):
- Theoretical production: ≈ 6W at 35 km/h
- Max: 30Wp
- Start at ≈ 12 km/h

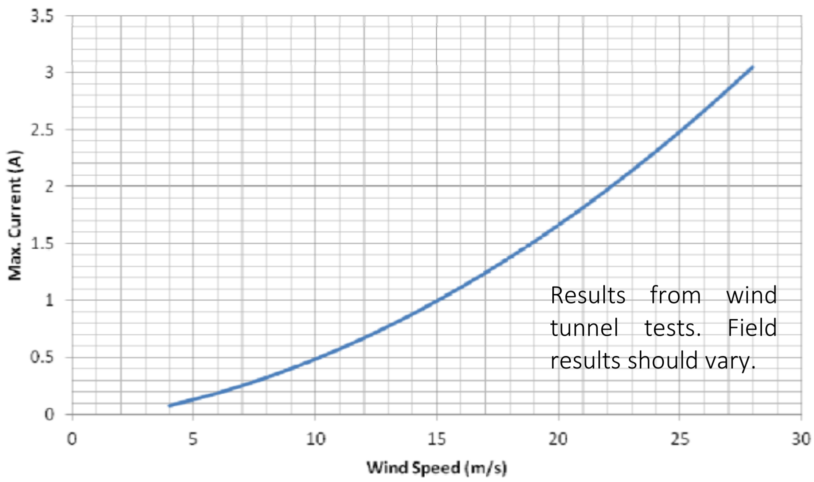


Figure 57 - Theoretical production of the "VAWT A" Wind turbine.

Electric installation:
- The wind turbine is directly connected to the 90 Ah battery. AC-DC Regulator inside.
- An electric charge of 200 mA (3 W) consumption.
- Battery protect that can open the charge loop. Set-up to open the circuit under on a 10,5 V threshold.

VAWT “B”:

Technical specifications

Rotor Diameter	300mm
Vane height	465mm
Output voltage	Suitable for 12VDC
Start-up wind speed	Approximately $2ms^{-1}$ (3.88knots)
Cut-in wind speed	Approximately $2.5ms^{-1}$ (4.85 knots)
Generator	Three Phase permanent magnet
Noise Level	Less than 5dB, 5m from unit
Coating	All exposed parts powder coated aluminium, centre shaft cold anodised
Bearing	Fully sealed
Temperature range	Normal Temperature: -20 °c to +50 °c, Low Temperature: -50 °c to +50 °c
Wire	10 metres 2 core wire (options available)
Mounting option	Pole mount, Wedge mount, Side mount, Rail mount
Weight	13 Kgs
Installation	Easy and simple
Warranty	2 years
Rated Power	50 W @ $20ms^{-1}$

Table 18 - Vertical VAWT "B", wind turbine. Source: FORGEN, adaptation ISTerre.

Powering (Figure 58):

- Theoretical production: ≈ 35W at 35 km/h
- Max: 70W
- Start at ≈ 6 km/h

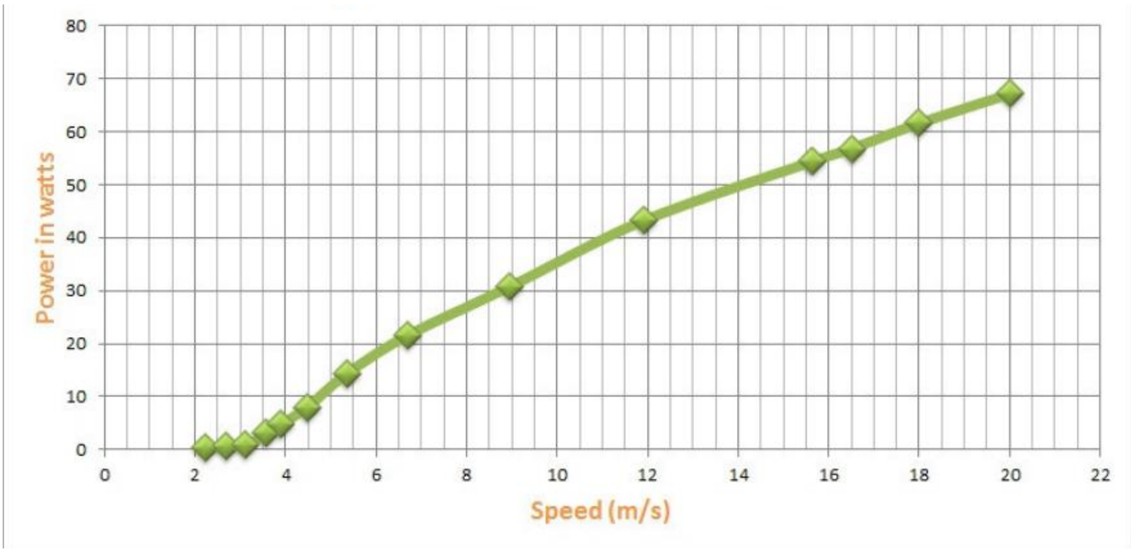


Figure 58 - Theoretical production of the "B" Wind turbine

Electric installation:

- The wind turbine is directly connected to the 90 Ah battery. AC-DC Regulator inside.
- An electric charge of 200 mA (3 W) consumption.
- Battery protect that can open the charge loop. Set-up to open the circuit under on a 10,5 V threshold.

Horizontal axis Wind turbine: “HAWT”

Technical specifications

Energy	Approx. 30 kWh/mo at 5.8 m/s (13 mph)
Swept Area	1.07 m2 (11.5 ft2)
Rotor Diameter	1.17 m (46 in)
Weight	5.9 kg (13 lb)
Shipping Dimensions	686 x 318 x 229 mm (27 x 12.5 x 9 in) 7.7 kg (17 lb)
Startup Wind Speed	3.58 m/s (8 mph)
Voltage	12, 24 and 48 VDC
Turbine Controller	Mircoprocessor-based smart controller
Body	Permanent mold cast aluminum
Blades	(3) Injection-molded composite
Alternator	Permanent magnet brushless
Overspeed Protection	Electronic torque control
Survival Wind Speed	49.2 m/s (110 mph)
Mount	1.5 in schedule 40 pipe 48 mm (1.9 in) outer diameter
Wind Speed Operating Range	3.6-22 m/s (8-49 mph)
Optimum Wind Speed Range	11-15 m/s (25-32 mph)

Table 19 - Horizontal “HAWT” wind turbine. Source: Primus Wind Power, adaptation ISTerre.

Powering (Figure 59):

- Theoretical production: ≈ 100W at 35 km/h
- Max: 400W at ≈ 50 km/h
- Start at ≈ 12 km/h

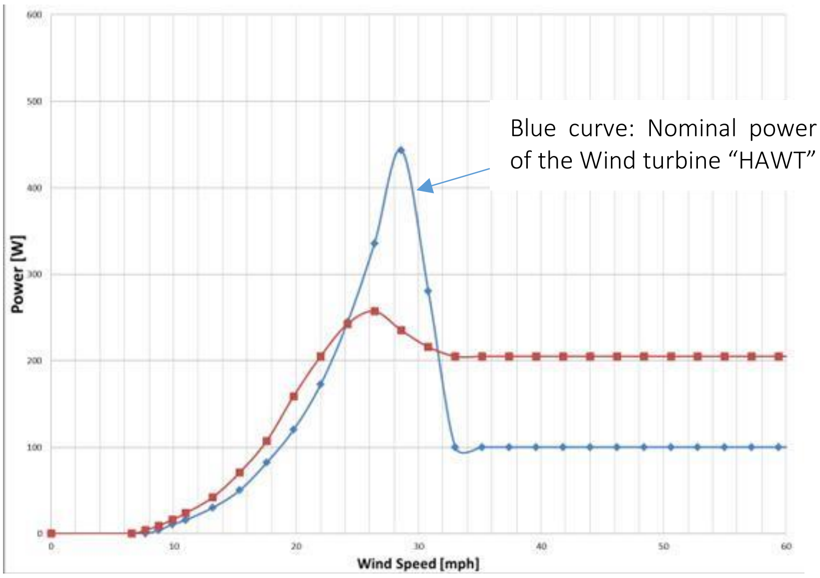


Figure 59 – Specification for the Wind turbine “HAWT” on blue curve.

Electric installation:

- The wind turbine is directly connected to 3 parallel 90 Ah batteries. AC-DC Regulator is located inside.
- An electric charge of 200 mA (3 W) consumption.
- Battery protector that can open the charge loop. Set-up to open the circuit under on a 10,5 V threshold.

c) Solar panels charge controllers

It was decided to compare the two major technologies as solar panel charge controllers, which are:

- PWM, as Pulse Width Modulation charge controllers.
- MPPT, as Most Power Point Tracking charge controllers.

The differences have been described in the technical chapter A "common knowledge on energy".
The chosen regulators have the following technical specifications:

	PWM	MPPT
Model	Victron PWM Duo	Victron MPPT Blue solar 75/15
Battery voltage (V)	12	12
Rated charge current (A)	20	15
Self consumption (mA)	4	10

Table 20 - Evaluated solar panels power regulators, MPPT and PWM.

Both PWM and MPPT lines are made with the same elements, exept of the charge controllers itself.

	MPPT system	PWM system
Solar panel	100 Wp monocrystalline, same reference.	100 Wp monocrystalline, same reference.
Solar panel tilt	Vertical	Vertical
Wires from solar panel to charge controller	2,5mm², multi-strand, same length (± 5%), same reference	2,5mm², multi-strand, same length (± 5%), same reference
Charge controller	MPPT Victron, 15 A max.	PWM Blue solar Duo, 10 A max
Wires from charge controllers to batteries	1,5mm², multi-strand, same length (± 5%), same reference	1,5mm², multi-strand, same length (± 5%), same reference
Other equipments	Battery Protect, 10,5 V threshold, same reference.	Battery Protect, 10,5 V threshold, same reference.
Batteries	YUASA VRAL Gel 90 Ah	YUASA VRAL Gel 90 Ah
Electric charge	Power resistance, 12 Ω, 50W max. Same reference.	Power resistance, 12 Ω, 50W max. Same reference.

Table 21 - Specifications of each electrical loop for solar panels regulators evaluation.

d) Data acquisition system

The data acquisition system is based on a Keysight 34970A multichannel data logger (Figure 60 and Figure 61). This data logger can measure 60 channels per second with 3 available slots for multiplexer cards. Each card can directly measure 20 channels of voltage U(V) and 2 direct current measurement of current I(A).

Figure 60 - Acquisition multiplexer card

Figure 61 - Acquisition data logger

The data logger main specifications are:

- 3-slots mainframe with built-in GPIB and RS242 interfaces
- 6 1/2-digit (22-bit) internal DMM
- Max voltage = 300 V
- Bandwidth = 10 MHz

Synaptic of the solar panels electric parameters acquisition, Figure 62 (Similar for wind turbines and charge controllers evaluations, just change the evaluated devices):

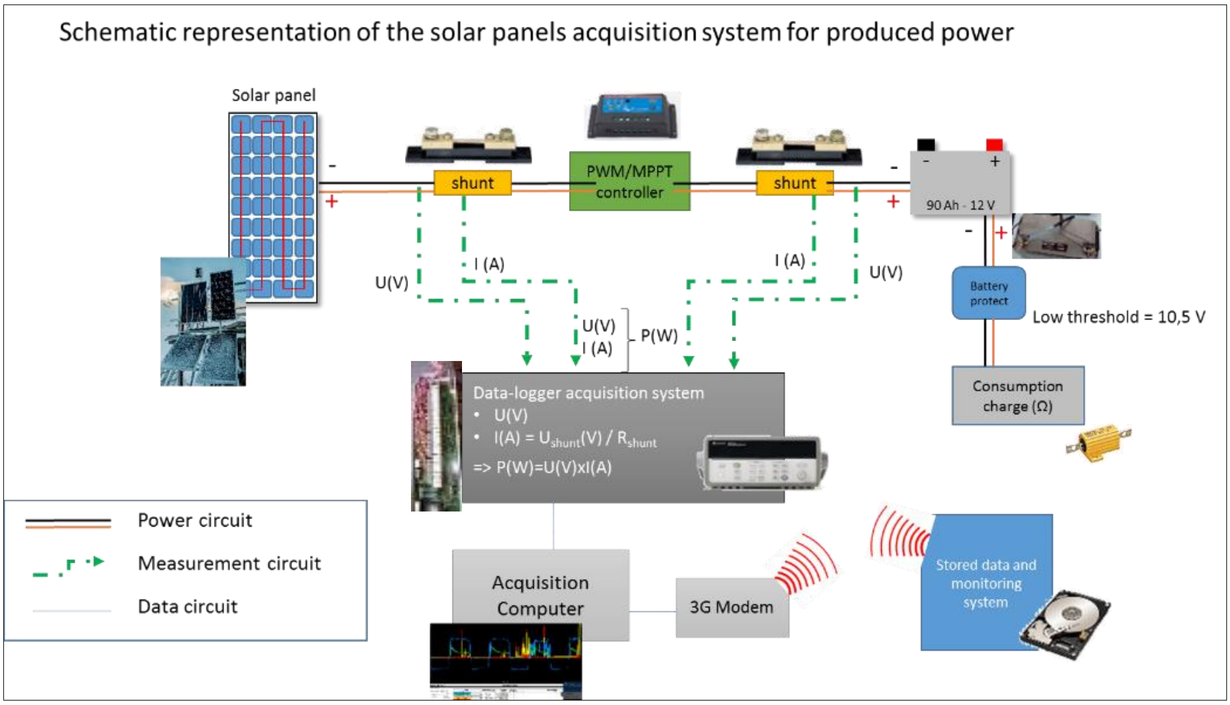


Figure 62 – Synaptic of the solar panels acquisition system for produced power.

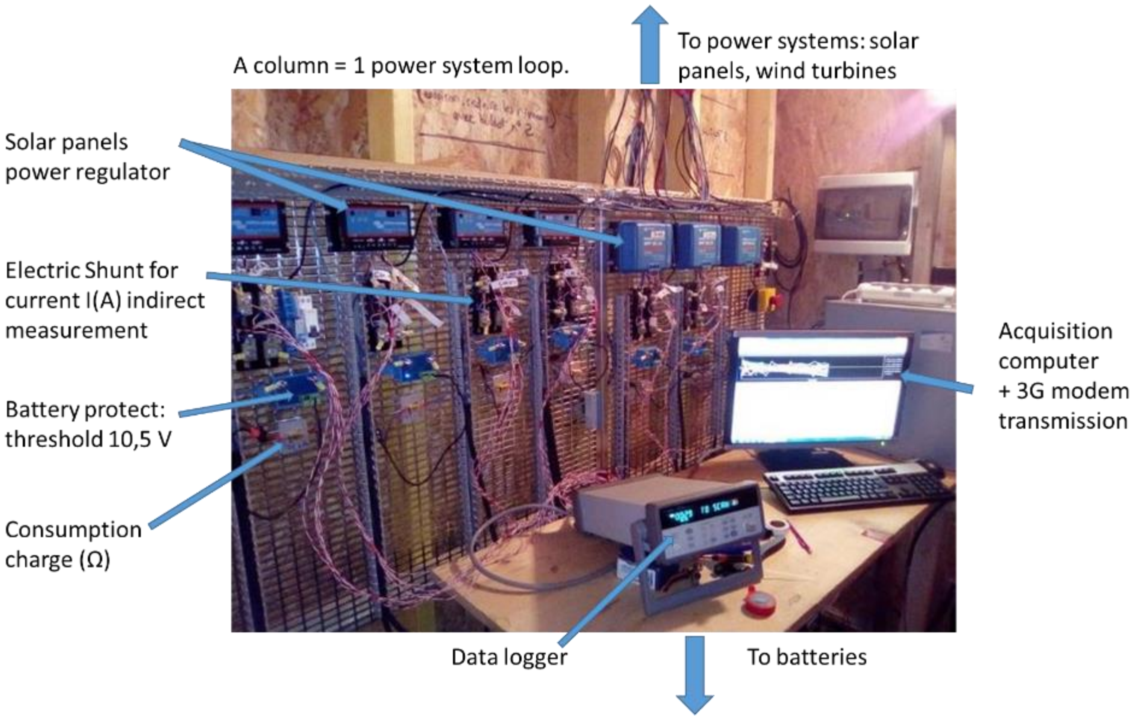


Figure 63 – ENVRI+ bench test solar panels acquisition system for produced power

As previously mentioned:

$$P(W) = U(V).I(A)$$

The purpose is to monitor U(V) and I(A) to obtain P(W), as displayed in the Figure 64:

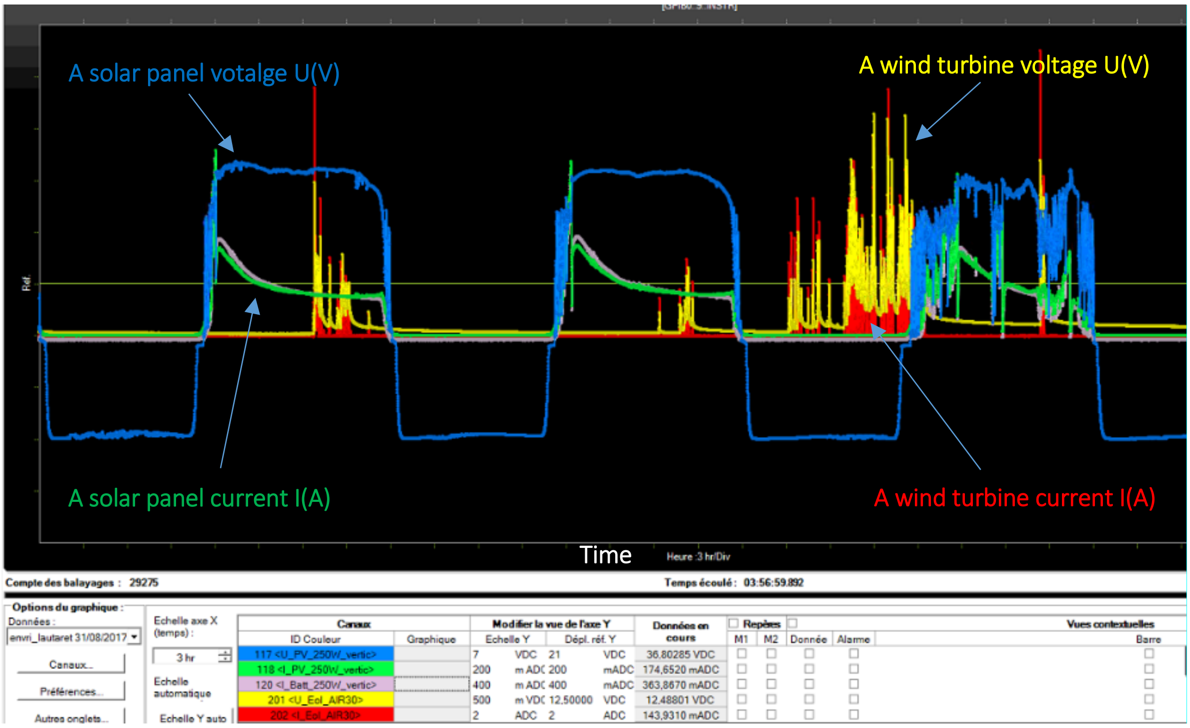


Figure 64 – Example of the data acquisition software displayed

The challenge was to set-up similar systems to the use one in fieldwork for scientific measurement (so with the whole system made with power production + storage). In order to evaluate power production systems, to fit research infrastructure needs (refers to ENVRI+ RIs Survey on energy, chapter B).
To do this, each power system loop is equipped with similar elements except for the power production part (eg: solar panel, wind turbine, …).

Precisions on all others similar equipment on each power loop:

- **Power circuit wires**: multi strand similar in diameter for each equal device (from 1,5mm² to 6)
- **Acquisition wires**: all length of twisted electric pairs are equal, in order to avoid uncertainty as we are measuring down from mV (1.10^{-3}) to µV (1.10^{-6}).
- **Batteries**: VRLA Gel 12 V, 90 Ah (refers to chapter A for batteries details)
- **Solar panels power regulators**:
  - PWM Duo for ≤ 100 Wp solar panels
  - MPPT for > 100 Wp solar panels
- **Consumption charges**: 2 W (R=75 Ω ± 5%) in the first measurement part (March to November 2017), then 12W (R=12 Ω ± 5%) from November 2017 to the end (still running at this report date, December 2018), to maximize solar panels production.

Note:
We will name "produced power" the power sent from solar panels to power resistors to be consume, through the batteries. We could also have talked about "energy consumed" as solar panels rarely reach them maximum nominal power, but just produce the needed energy to refuel battery and provide the online consume energy.

III. Evaluations results

1. Photovoltaic

a) Usual 100 Wp solar panels: vertical or 36° tilted, poly or monocrystalline.

Reminder:
100 Wp solar panels are “usual ones” for fieldwork measurements. A good compromise between enough power and appropriate size for human transportation. This is why 100 Wp solar panels have been chosen for this work.

- Global results

The Figure 65 presents recorded data from June to December 2017 of cumulated produced power from the four[11] 100 Wp solar panels.

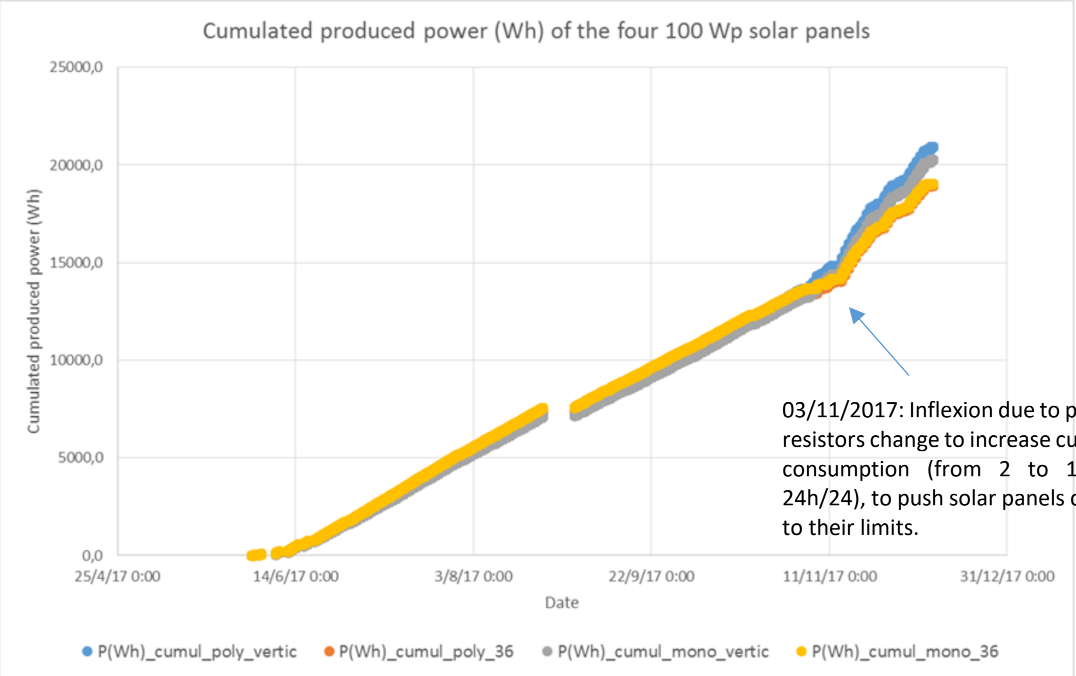


Figure 65 - Cumulated produced power (Wh) of the four 100 Wp solar panels (June to December 2017).

First of all, some precisions:

1: Data acquisition starts on March 2017. But previous data are not displayed here as the frequency acquisition changed in June from a f=5min (1/300 Hz) to a f=30 s (1/2 Hz) one to better record solar panels power regulators change in pulsation. For simplification we only kept the f=1/2 Hz data. Previous data from March to June does not change total results.

2: What does the inflexion curve mean in production, on 03 November 2017 ?.

The change of power resistors was made to consume more power and so to push solar panels closer to their limits to be able to highlight their potential differences. Indeed, power charges were first only consuming about 2W (75Ω in 12V, I ≈ 150 mA), that is representative of a typical seismograph or a weather station, but that is not enough to force solar panels to produce power (Wh) all day long as linked batteries have not been empty enough

[11] Vertical or 36° tilted, monocrystalline or polycrystalline. Refers to chapter C.II.2 for more details.

during nights, or even during few days without sun. We changed power resistors for new R=12 Ω ($I=U/R=12/12=1A$. $P=RxI^2=12x1^2=12W$) for 100 Wp solar panels, and R=5 Ω ($I=U/R=12/5=2,4$. $P=RxI^2=5x2.4^2=28.8$ W) for 250 Wp ones. We should have chosen to test solar panels without batteries, but just with a direct charge consumption to make them produce all day long, close to their limit. Without a possible "full tank" that makes the production stop. That would have been this protocol in standardization laboratory as ISO, AFNOR, But our aim is was different: to compare global systems in the way we are using them, on the fieldwork. Thus, with batteries and low consumption, as we need power production and storage for autonomy.

Back to total produced power (Figure 65).
Recorded data shows two main facts:

1: Vertical Vs 36° tilted present high differences: vertical solar panels clearly produced more than 36° tilted ones.

2: Mono Vs Poly present low differences. Produced power are very close.

Let's focus on those two aspects.

- Vertical versus 36° tilted.

The following histograms (Figure 66) present same results as the previous Figure 65 but clearly highlights produced power gap from vertical to 36° tilted solar panels.

Do not compare absolute production that are just representative of the total running hours (that are of course similar for all of the four 100 Wp solar panels) but pay attention to their relative comparison.

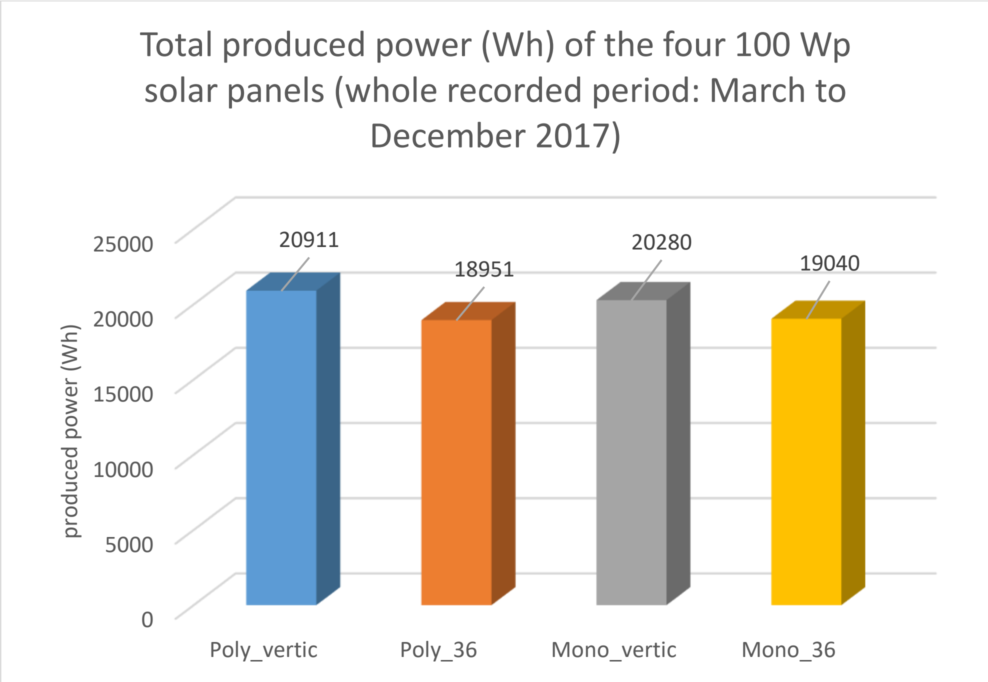


Figure 66 - Total produced power (Wh) of the four 100 Wp solar panels (whole recorded period: March to December 2017).

If we average vertical and 36° solar panels production, we obtain the following Figure 67 that precise this difference: **+8%** from vertical to 36° tilted

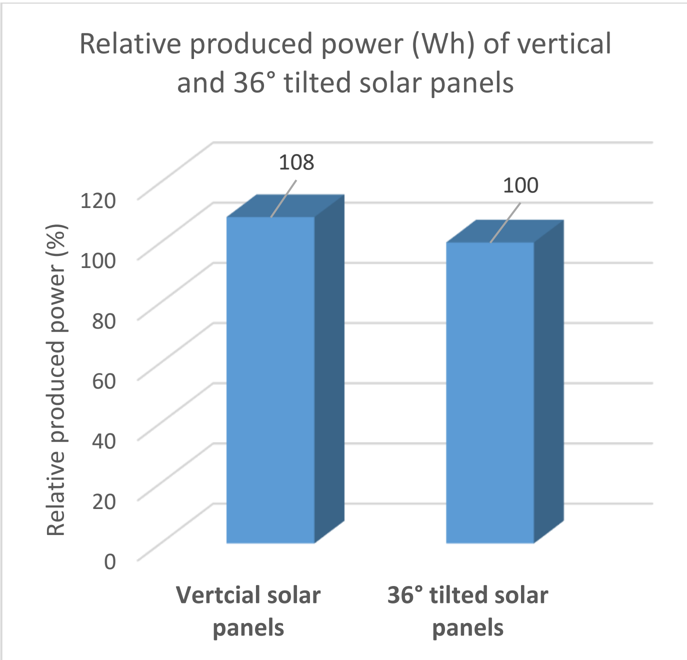


Figure 67 - Vertical and 36° tilted solar panels difference in terms of produced power (Wh) on the total recorded period.

As we know, main reasons for this difference are: a lower sun in winter above the horizon as well as a higher albedo effect (ground light reflection), that both favor vertical solar panels. Let's focus on the second period (after power resistor change on 03/11/2017) that increase current consumption level and so production differences. And where snow was recovering the ground. Furthermore, snow can of course cover a 36° tilted solar panels as it cannot shadows a vertical one.
Winter results are displayed in the following Figure 68.

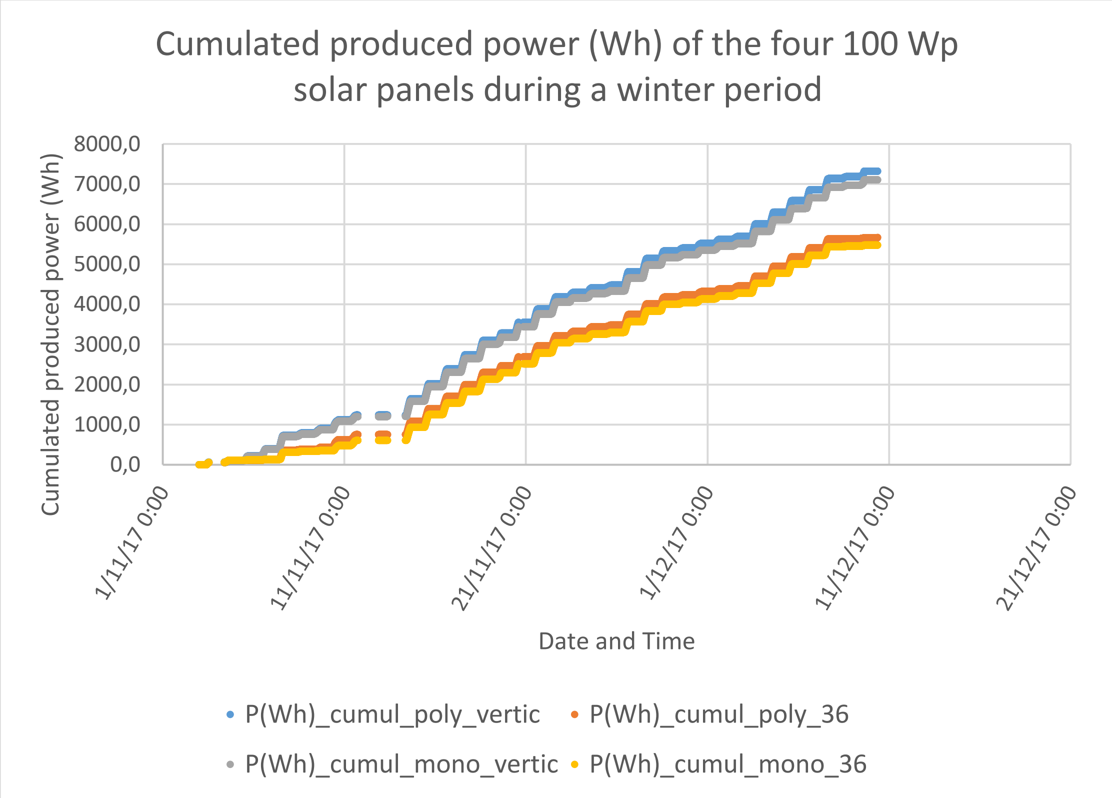


Figure 68 - Cumulated produced power (Wh) of the four 100 Wp solar panels during a winter period (3/11 to 11/12).

A higher gap in terms of produced power is clearly recorded, with a **+29,5%** gain from vertical solar panels to the 36° tilted ones. (Base 100 = 36°). As presented on the next histogram, Figure 69.

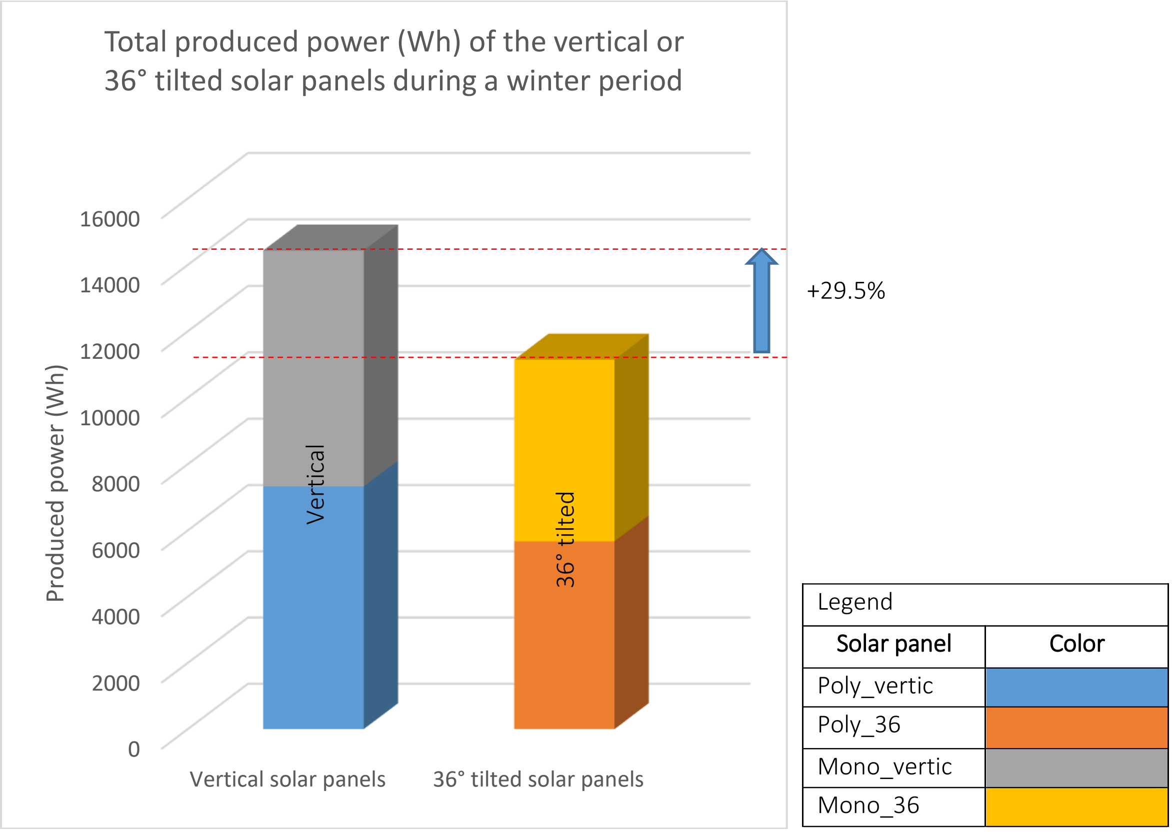


Figure 69 - Total produced power (Wh) of the vertical or 36° tilted solar panels during a winter period (3/11 to 11/12).

Trying to go further in the understanding of those interesting differences for our special in fieldwork uses, let's try to analyze data in the way of the main reasons for this gap:

1. **Sun is lower above the horizon during winter time**, that favors vertical solar panels more than 36° tilted for a maximize production.
2. **Snow effects**: deposition is avoided for vertical solar panels (as we can see on the Figure 72) and Albedo effect, reflected light by the snow cover.

Details:

1. Sun is lower above the horizon during winter time, that favors vertical solar panels tilted more than 36° for a maximum production.

In the northern hemisphere, sun is the lowest on 21th of December. This is the winter solstice. At this time, an optimum angle for solar panels production at a 45° latitude site (As the city of Grenoble) would be: 45° + 23,5° = 68.5° (0°=horizontal). A vertical solar panel (that better avoid snow deposition) will have it's higher yield at this time.

On the opposite, the equinox day (half way from the zenith to the nadir) for a 45° latitude site will be the optimum for a 36° solar panel.
The following table (Figure 71) presents total produced power as well as maximum rated power of the four solar panels during those two major periods.

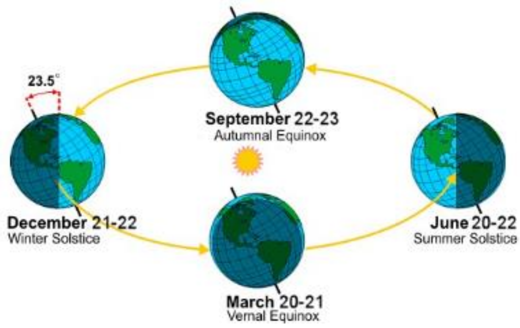
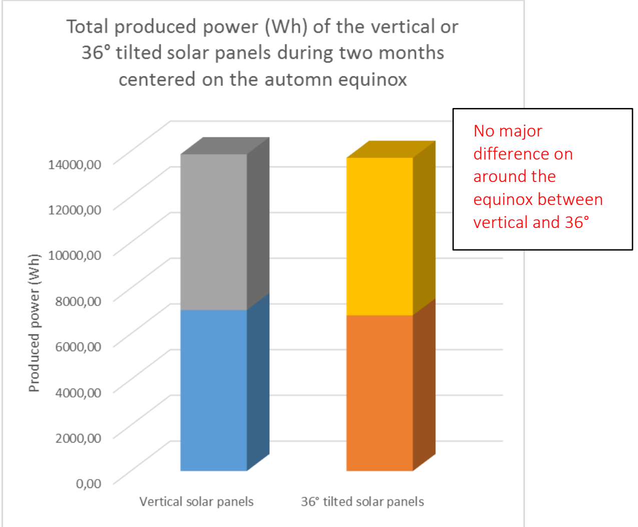
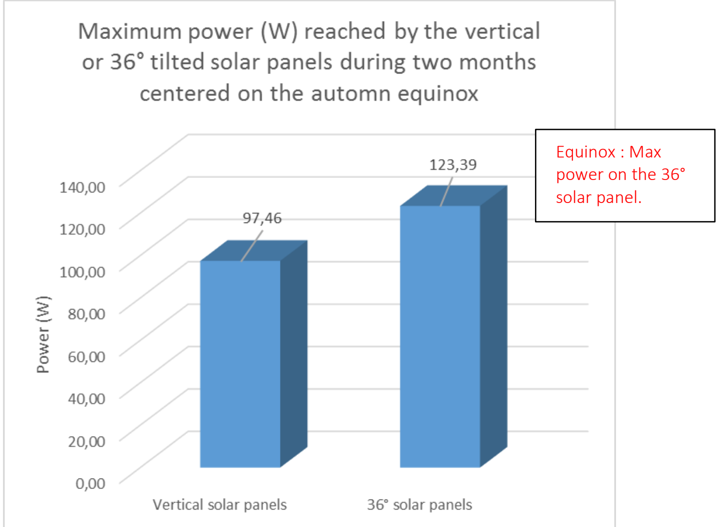


Figure 70- Incident Sun light on Earth surface at Equinox and Solstice.

Produced power (Wh) | Maximum rated power (W)

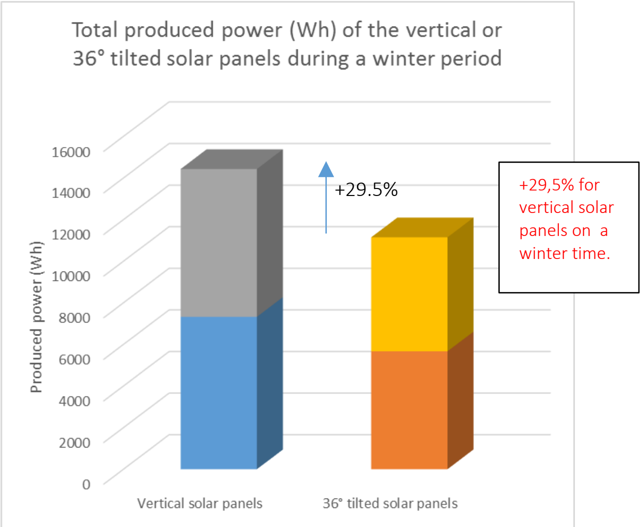
Equinox period

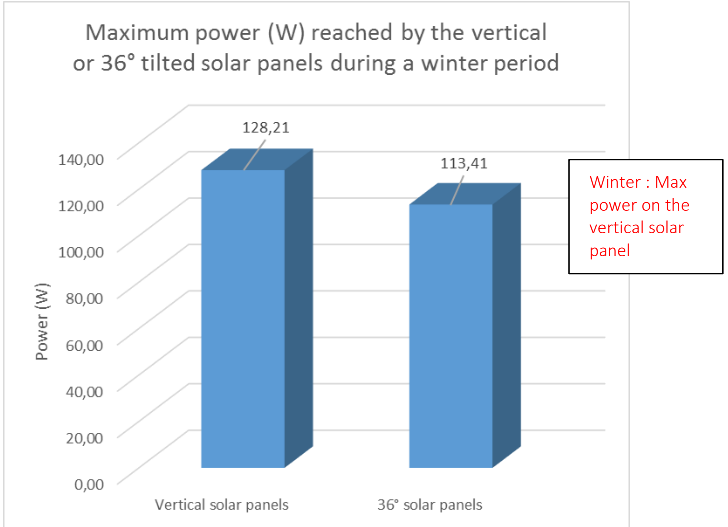




Differences
➔ Vertical solar panels produced + 1.1% (base 100 = 36°)
➔ 36° solar panels maximum power exceeded vertical by + 21% (base 100 = 36°)

Winter period





Differences
➔ Vertical solar panels produced + 29.5 % (base 100 = 36°)
➔ Vertical solar panels maximum power exceeded 36° by + 13% (base 100 = 36°)

Figure 71 - Comparison of solar panel produced power (Wh) between Equinox and Winter period.

2. **Snow effects**: deposition is avoided for vertical solar panels and Albedo effect, light reflection on snow cover.

First a quick explanation about the "Albedo effect".
The albedo effect is the reflection of the incoming solar light, the irradiance. It is represented by a 0 to 1 value.

- 0 is for a perfect black surface that could (theoretically, in physics we would talk about a perfect "black body") absorbing all the incident electronic radiations.
- 1 Would be for a perfect mirror that could reflects 100% of the incoming light.

The following table gives values for the main ground covers:

Surface	Albedo
Ocean	0.05 – 0.1
Sand	0.25 – 0.40
Ice	0.30 – 0.60
Fresh snow	0.90

Table 22 - Some Albedo values. Source: CNRS

In our case, for high mountains or polar regions, important factor is the fresh snow that can reflect up to 90% of the incoming light on bright day.

Then, let's have a look on a snowy day, where snow deposition can be added as an inconvenient for 36° solar panels, in addition to their less capacity to use the albedo effect.

On the 29/11/2017, there was such a snow deposition on the 36° tilted solar panels, as seen on the following Figure 72.

Figure 72 - Snow deposition on 36° tilted solar panels

On this day, the cumulated produced power (relative, in %, base 100 = vertical solar panels of each technology.

e.g: poly or Monocrystalline) was as presented on the next Figure 73.

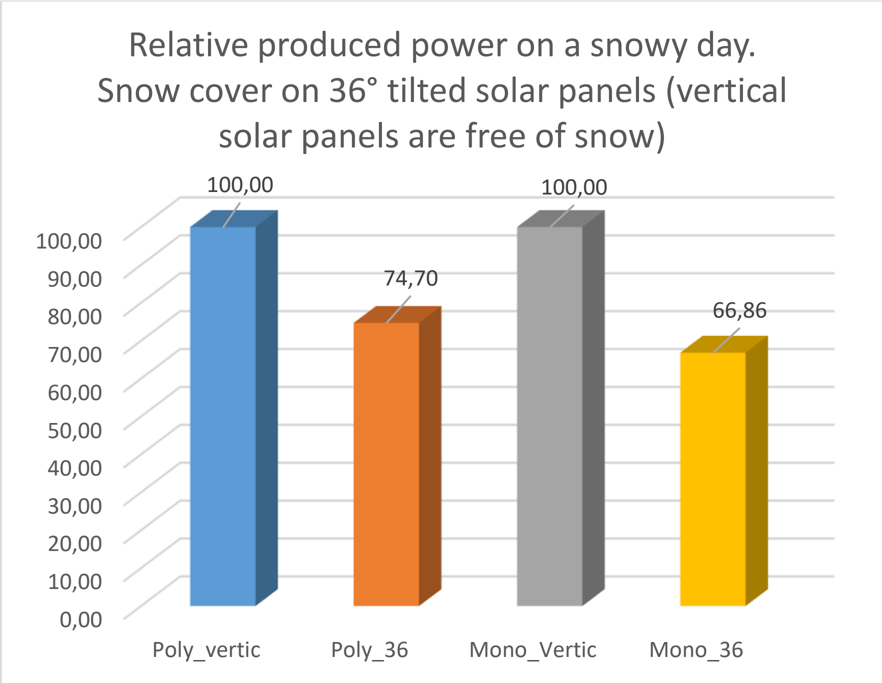


Figure 73 – Relative produced power on a snowy day. Snow cover on 36° tilted solar panels (vertical solar panels are free of snow)

For this day, **36° tilted solar panels produced about 30% less electricity** than vertical solar panels.

Remark: an explanation for Mono_36 to Poly_36 shift in production would be a difference in terms of snow quantity from one to the other. As visible on the Figure 72 (poly is on the left, mono on the right)
With more data on snowy days, we could strengthen this first result. Still, this is a global tendency.

Conclusions:
Regarding vertical versus 36° tilted solar panels we can strongly advise users (especially for high mountains and polar regions) to stand them in vertical, or close to position.

- Polycrystalline Versus Monocrystalline

As seen on the next **Erreur ! Source du renvoi introuvable.** (total cumulated produced power of the four 100 Wp solar panels), Monocrystalline and polycrystalline solar panels have produced:

Solar panel	Produced power (Wh)
Poly_vertic	20911
Poly_36	18951
Mono_vertic	20280
Mono_36	19040

Table 23 - Cumulated produced power (Wh) of the four 100 Wp solar panels.

If we average poly or mono production, we are getting the following values:

Solar panel	Produced power (Wh)	Relative produced power (%, base 100 = poly)
Polycrystalline solar panels	19931	100
Monocrystalline solar panels	19660	98,6

There is only a difference of 1,4% (base 100 = polycrystalline) in production, in favor of the polycrystalline solar panels.

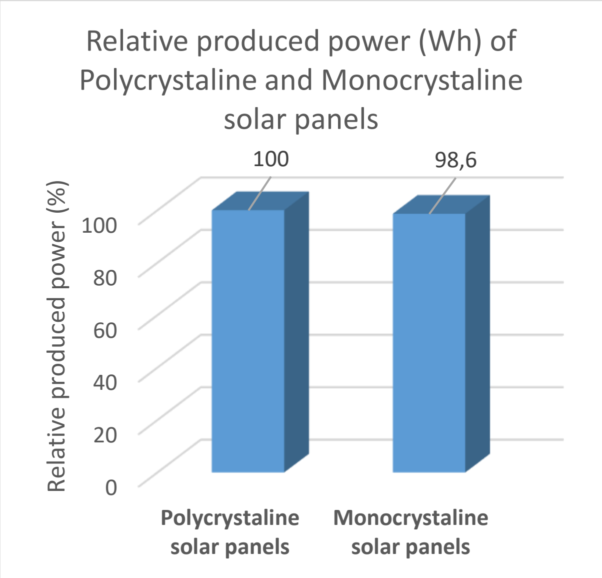


Figure 74 - Relative produced power (Wh) of Polycrystalline and Monocrystalline solar panels

Those four solar panels had been certificated by the same constructors as a nominal production of 100,3360 Wp. That is so expected to have a very similar production.

A question of size:

The only characteristic that reflects their yield differences is about their size. As presented in the following Table 24.

	Polycrystalline	Monocrystalline
Number of photovoltaic cells	36 (9x4)	36 (9x4)
Cell length (cm)	15,5	12,5
Cell larger (cm)	10,5	12,5
Cell surface (cm²)	162,75	156,25
Total cells surface for 1 solar panel (cm²)	5859	5625
Area difference (%)	100	96

Table 24 - Photovoltaic area of the 100Wp solar panels.

Polycrystalline technology needs a larger area to produce the same quantity of energy as its yield is generally lower than one in monocrystalline technology (i.e: chapter A, Figure 10 - Best research cells efficiencies. Source NREL. https://www.nrel.gov/pv/). But for our needs (isolated station about 2 to 50 W) we do not care about having 1 or 1,05 m².
This could be an important issue for people who plan to produce and sell electricity from their roof that has, indeed, a limited area. They will of course try to find the best surface yield to maximize production on each square meter.
In our case, polycrystalline solar panels area difference is about 4% as calculated at the previous Table 24. Leading to a 4,15% shift in terms of relative yield (base 100 = polycrystalline solar panels).

	Area (cm²)	Produced power (Wh/cm²)	Yield (Wh/cm²)	Relative yield (%, base 100 = poly)
Polycrystalline solar panels	5859	19931	3,407	100
Monocrystalline solar panels	5625	19660	3,548	104,15

Table 25 - Estimated yield differences between poly and monocrystalline solart panels from our evalations.

This is not an important issue for on-site scientific station power supply. Furthermore, our present bench test (Col du Lautaret) that is a fieldwork evaluation, has intrinsic incertitude due to a changing environment (but on the other hand, changes are similar for all solar panels) because that it is tricky to conclude on a so small yield difference of 4,15 %.
But, correlated with what we saw in chapter A “common knowledge on energy”, we can still advice users to go for monocrystalline technology, as this one has typical higher yields about 5%).

And as far as we saw, it is more important to put you solar panel in vertical position to avoid snow deposition and to maximize albedo effect, where difference is about 30% from vertical to 36° tilted, than focusing on poly or monocrystalline differences, where we are talking about difference of ± 5%.

Global conclusions for our special uses are thus:
1. To stand them in vertical (high mountain and polar regions).
2. To prefer monocrystalline technology rather than polycrystalline.

As complementary information on solar photovoltaic cells yield regarding others technologies, you can refers to Annex I as the SIRTA bench test, or to national research center on solar energy (as the French INES, the American NREL,…)

b) Bifacial east-west Vs Monofacial south oriented

For a snowy period, with albedo effect, Figure 76 represents the cumulative produced power (Wh) of both bifacial and monofacial solar panels.
The monofacial rates 250Wp, as the bifacial is a 270Wp. A coefficient of 270/250 = 1,08 had been applied on the monofacial solar panel production to be compare to the bifacial one.
As a reminder, the bifacial is West-East oriented, as the Monofacial is south oriented: Figure 75 .

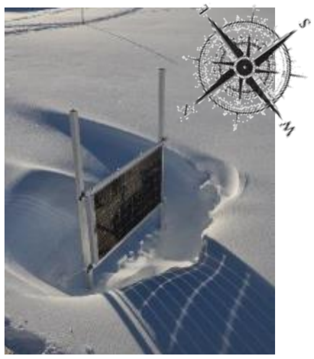


Figure 75 – Picture of the bifacial solar panel. Est-West oriented, and vertically tilted.

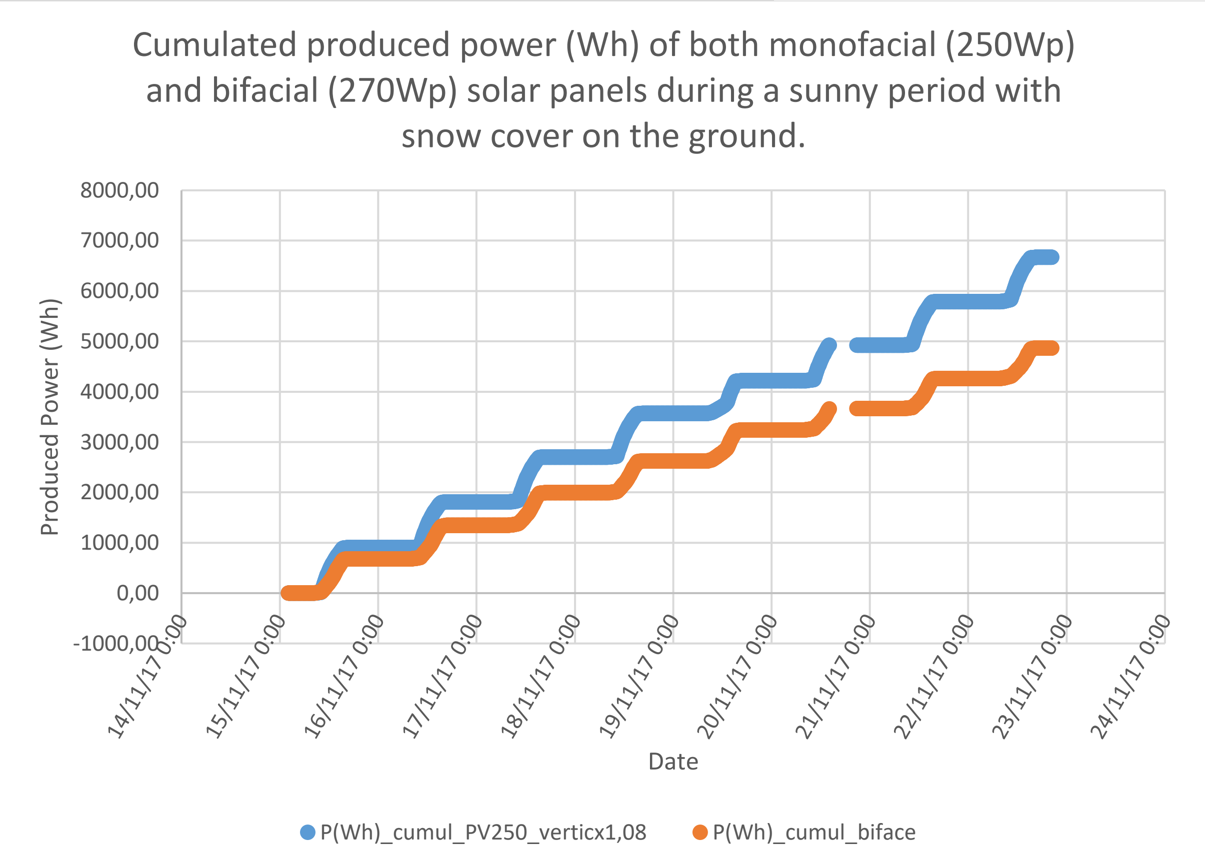


Figure 76 - Bifacial and Monofacial produced power on a sunny period with snow cover.

During this period, the **monofacial south oriented solar panel produced 26% more energy than the bifacial one**.

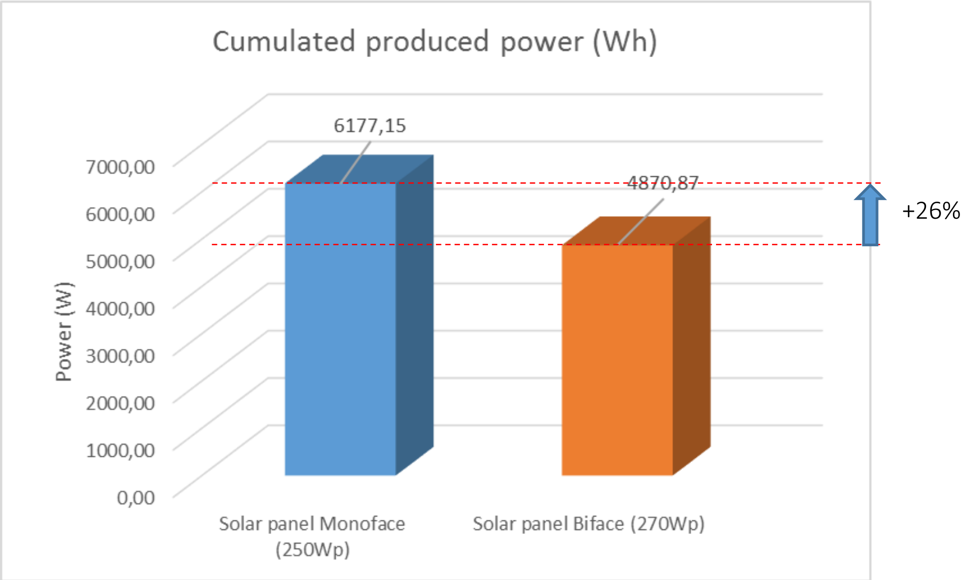


Figure 77 - Total bifacial and monofacial produced power on a sunny period with snow cover .

This a major difference.
Interest of bifacial solar panels should be on winter period and for polar regions with very low sun above the horizon, and turning all day long for the sunny period.
But in our alpine case, a higher sun around mid-day makes the production increasing far more speeder than the gain in the morning and in the evening of the East-West oriented bifacial solar panel.
That is right that voltages are higher in the beginning and end of day for the east-west oriented bifacial solar panel, as shown on the Figure 78.

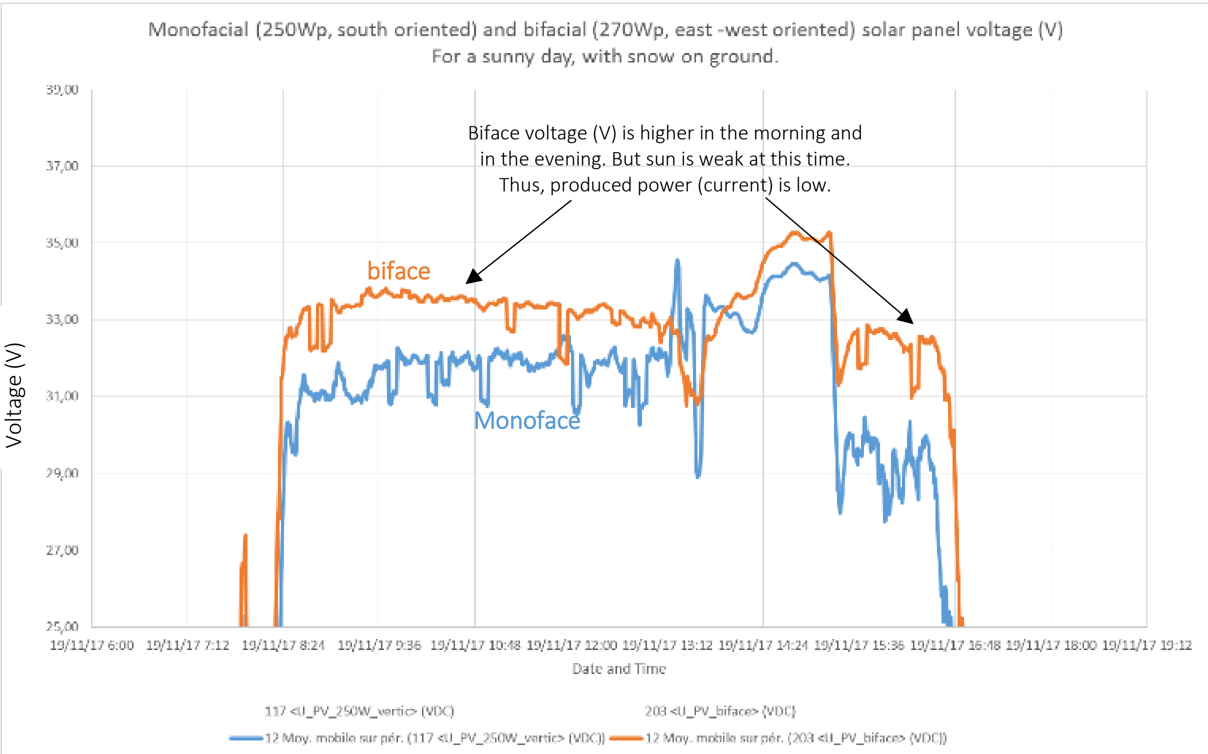


Figure 78 - Monofacial and bifacial solar panels voltage (V) during a sunny day with snow cover on ground.

But as the sun is so weak that it is low above the horizon (a very much longer atmosphere to pass through, enhancing light attenuation, like the “red-shift”), only few Amperes will be produced. The final produced power is thus lower than just during the mid-day hours where the sun is striking hard, as we can see in the next Figure 79. Moreover increased by a high albedo effect with the snow cover.

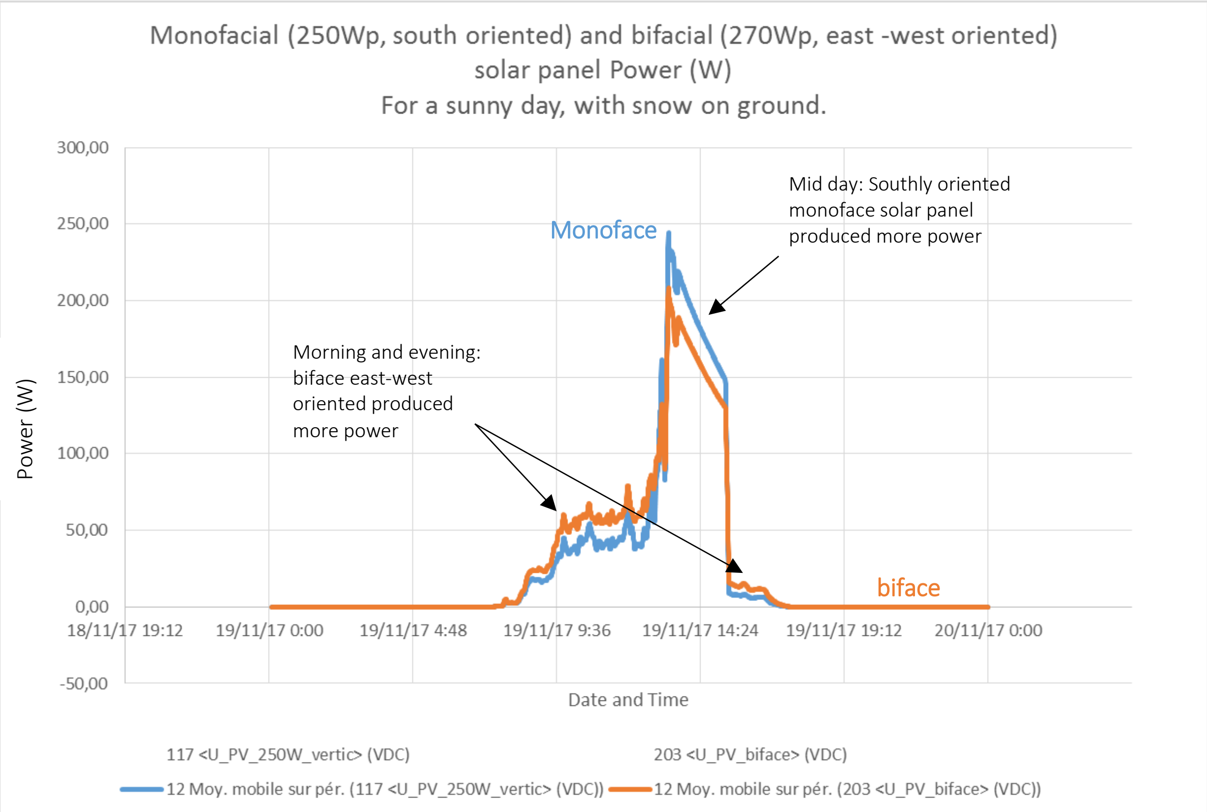


Figure 79 - Monofacial and bifacial solar panels power (W) during a sunny day with snow cover on ground.

As we can see in the next Figure 80, taken during this very sunny day with snow on ground, the biface maximum rated power is relatively low: 211,38 W ($P_{nominal}$ = 270 Wp), as its cells are never perpendicularly oriented to a powerful sun.

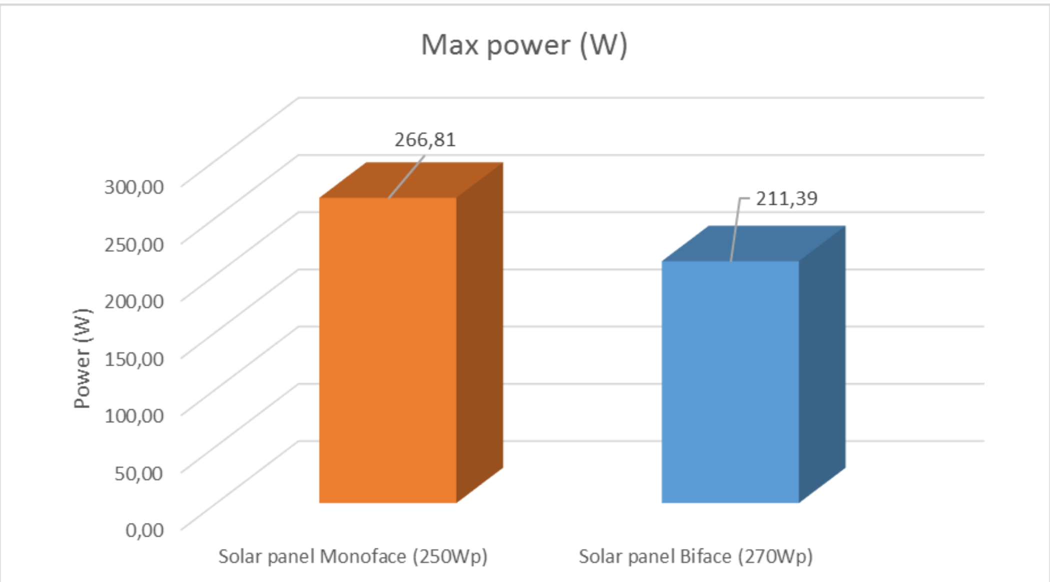


Figure 80 - Monofacial and bifacial solar panels maximum rated power (W) during a sunny day with snow cover on ground.

Conclusions:

- East West Bifacial solar panels are (in usual cases) not relevant for an alpine isolated scientific stations. As an equivalent (in power) monofacial south oriented one will produce more power during the mid-day hours than the east west bifacial during morning and evening.
- From our evaluation, we cannot confirm usual announced advantages of a "≈ 20% more energy" coming from bifacial solar panels, highlighted by manufacturers. Voltage $U(V)$) can be 20% higher, but as the sun is weak at this time of the day, and as current is directly proportional to photon ($I\ (A) = f\ (light)$), then power $P(W) = U(V).I(A)$) is low.
- Could be interesting in polar regions as the sun during its "ON" period will turn all around 24H/24.
- Bifacial solar panels are actually (2017) only available from the world photovoltaic market in big size, ≈ 1,60 m x 1,10m. which is too high to be man-transported on the field. That is a critical issue that actually make bifacial solar panels not relevant for Ris special cases.

Remark:

We did not test a bifacial solar panel south oriented and vertically tilted. That could be more powerful than an equivalent of Monofacial panel, thanks to the albedo effect on the back of the solar panel. But for this case, the problems of available sizing on the market will be the critical issue.

2. Wind turbines

Recommendations:
1: From our cases of scientific data stations, it is not relevant to talk about the average produced power (in Wh) of a wind turbine for a special period. Indeed, we do not intend to maximize electricity production to sell it. Wind turbines will be set-up at the exact place where measurement will take place and wind will sometimes just not blow. The wind turbines will so be off (no production) for an significant part of the time.
An average will so include lots of “zero production” that will show this one in a very much lower level than presented by the manufacturer specifications, where data comes from laboratory wind tunnels.
This will be important to keep in mind for sizing.

2:
A f=30s (0,5 Hz) frequency acquisition is sometimes be not speed enough to record all electricity impulsions sent from wind turbines to batteries, due to their Pulse Width Modulation charge regulators. But as it was the right balance between file sizes (and so to send them with 3G network from an isolated site) and strong enough accuracy for solar panels, we kept this 30s frequency.
Consequences for wind turbines are that we maybe lost the highest production peaks. That makes the visible average production decrease. But, relative productions from one to another are still correct to be compared as they faced same winds. We will not focus on absolute values, but we will analyze them in a relative point of view.

3:
Evaluations of wind turbines are focusing on the following characteristics:
- Mechanic resistance: with respects to manufacturer set-up guidance.
- Comparison of the total relative produce power for a same period, for the three tested wind turbines.

a) Overall results:

Wind speed at the Col du Lautaret
- Average 2015 = 15 km/h
- Average from September to December 2017 = 16,7 km/h

Reminder:

	HAWT	VAWT A	VAWT B
Power (W) @ wind = 35 km/h	100	6	35
Max power (W)	400	30	70
Starting wind (km/h)	≈ 12	≈ 12	≈ 6



Table 26 - Reminder: specifications of the evaluated wind turbines.

Mechanic:
The Horizontal Axis Wind Turbine (HAWT) and the Vertical Axis Wind Turbine A (VAWT A) have been used at this site during two winters without any damages. But with a regular two months check-up and maintenance: screwing and adjusting vertical and horizontal axis to prevent from a premature usury.
Strongest winds reached 80km/h.

The VAWT B had been evaluated during 2 months before going to its final destination: on a rocky glacier at more than 2500 m high, to power seismometers.
The following Figure 81 presents a part of the common recorded produced power from those three wind turbines.

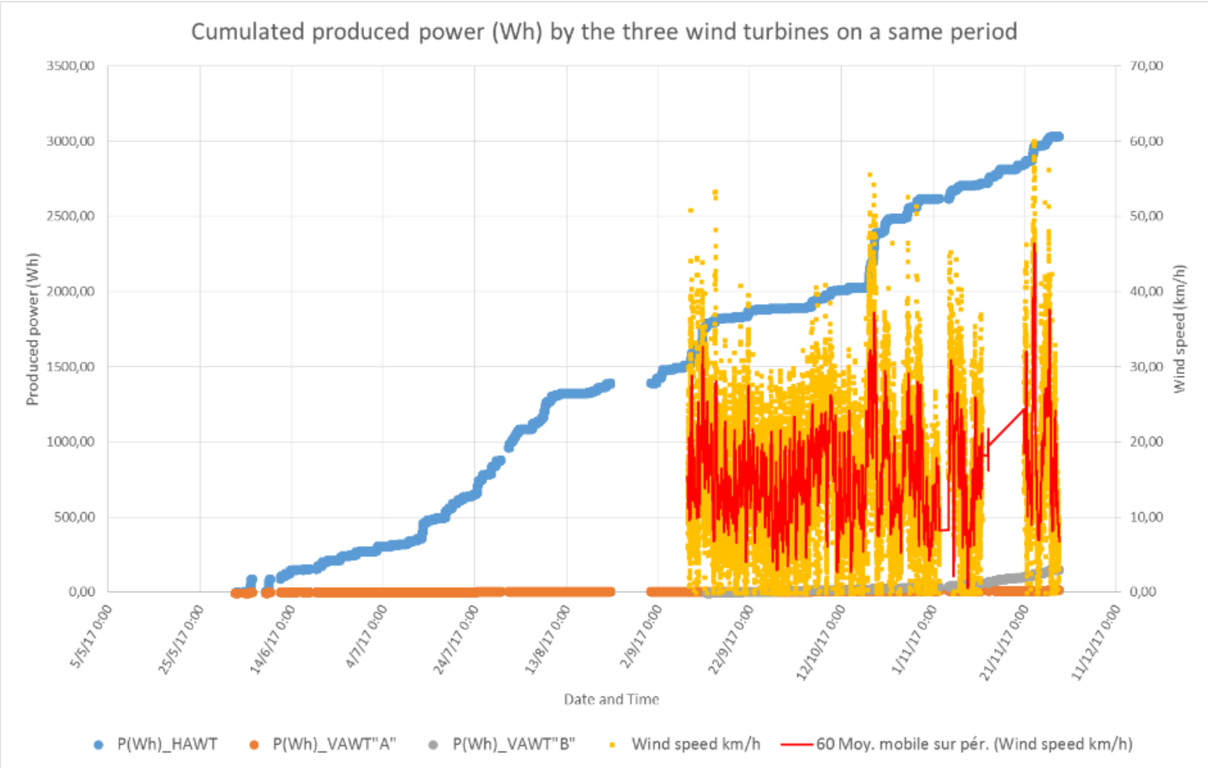


Figure 81 - Cumulated produced power (Wh) by the three wind turbines on a same period.

In a relative point of view (% Wh, base 100 = VAWT B), those three wind turbines produced the following energy in Wh (Figure 82):

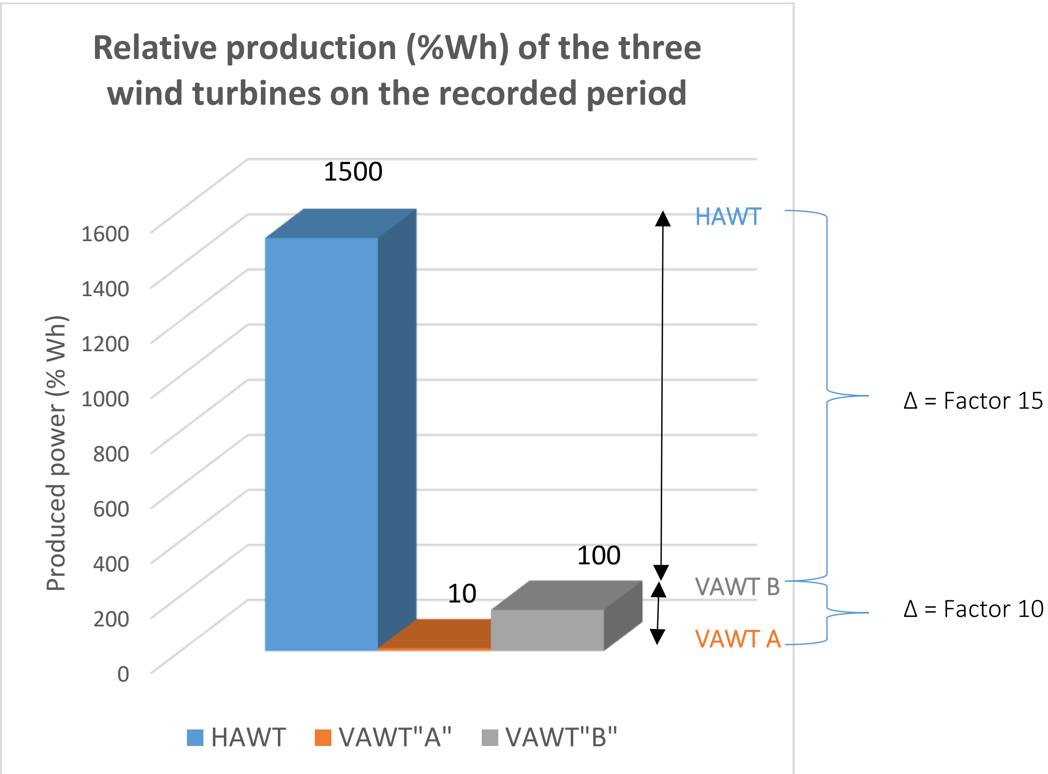


Figure 82 - Relative produced power (Wh) of the three wind turbines during a same recorded period.

Prices:
All those three wind turbines costed about 800€ (±100) in 2017.

Mechanics resistance:
At the date of this report, all those three wind turbines past 1 or 2 winters, with winds up to 80km/h.

Remark:
A f=30s is not fast enough as wind gusts can change more quickly. We could have missed the highest power peak with the strongest gusts. This is one of the reasons why manufacturers speak more about produced power (Wh) than nominal power (Wp) for a special wind turbines. But attention! Tests are of course made in laboratory, using wind tunnels. That is, indeed, far away from our on-site real conditions.
=> For on-site application, it is so important to oversize wind turbines potential power, as the nominal power announced by manufacturers is of course far from power in real conditions.

At the Lautaret site, annual wind speed average is about 15 km/h, which is also the lower speed limit for both VAWT A and HAWT (down to 12 km/h, but at this speed they just “start” to move). If we so have a look to the produced power for different wind speed ranges, as displayed on the Figure 83, we can see that:

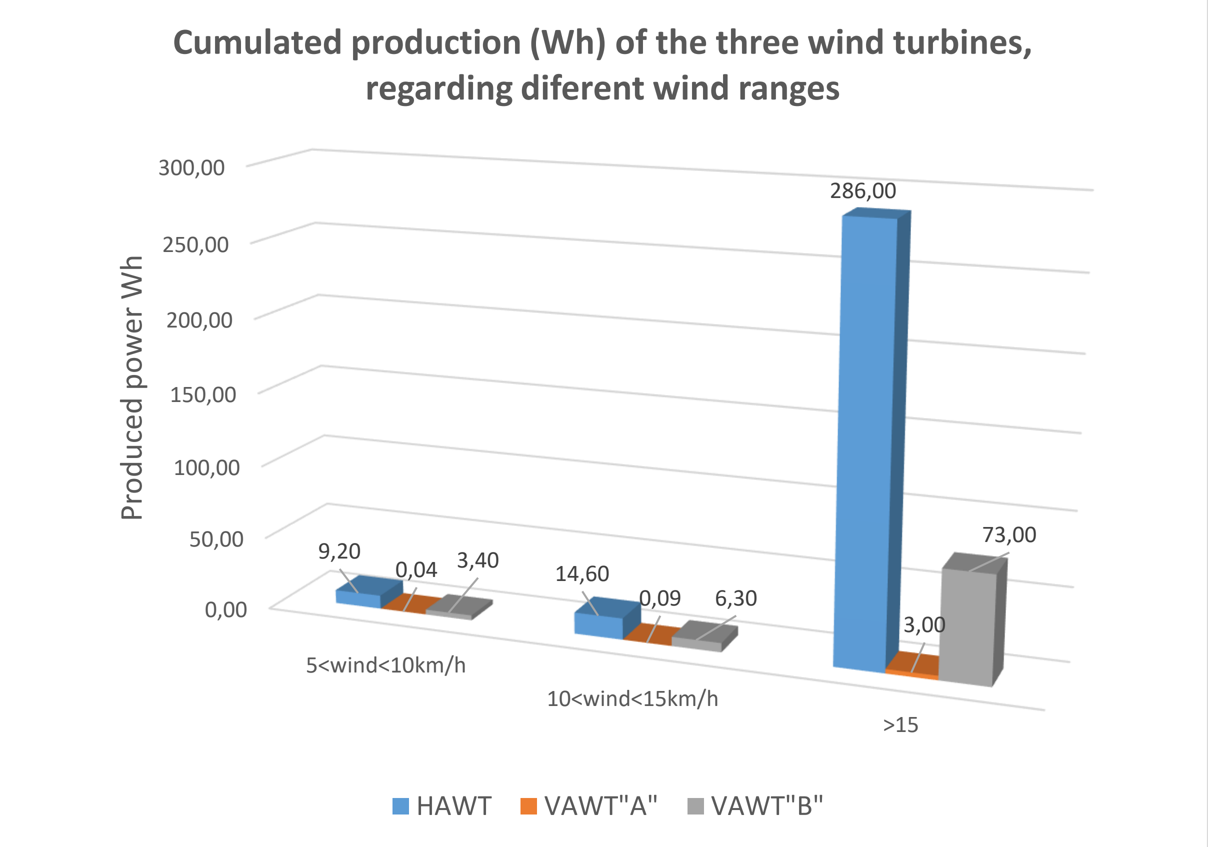


Figure 83 - Cumulated production (Wh) of the three wind turbines, regarding different wind ranges.

1. VAWT A is not powerful enough in our on-site conditions.
2. HAWT is four times more powerful than the VAWT B with wind speed up to 15 km/h.
3. HAWT is “only” two times more powerful for winds under 15 km/h. that makes the VAWT B relatively interesting.

The VAWT B could be appropriated for very low wind speed sites. That is correlated with theoretical manufacturer’s datasheets which announce a starting wind speed at 6 km/h.
Production for HAWT and VAWT A for wind speed lower than 12 km/h are due to the average of the 30 s acquisition that can mask some wind gusts.

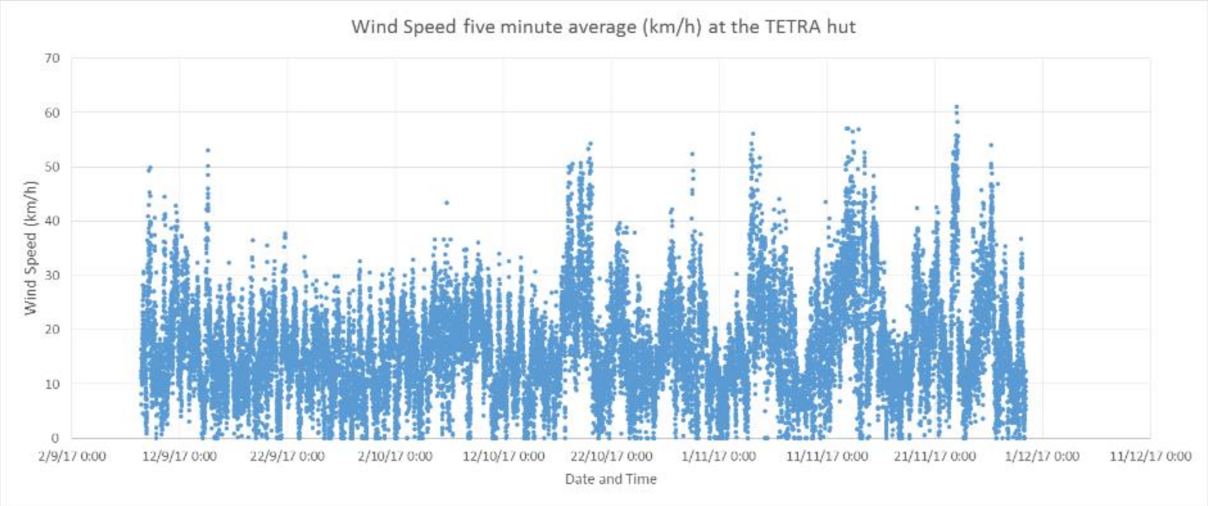


Figure 84 - Wind Speed five minute average (km/h) at the TETRA hut.

Wind speed (km/h)	% of occurrence on the recorded period
>15	50
35<Ws<50	4
>50	0,3

Table 27 - Wind speed ranges occurrences at the TETRA Hut .

An additional feedback on wind turbines VAWT B

Following the first evaluation on the ENVRI+ site (TETRA Hut), the wind turbine B moved to its final destination that was the rocky glacier in the Laurichard Val (Valon du Laurichard), 2500 m high in the Alps mountain.

Figure 85 - seismic monitoring of a rocky glacier in the alp mountain , powered by two vertical axis wind turbines (in the red circles).

Energy consumption of the whole scientific system was: 1 ≤ P(W) ≤ 3 W. There is no data transmissions, only acquisition.
Power equipment at date was: Two VAWT B and one 100 Wp solar panel in parallel. They were connected to more than 400 Ah 12 V batteries.
Wires length between batteries and data logger caused a 0,8 V lost (about 50 m length).

The following Figure 86 presents the recorded seismic data logger entry voltage (V):

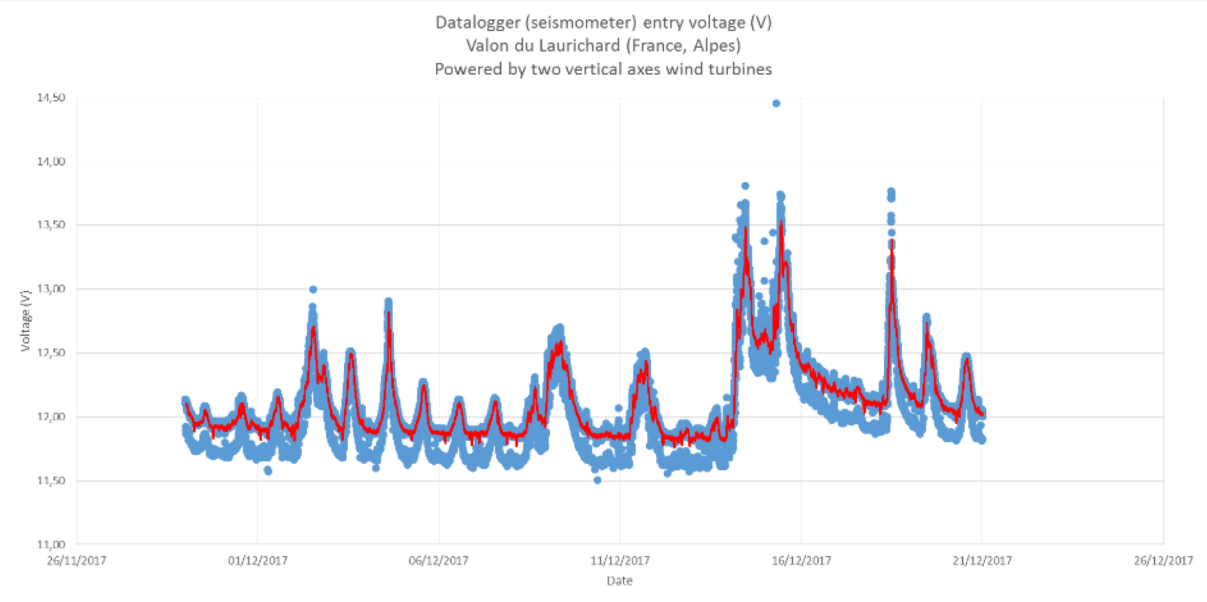


Figure 86 - Data logger (seismometer) entry voltage (V) Valon du Laurichard (France, Alpes) Powered by two vertical axis wind turbines.

All the daily "little" peaks (about +0,2 V) can be due to:

- The solar panel, that even if it is located in the shadow on this December period could still produce few amps thanks to albedo/reflection effects.
- Voltage variation correlated to temperature variations. They are centered on the sun zenith (13-14h00) where both temperature and light are at their higher rate.
- Small thermic winds (probably not katabatic as they are not happening on the evening).

Taller peaks appear due to the two parallel VAWT B wind turbines. Showing that two such wind turbines work for a similar isolated scientific station.

As an additional information, other feedbacks from northern region reported on the use of the HAWT wind turbines, such as, for examples in Quebec, Figure 87.

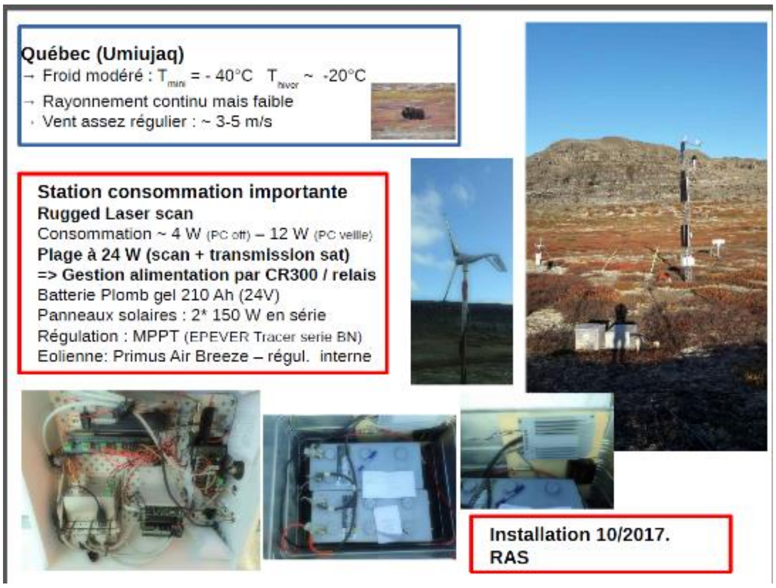


Figure 87 - Additional example of the HAWT use on field (Quebec). Source: IGE

This HAWT will likely be approved as a strong one to face hard conditions, while producing enough energy for scientific station (about 10 W consumption).

Conclusions:

Regarding the evaluated wind turbines for our special use-cases (There are other cases that could fit as well):

- HAWT is one of the most appropriate turbine for our alpine site.
- The VAWT B could also be appropriate, if doubled. A strong fixation is needed.
- Tests are needed in polar region with very strong winds (sometimes up to 150 km/h) and very low temperatures. In this case, the VAWT A could be considered as more appropriate one.
- Do not hesitate to oversize wind turbines nominal power, as there is a huge gap between theoretical manufacturer's specification (made in wind tunnel laboratories) and in the field reality.

b) Complements on the vertical axis wind turbine B: VAWT « B »:

The following Figure 88 shows the VAWT B battery voltage (yellow curve) during wind events (blue curve). We can see that the VAWT B starts to overpass the 3W consumption, and so to charge battery electricity tank, with winds up to ≈ 12 km/h (horizontal threshold red line on the Figure 88).

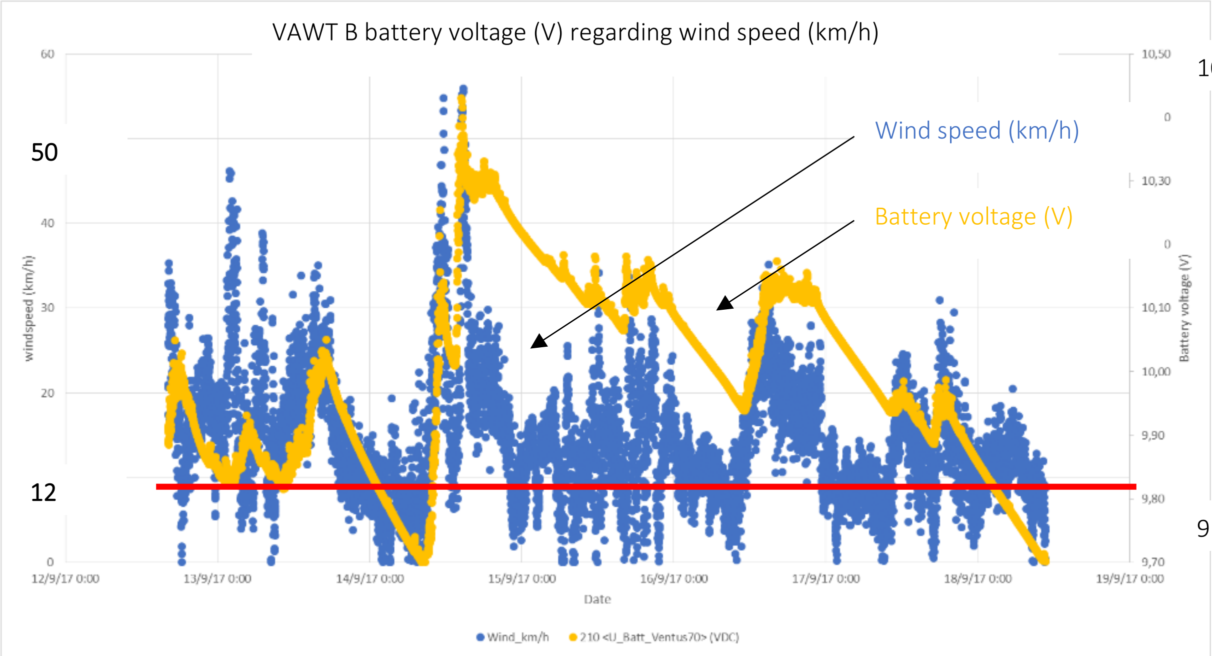


Figure 88 - VAWT B battery voltage (V) regarding wind speed.

Red curve = VAWT B battery showing 4 wind events.
Blue curve = solar panel voltage, showing days and night

- VAWT B battery voltage during 3 wind events, showed on the acquisition screen.

To ask to your manufacturer, it does exist two kinds of mounting fixation systems:

- Pole mount: to be attached on the top of a vertical tube.
- Side mount: to be attached by both wind turbine extremities, like a clamp.

c) Complements on the horizontal axis wind turbine: HAWT :

The below Figure 90 presents the evolution of the HAWT battery voltage regarding wind speed.

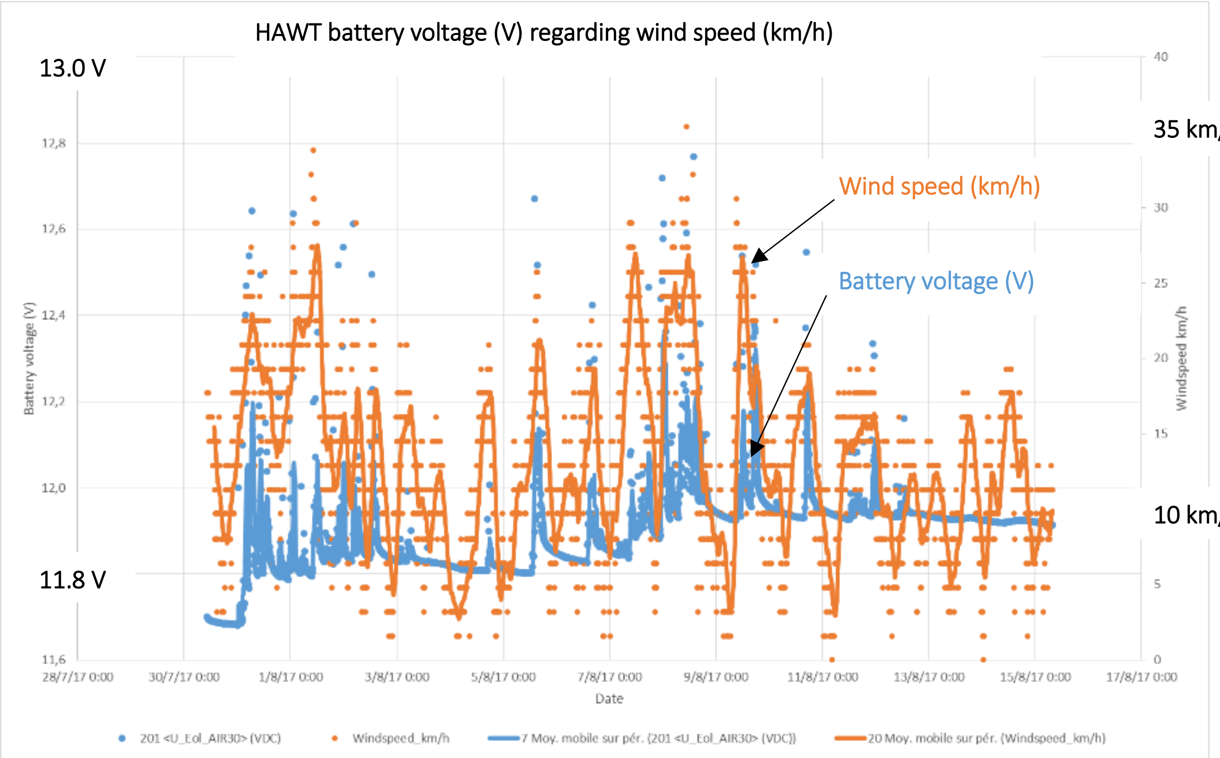


Figure 90 - HAWT battery voltage (V) evolution regarding wind speed (km/h).

With a continuous 3 W consumption, the battery had been regularly charged and maintained in a correct voltage range: from 11,5 V to nearly 13,0 V. From the last recording period (August to December 2017) data confirmed that batteries had been regularly and correctly charged.

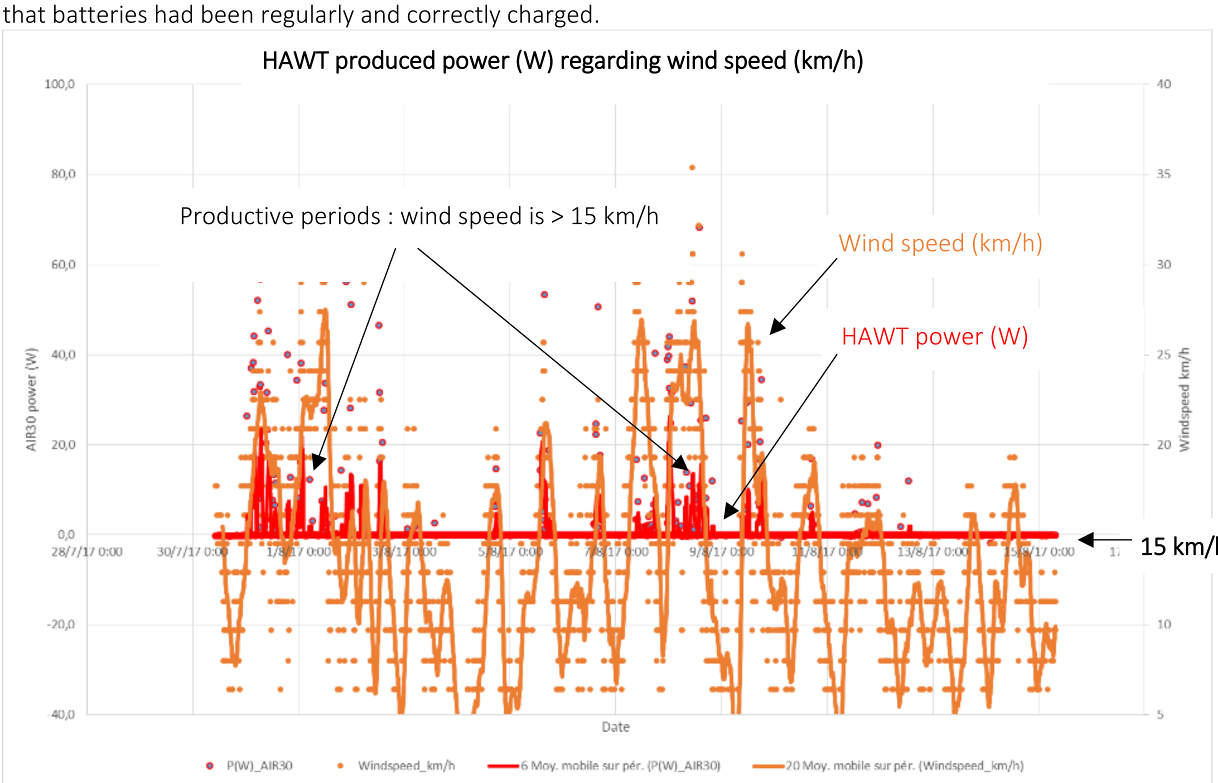


Figure 91 - HAWT produced power (W) regarding wind speed (km/h).

3. MPPT Versus PWM solar charge controllers

During the recorded period (03 to 23/11/2017, still running in January 2018, however, global results do not change), the MPPT line (100 Wp solar panel + MPPT charge controller) produced **28% more energy** than the PWM, Figure 92.

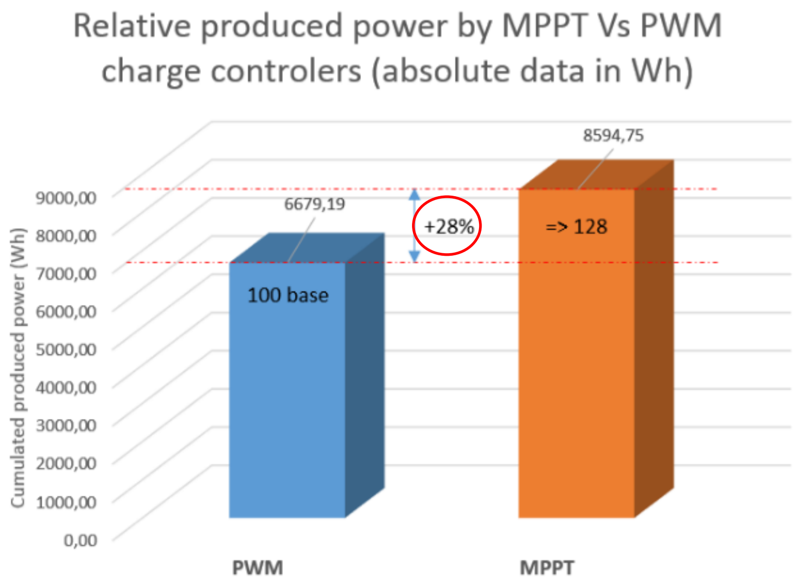


Figure 92 - Relative produced power by the MPPT versus PWM charge controllers.

As they are powered by similar solar panels, maximum power rated have respectively been of 118,70 W for the MPPT and 96,42 W for the PWM one, as displayed in Figure 93.

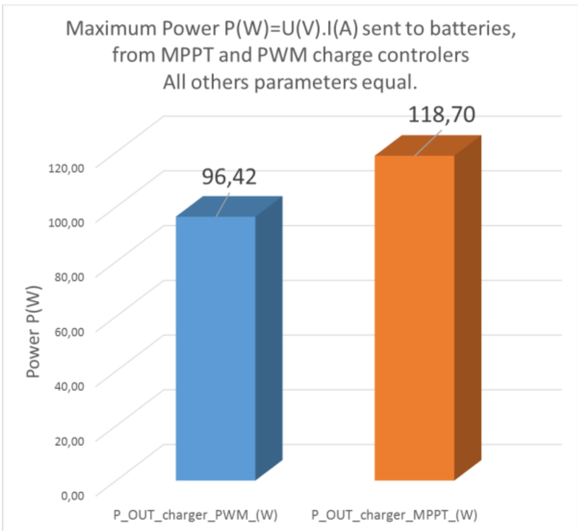


Figure 93 - Maximum power sent to batteries from MPPT and PWM charge controllers.

Of course, maximum rated power is not representative as it only happens in very few occasions at all best environmental conditions (sun, temperature, wind, etc.). But still it highlights the higher performances of the MPPT technology regarding the PWM.

We can also notice that produced power exceeded its nominal value of 100 Wp. As it was explained in chapter A "common knowledge on energy", solar panel performances increased with colder temperatures. That had been the case for this measurement (2100 m high, winter time, with snow albedo reflection and some very sunny days)

Consequences on battery charge (voltage level), Figure 94:

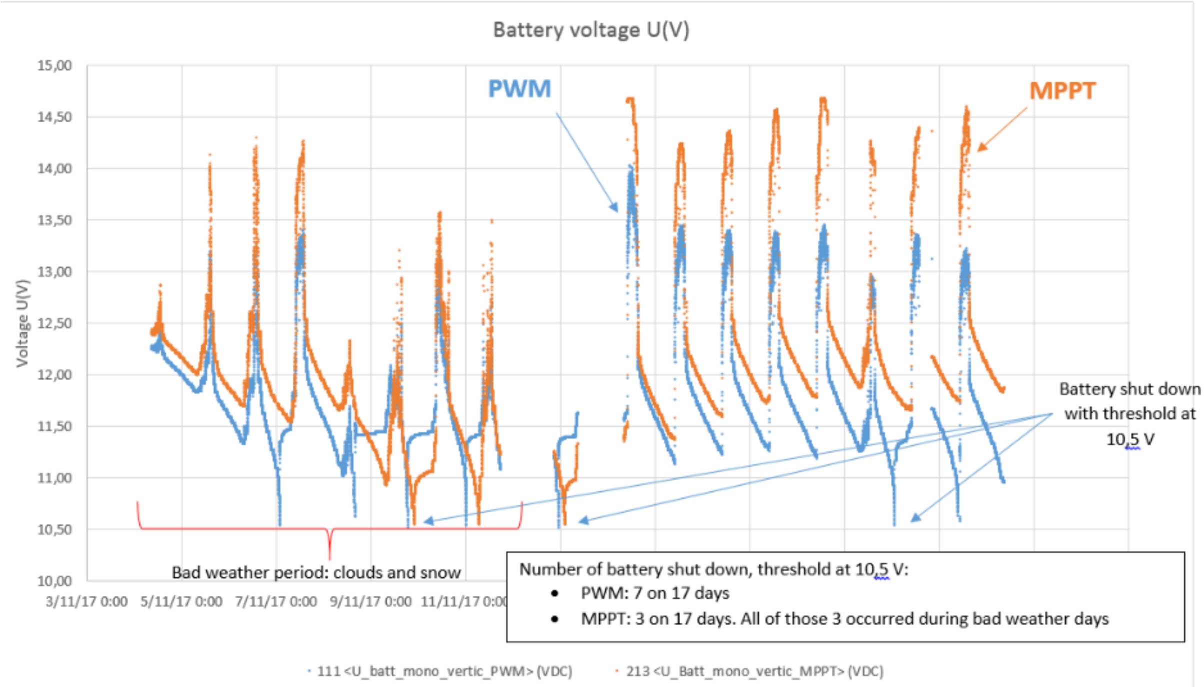


Figure 94 - Batteries voltage U(V) of MPPT versus PWM comparison.

We can see that during this period, the PWM line shows seven batteries failures in 17 days, due to battery protector that opened the circuit when battery voltage was dropping down under a 10,5 V threshold, to prevent from too deep battery discharge.
In the same time, the MPPT line showed only three batteries shut down.

Focus on a snowy winter day with only one to two hours of sun: on the 09/12/2017 (minimum sun - solstice - is on December 21th). Figure 95.

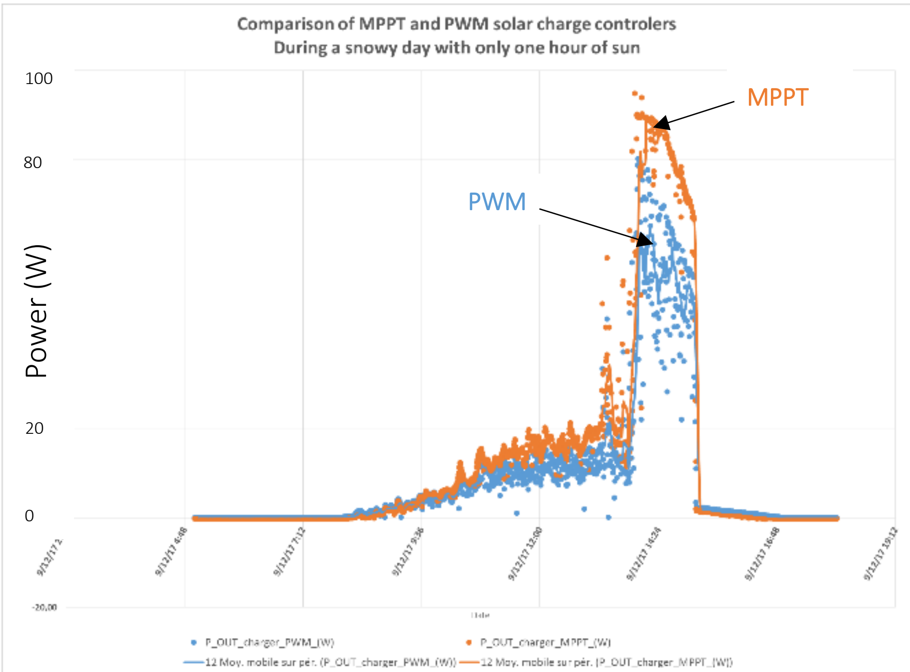


Figure 95 - Power (W) reach by both MPPT and PWM charge controllers on a snowy day.

During this very short window to recharge batteries, PWM and MPPT charge controllers reach the following values of power:

	MPPT	PWM	% of difference
Average power (W)	13.73	8.88	+64% (base 100 = PWM)
Max rated power (W)	94.78	80.20	+18.2%

Table 28 - Reached Power with both MPPT and PWM solar panel regulators.

Consequences on battery voltage level are quite evident, the MPPT battery was charged better in approximately one hour than the PWM. Furthermore, during the following night, a shutdown occurred for the PWM battery, as it didn't for the MPPT . You can notice (Figure 96) that the PWM battery level was higher at the beginning of this day than the MPPT one.

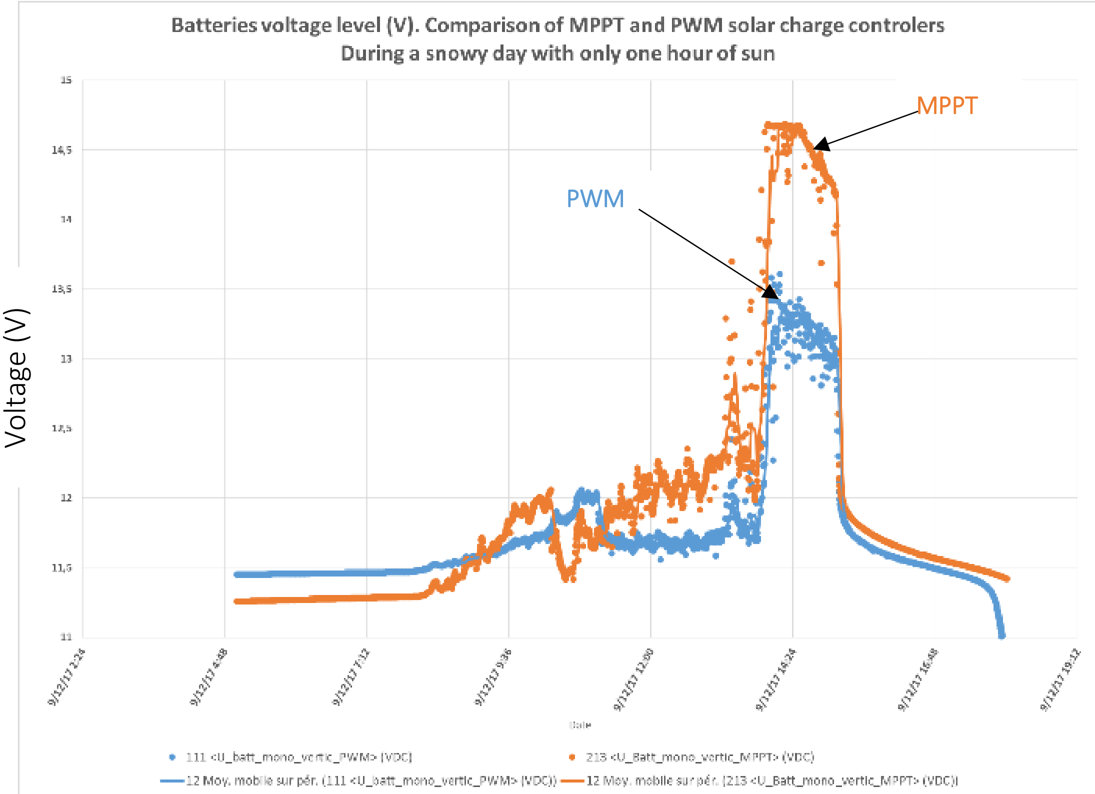


Figure 96 - Battery voltage U(V) reached on MPPT and PWM lines.

Conclusions:
Produced power differences are high enough (about 30%) to strongly advice users to use MPPT technology. Price differences are not significant in comparison of the entire costs of a scientific station. For a 100 Wp solar array, MPPT solution costs about 160€ while PWM costs about 100 €[12].

[12] Averages prices from different sellers, 2017.

D. In laboratory climate chamber, energy storage (batteries) evaluation.

Many RIs have to face cold conditions at their measurement stations, particularly for the ENVRI+ Grenoble community (Alps mountains and polar exploration). Batteries evaluation in cold conditions was set-up in the IGE laboratory, using their climate chamber that allows cooling down to -70°C.
Following the ENVRI+ survey of "Who is using what?", the main used batteries, lead-acid, have been evaluated.

A student trainee, M. Bastien BOURJAILLAT, operated those evaluations from March to June 2017. The following paragraph presents his report, precede by a global abstract summarizing the main technical knowledge.

I. Abstract, main results.

Main technical information obtained during this evaluations about lead-acid batteries are:

1. Typical battery discharge cycles.
2. Effect of temperature on batteries capacities.
3. Differences between Gel and AGM.
4. Effect of age (cycling) on batteries capacities.
5. Correlation between impedance (Z) and battery State of Health (SoH).
6. Importance of charge quality on batteries capacities.
7. Validation of a quick test for batteries SoH

The five first points are presented below.
The two last ones (6: "importance of charge quality on batteries capacities" and 7: "Validation of a quick test for batteries SoH") were already discussed in the Chapter A "common knowledge".
All information are gathered in
"technical summarize data-sheets".

1. Typical battery discharge cycle

The following Figure 97 explains what happens during a battery discharge.

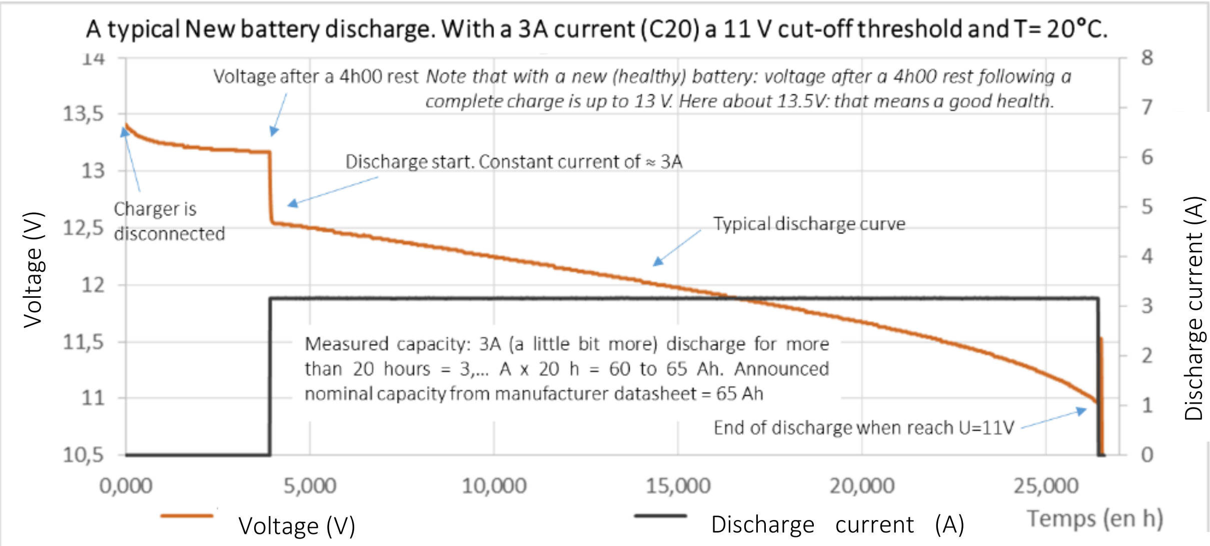


Figure 97 - A typical new battery discharge. With a 3A current (C20), a 11 V cut-off threshold and T= 20°

2. Effect of temperature on batteries capacities

In negative temperatures (below 0 degrees) lead-acid batteries can be expected to show only 60-70% of their nominal capacity, as shown in the next Figure 98 and Figure 99. This important phenomenon have to be keep in mind for station batteries sizing.

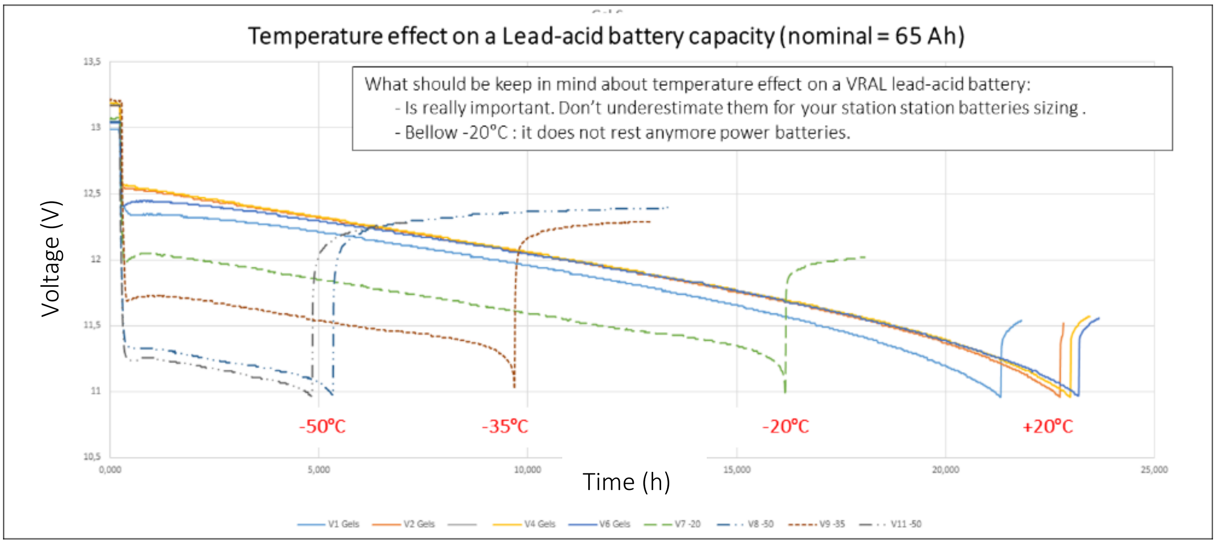


Figure 98 - Temperature effect on a Lead-acid battery capacity (nominal = 65 Ah)

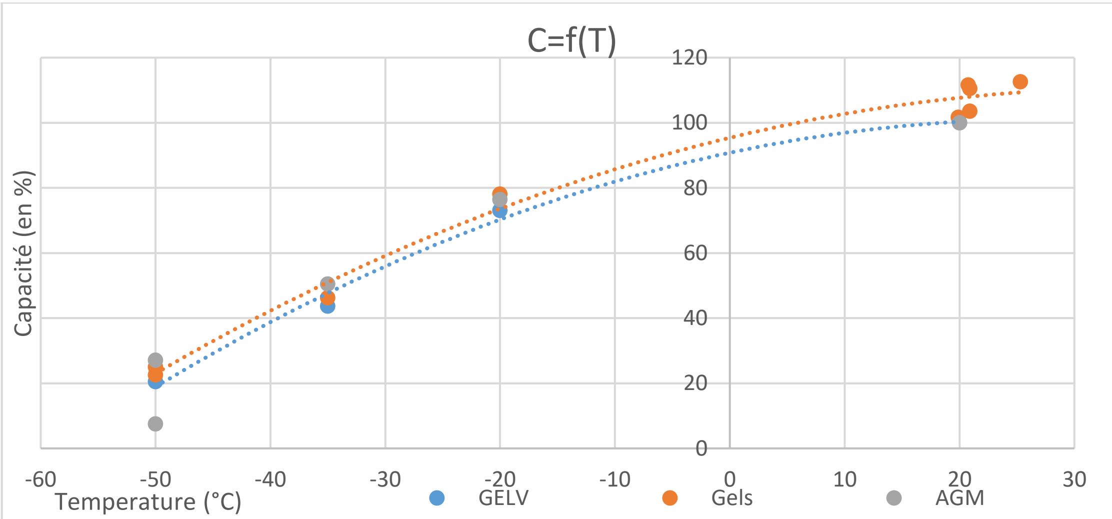


Figure 99: Batteries capacity response as a function of temperature.

During a long term use of a battery, characterized by large number of charge + discharge cycles, its capacity will of course decrease as sulfate crystals will appears, and as both plus and minus plates will be deteriorated along with chemicals reactions.

3. Differences between Gel and AGM:

Gel technology was a newer one than the AGM technology. In the beginning, Gel showed higher performances than AGM, particularly while facing cold conditions. Gel technology was more reputed for working under cold conditions. But by now (2017) it looks that AGM evolution caught up this gap.

From our evaluations, we could not see major differences in terms of capacity in cold conditions between Gel and AGM batteries coming from the same manufacturer, as displayed by Figure 99.

4. Effect of age (cycling) on batteries capacities.

The following Figure 100 displays examples of some old batteries, and their percentage of nominal capacities.

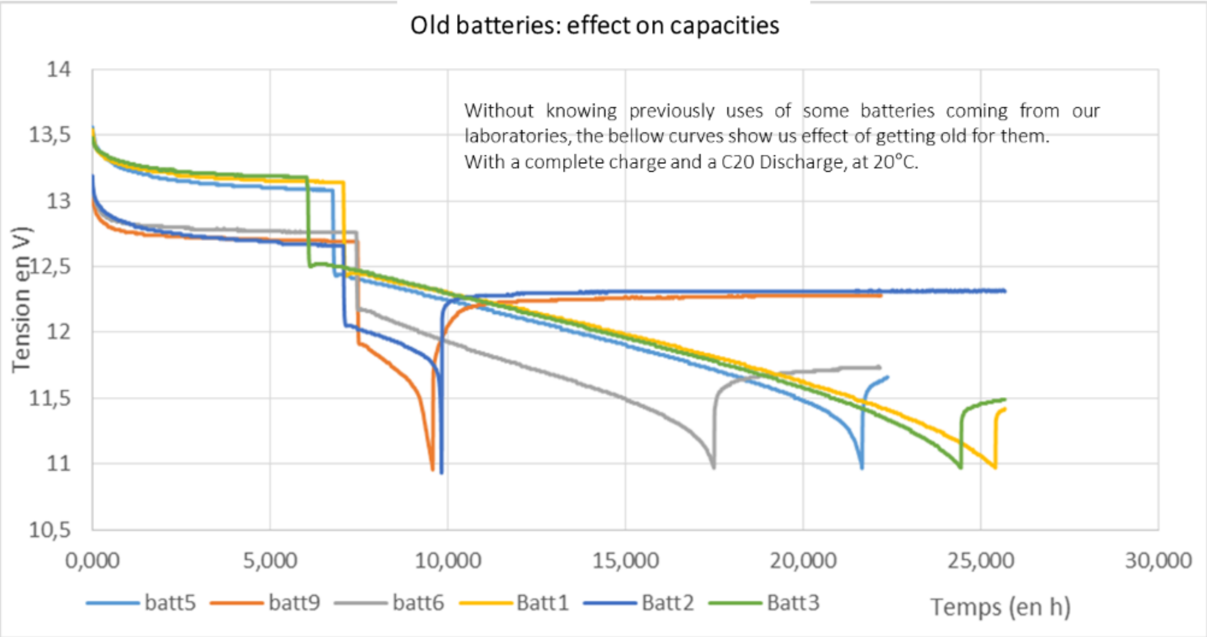


Figure 100 - Old batteries: effect on capacities

5. **Correlation between impedance (Z) and battery State of Health (SoH).**

The internal impedance (Z in Ω) represent the capacity to make electron move in it. This is in a way, its "resistivity" (for physical reason as there are 3 dimension resistances, we called this one impedance), or the reverse of conductivity.
Thus, the newer is your battery (its State of Health - SoH - is close to 100%), the lower will be your impedance. As confirmed by recorded data represented on the following Figure 101.

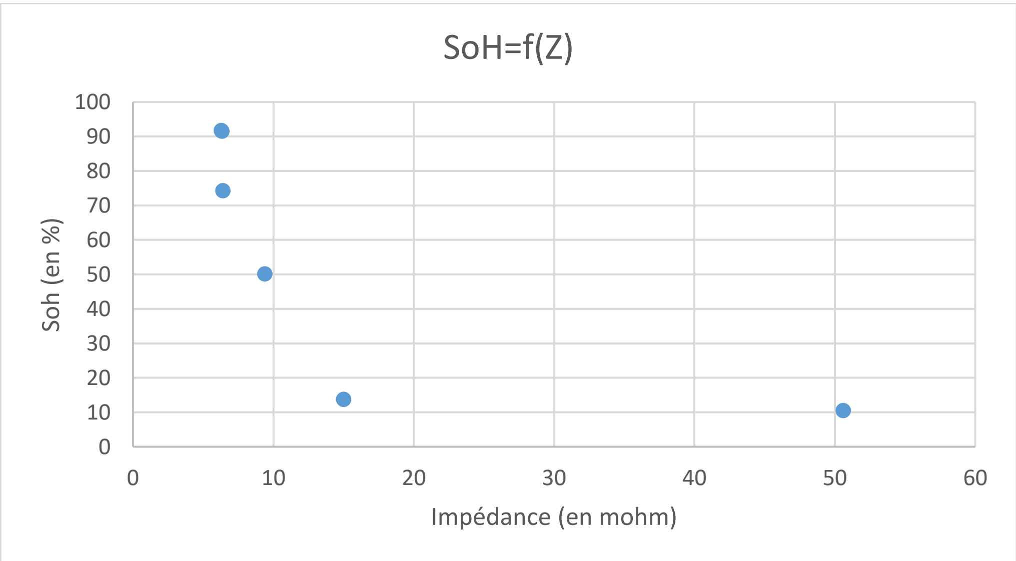


Figure 101 - Graph showing battery state of health according to impedance.

II. Battery evaluation report

Context: The OSUG: Observatory of Universe Sciences, Grenoble.

The OSUG, as the "Observatory of Univers Sciences Grenoble", in close collaboration with Université Grenoble Alpes, was founded in 2011. An observatory of earth sciences (OSU) is a group of laboratories responsible for conducting long-term operations in the field of earth sciences13. These observatories are directed by the CNRS scientific research centre's National Institute for Earth Sciences and Astronomy (INSU). [1]

The OSUs aim to develop knowledge in the following ways:

- acquisition of observation data;
- development and operation of appropriate resources;
- elaboration of the required theoretical tools;
- (in geophysics) monitoring and prediction of natural phenomena;
- (in oceanography) implementation of programs to operate and protect the ocean habitat.

The OSUG is therefore a large group of 6 laboratories located on the campus, including ISTerre[14], which is where Olivier GILBERT works, and IGE, which is where I have been working with Luc PIARD.

The Institute for Geosciences and the Environmental: "IGE"

IGE, the Institute for Geosciences and the Environmental research is, as its name suggests, a French public research laboratory for earth sciences and the environment, resulting from the merging of LTHE and LGGE, on January 1 2017. This new research unit represents one of the main laboratories of the Grenoble Observatory of Earth Sciences.

On 3 April, the 4 supervisory organisations[15] of IGE officialised the launch of the new unit during a day event bringing together all personnel, OSUG laboratory directors and representatives from various IGE partner organisations (CNES, IPEV, IRSTEA Météo-France, Grenoble city council). After a series of presentations and round table discussions, which I was able to attend, the various laboratory teams presented their works and results. I was delighted to have been invited to this event, which enabled me to develop my general knowledge, to see just how broad the field of geosciences is and to start building a network.

I work in the building that used to be LGGE, created in 1958, specialized in research into snow, ice, glaciers, atmospheric climate, oceans and environment. The laboratory has gained fame by specializing in coring glaciers and the polar ice caps. In its early years, LGGE studied the slide and fluctuation mechanisms of temperate glaciers, before turning to the analysis of ice cores, providing information of capital importance on the climate and the composition of the atmosphere over more than 800,000 years. In the same premises, researchers are currently working on a new coring technique to trace climate composition over a million years (for example). In addition to these major missions, teams are also studying the measurements from observatories placed on the world's largest glaciers. These are simply weather stations, equipped with a number of sensors to measure temperature, humidity, precipitations, sunlight hours, etc. A major challenge is how to operate such observatories, located far from electric power lines?

Figure 102 - Map of IGE observatories

My placement project was therefore focused on the power supplies of autonomous stations (Figure 102),

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[13] Astronomy, earth physics, oceanography, environment
[14] Institute of Earth Sciences
[15] CNRS/INSU, IRD, Université Grenoble Alpes (UGA) and Grenoble-INP.

contributing to a vast European project, ENVRIplus, which brings together European environmental research laboratories to share, innovate and propose solutions for the world's environmental challenges. I attended ENVRIweek, held in Grenoble from 15 to 19 May, and a trade fair where a number of partner companies were presenting their innovations in the field of meteorological sensors; I was able to meet with some of them, and discuss their products (in English). The fair also included conferences (in English), recalling the importance of metrology and meteorology and the relationship between the two. I went to the Col du Lautaret site to examine a test station[16] installed by Olivier GILBERT, which helped me to gain full understanding of the challenges of my placement project. The power supply required for the acquisition and transmission of data in these remote areas is massively overestimated to ensure that no measurements are lost. However, it is also imperative to know whether the battery used is in good condition. I therefore implemented tests to improve our understanding of how batteries react in these extreme conditions and how we can predict their inevitable deterioration more accurately, to avoid having to replace them every five years, for example.

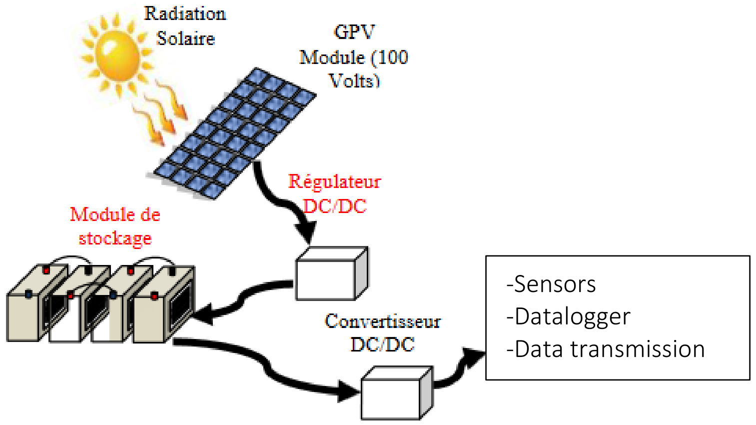

Figure 103 - Diagram of an autonomous station

Introduction to batteries

History

Figure 104: La Jamais Contente

Sixty years after the invention of the first battery by Alessandro Volta, Frenchman Gaston Planté developed the first rechargeable battery in 1859. Forty years later, the "Jamais Contente", an electric car, became the first vehicle to exceed 100kph. Since then, various improvements have been made in terms of safety and performance. Today, this technology is known as VRLA, valve-regulated lead-acid. Various battery technologies now exist, depending on the area of use, with applications as different as aeronautical systems, smartphones and cars. Which battery is best suited to autonomous measurement stations in the field?

Autonomous measurements

Regardless of the measurements to be made, the sensors we use will always require a power supply. This energy must therefore be optimized, to enable uninterrupted operation of the observatories and limited cost. For the ENVRIplus project, my tutor, Olivier GILBERT, gathered information on the battery technologies used by various European laboratories for their measurement stations. It appears that, as for It appears that they, like IGE, mostly use lead-acid batteries (VRLA), mainly because of their low cost and resistance to the cold. Table 29 presents (in French) a summary table of some battery technologies and their characteristics. The next section examines the sealed lead technique, with two different types of electrolyte: AGM battery and GEL battery.

[16] Electricity production systems

		Plomb, acide ou gel	Lithium ion Li-ion (NMC)	Lithium polymère Li-Po	Lithium fer phosphate LiFePO4
Energie stockée	Classement	- -	+ + +	+ + +	+ +
	Wh/kg décharge lente en 20 heures	40	200	190	120
	Wh/kg décharge rapide en 30 minutes	20	190	150	120
Durée de vie	Classement	-	+	+	+ + +
	Nbre de cycle	200 à 400	300 à 500	300 à 400	2000
Prix	Classement	+ + +	-	- -	-
	en € par Wh	0,20 €	0,65 €	0,7 €	0,9 €
Dangerosité	Classement	-	- - -	- -	+
	Risques	Explosion et acide	Explosion et incendie	Incendie	Dégagement de chaleur
Environnement	Classement	- - -	+	+ +	+ + +
	Polluant	Plomb et mercure	faible cobalt, nickel	faible cobalt, nickel	Aucun

Table 29 - Table comparing the different battery technologies.

Operation

A battery, or accumulator, is a storage tank of rechargeable electric energy, comprising a set of electrochemical cells connected in series or in parallel that produce voltage and capacity. Each cell comprises an electrolyte enabling separation and direction of the ions between the positive electrode and the negative electrode. In the case of lead, the pair involved is {PbO2/Pb} immersed in sulphuric acid (H2SO4). Figure 105 and Figure 106 show the chemical elements present when the battery is charged or discharged.

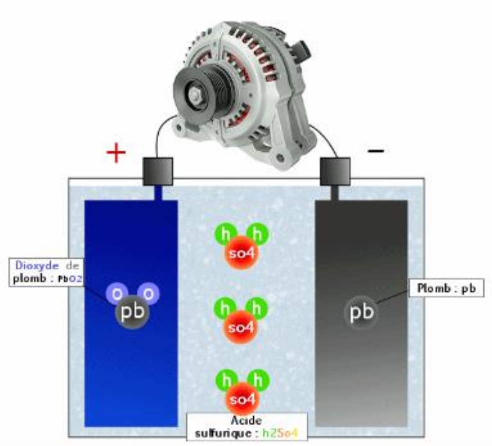

Figure 105 - Charged lead battery.

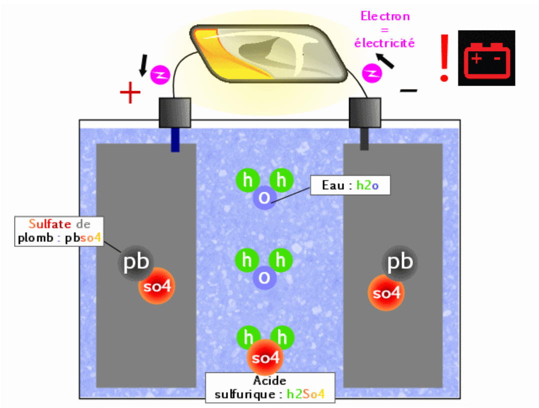

Figure 106 - Discharged lead battery

We can see that an electrochemical battery operates on the principle of an oxidation-reduction (redox) reaction, as follows:

$$PbO_2 + Pb + 2\,H_2SO_4 \underset{Charge}{\overset{décharge}{\rightleftharpoons}} 2\,PbSO_4 + 2\,H_2O$$

By calculating the apparent potential of the cell, the following result is obtained:

Anode (-) :	$Pb + H_2SO_4$	$\rightarrow PbSO_4 + 2\,H^+ + 2\,e^-$	$E_0 = -0{,}36$ V
Cathode(+) :	$PbO_2 + H_2SO_4 + 2\,e^-$	$\rightarrow PbSO_4 + 2\,OH^-$	$E_0 = +1{,}67$ V
CELLULE :	$PbO_2 + Pb + 2\,H_2SO_4$	$\Leftrightarrow 2\,PbSO_4 + 2\,H_2O$	**$E_{0cell} = +2{,}03$ V**

For a 12-volt battery, for example, six cells must be placed in series to increase voltage. Current depends on the surface of the plates. Since chemical kinetics are involved, temperature will play an important role in these exchanges, modifying various properties of the battery.

Different properties of sealed Pb accumulators

Nominal voltage

The nominal voltage, expressed in volts, is determined by the potential of the chemical reaction of the redox pair used. For example, the nominal voltage (operational voltage) per cell of a lithium accumulator is 3.6 volts, compared with that of lead, which is 2.03 volts.

Open-circuit voltage

This is the voltage that can be measured with a voltmeter positioned on the battery terminals, for example. It is directly related to battery charge and can indicate battery malfunction. Manufacturers indicate a minimum voltage threshold that must not be exceeded, often 10.5 volts for lead batteries, since deep discharge can damage the cells.

End of charge voltage

When fully recharged, accumulator voltage is not 12V but closer to 13.5V when the battery is new. It takes approximately four hours for battery voltage to stabilize after a charge-discharge cycle, as shown in Figure 107. It is therefore important to leave the battery to rest to be able to take repeatable measurements.

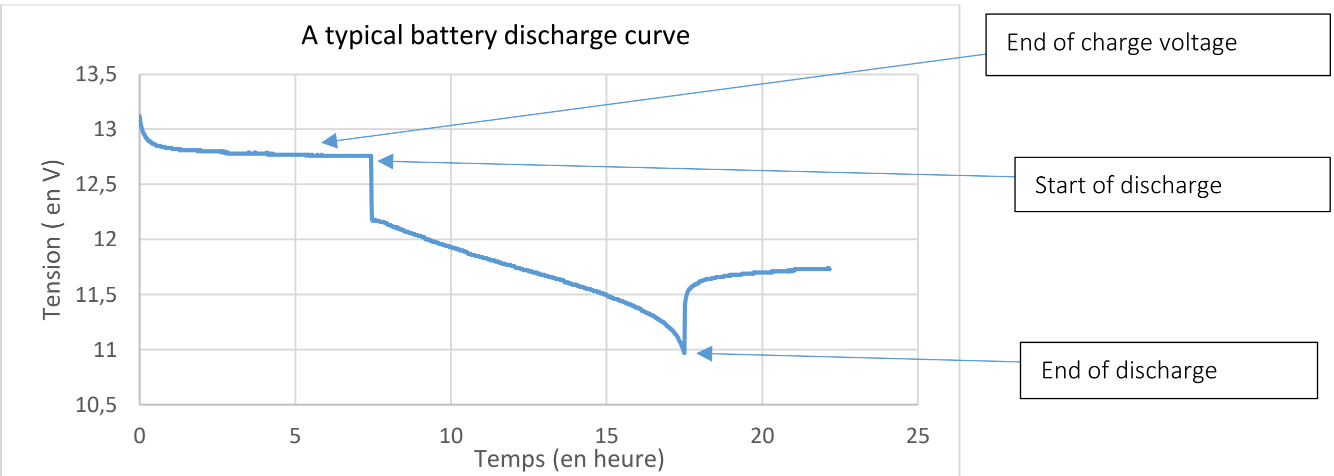

Figure 107 - Typical discharge curve

Capacity

A battery's capacity is the amount of electric energy that it can supply after being fully charged, under given discharge current conditions, and at a specific stop voltage and defined temperature. It is generally expressed in amp hours (Ah), and is the amount of electricity (i.e. electrons) passing through a section of a conductor supplied with a current of 1 amp for 1 hour. In international system units, 1Ah is equal to 3,600 coulombs.

Theoretically, a battery with a nominal capacity (Cn) of 90Ah should be able to provide 90 amperes for 1 hour, or 45 amperes for 2 hours, or 4.5 amperes for 20 hours.

$$Cn = \int_0^t I\,dt$$

However, it is much more difficult for a battery to deliver high current than low current, which is the Peukert effect. The manufacturer therefore specifies a discharge time with the nominal capacity of each battery: 90Ah C/20. This means that Cn=90Ah, t=20 hours, therefore I=4.5A at constant current. The effect of temperature on this capacity will be examined to enable optimal sizing of the stations.

Internal impedance

Impedance corresponds to the sum of the electric resistances and capacities of the solid materials (electrodes, connections) and the electrolyte solution. Typically, this impedance is on the milliohm scale, and varies according to temperature, state of charge and overall condition (state of health) of the battery. By setting the first two parameters, we will examine whether it is possible to estimate the state of health of the accumulator.

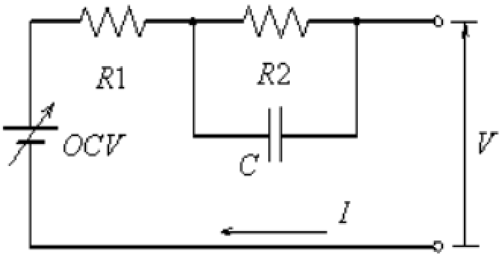

Figure 108 - Battery equivalence scheme.

State of charge (SoC)

As on our smartphones, the level of energy left stored in the battery, i.e. the state of charge, can be defined. It is 100% when the battery is fully charged and 0% when empty. For lead accumulators, the state of charge is not proportional to battery voltage because discharge is not linear. It can be calculated easily if used capacity as a function of nominal capacity is known.

$$SoC(\%) = \frac{Qt}{Qn}$$

State of Health (SoH)

Unfortunately, batteries age over time and lose capacity, so their overall condition must also be known[17] to avoid nasty surprises during use. The manufacturer defines a number of cycles[18] that the battery is able to complete before losing capacity. For a Pb battery, it is approximately 800 cycles. However, these "cycles" are clearly defined with full charges and non-deep discharges, while in the field, our batteries do not follow perfect cycles and may therefore deteriorate more quickly. The easiest way of knowing its overall condition is to implement a full discharge to find out the capacity of the battery (Ctot). SoH is calculated as follows:

$$SoH(\%) = \frac{Ctot}{Cn} \times 100$$

Where Cn is the nominal capacity defined by the manufacturer. However, it takes a long time to discharge a battery fully, which is why I conducted experiments to determine battery efficiency in cold conditions and to find a simple means of defining SoH.

Temperature dependency

Problem

As explained previously, IGE's observatories are located in areas where climate conditions are extreme. In the

[17] State of Health (SoH)

[18] Number of successive discharges-recharges

Antarctic, there are seasons with very little sunlight, no wind and temperatures of -50°C, which is problematic for the power supplies of autonomous stations. Over-dimensioned battery packs are assembled to overcome these conditions. The precise response of accumulators to these conditions has rarely been quantified and not shared. How does the cold affect the electrochemical kinematics of batteries?

Protocol

To quantify this temperature dependency, the protocol requires temperature to be varied while all other parameters are kept constant. To achieve this, I developed a repeatable, precise and strict protocol to allow other users to continue the tests after my departure. There is a monitoring form associated with the protocol to be completed throughout the experiment to record and date all information and to record any relevant observations.

Temperature protocol:

- Charge the battery to 100% at 20°C with the MXS 5.0 charger. Fill in the monitoring form.
- Connect the electronic charger to obtain voltage evolution at the end of the charge and measure voltage and impedance with the BT3554. Fill in the monitoring form.
- Leave the battery to rest and acclimatize to the temperature if operating in cold conditions for at least 4 hours, then measure impedance and voltage again with the BT3554. Fill in the monitoring form.
- Start the discharge, again with continuous acquisition, at a constant current of C/20 for the first tests. Set the threshold voltage to 11V to avoid deep-discharge that may damage the battery. Fill in the monitoring form.
- When the voltage threshold is reached, the electronic charger stops automatically, and indicates battery capacity. Measure voltage and impedance again after a four-hour rest period. Fill in the monitoring form.

Step	Charge time (h)	Measurement	Rest + temperature adaptation	Measurement	Discharge (h)	Measurement
Time (h)	24		4		20	
Total time (h)	24		28		48	

Table 30 - Summary table indicating the protocol for discharge at C/20.

As shown in Table 30, a single operation at C/20 takes 2 days. I therefore decided to carry out most tests at C/20 and to see if the behaviour obtained was the same at C/100, an operation lasting an extra 3 days.

Bench test

Unfortunately, it was not possible for me to select the test bench tools because my tutors had already chosen the equipment before my arrival. I studied the characteristics of three new 12V batteries, one AGM, one 90Ah C/20 GEL[19] by *Victron energy* and one 65Ah C/20 GEL[20] by *Sonnenschein*. These are both reputed manufacturers.

I had two *CTEK* MXS 5.0 chargers, used with the normal program. It is important always to use the same charger to see if it affects battery efficiency. I worked in an air conditioned room, with the temperature set at 20°C, equipped with a *SECASI technologie* ST340 climate chamber, able to operate as low as -70°C. I used the on-board software to program the temperature drop and stabilization.

I used the *HIOK*I Battery Tester 3554 to measure the impedance of the batteries. It is not possible to use an ohmmeter to measure impedance because, as explained above, the equivalent circuit of battery impedance is not simple resistance. The tester sends a low alternating current, frequency 1 KOhm, and returns battery impedance. It is important always to connect to the same place on the accumulator terminal as resistance may vary due to current density.

I had two *Elektro-automatik* EA-El 3160-60 electronic chargers to enable constant current discharges. I soldered 3 wires to be able to retrieve the data of interest on an acquisition station.

I obtained the voltage and current values on a *Campbell* CR1000 acquisition station using *Loggernet* software, which was relatively easy to use. I was thus able to write a program to select the outputs, acquisition time, means of data retrieval with the required sensitivity or the voltage divider for the PT100 4 files.

[19] Noted GELv

[20] Noted GELs

The measurements were imported into Excel for processing, and discharge graphs were generated for two batteries at once.

Results

C/20 discharge

Below is a typical graph for battery discharge at C/20, in this case, the 65Ah GELs. Reminder: at constant current, to have C/20, $= \frac{65}{20} = 325\ A$. Note the voltage reduction before stabilisation after 4 hours, then the start of the electronic charge, which causes a marked voltage drop, then steady decrease to the 11V threshold. We know that $C = \int_0^t I\,dt$, with current being constant, the capacity obtained is simply the time taken by the battery to reach the threshold multiplied by the discharge current. It must therefore be remembered that for the same current, the longer it takes the battery to discharge, the larger its capacity.

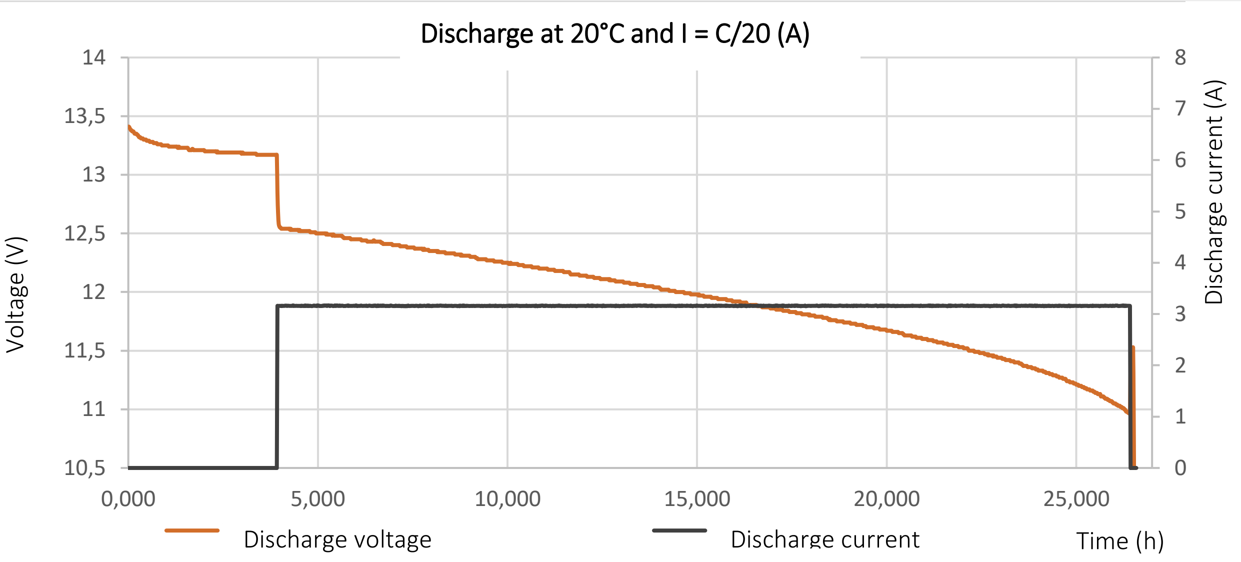

Figure 109 - Typical lead-acid battery discharge graph (3A current).

I started by conducting three experiments on each battery at 20°C to ensure the feasibility of the protocol, and to make sure that the batteries reacted in the same manner and that the measurements obtained were useable. Note that for the AGM, the tests give capacity with a standard deviation of 1.1%. The first graph for the GELv and the GELs do not correspond exactly to the two others, but this is explained by the charger: for the first graph, I had used an old charger, less sophisticated than the MXS. This demonstrates the **importance of the charger used, which caused a 15% difference in battery capacity in this case**. It appears that room temperature is sufficiently regulated for our experiments. However, the Victron batteries, supposed to have been rarely used, did not respond at 100% of their nominal capacity, while the new Sonnenschein battery responded perfectly according to the manufacturer's data. This difference may be due to inadequate servicing by the seller or mis-use occurring before I obtained the batteries. This will be problematic for comparing the batteries according to temperature because the batteries have not been subjected to exactly the same conditions in the past.
Since ordering new batteries was not an option (not the objective set), I moved onto the GELs tests in the climate chamber, using different line styles to represent the different test temperatures. For the tests at -50°C, I left the battery to acclimatize for at least 6 hours to make sure that it was at the right temperature. It is easy to see that the batteries do not work well at low temperatures, because they discharge more quickly.
Figure 110 shows that this decrease appears to follow similar characteristics. The battery responses are similar although it appears that the GELs works better. However, the AGM, which appeared to be the best during the first test at -50°C, collapsed totally during the second test. I did not have enough time for another experiment, but this supports the literature, which indicates the superiority of GEL batteries in cold conditions.

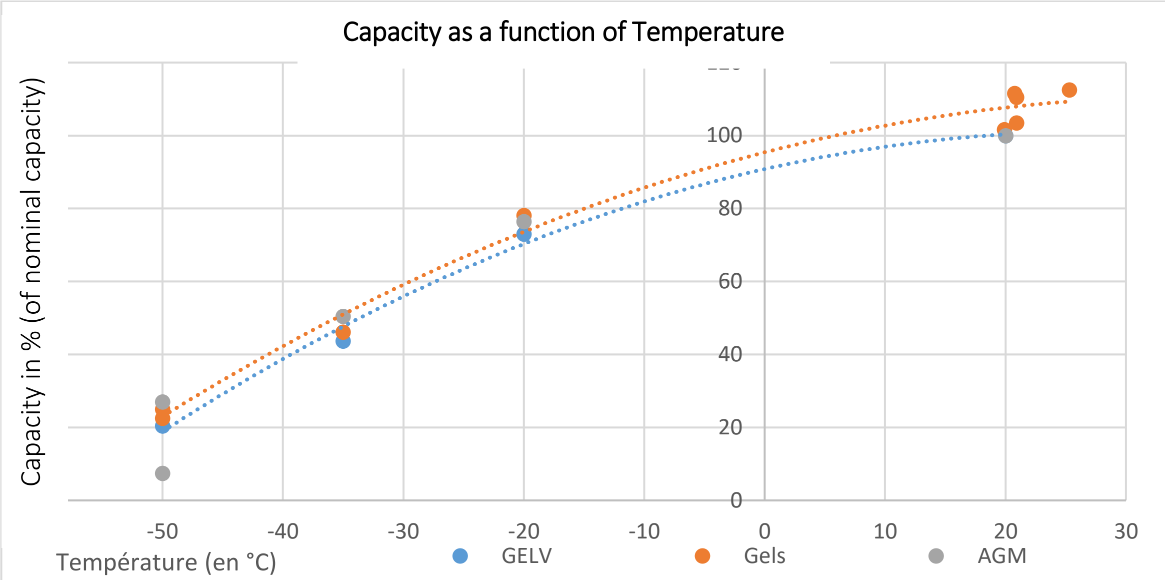

Figure 110 - Graph of the capacity response as a function of temperature.

The energy required by the stations in the field is, however, very low, on the scale of the watt, since they operate at very low currents, around one hundred milliamps. Such experiments would take a very long time to complete. A compromise between the time available and the research objectives was therefore found with discharges at C/100 to see if accumulator behavior was the same.

<u>C/100 discharge</u>

At C/100, the current is five times smaller than previously, i.e. 0.9 or 0.65A, depending on the battery. Due to time constraints, I carried out this test on the two GEL batteries. The batteries deliver more capacity. However, it appears that this merely represents an offset compared with the C/20 results. We can therefore hypothesize that at lower current, the curve moves further upwards, but without significant alteration to the shape of the curve. It is therefore possible to estimate, following further testing, the capacity of our batteries in the extreme conditions of actual use. The question remains: is there no quicker way of determining battery capacity than by operating a full discharge?

<u>Partial discharges</u>

By observing the curve shapes, I realized that they were often the same shape. I therefore tried to find a way, with a shorter discharge, of extrapolating the points to estimate final capacity in just a few hours.
Firstly, with a linear approach, using the slope of the line in discharge mode over just a few hours, for example. However, even using all the points, error remains greater than 20%. The shape of the curve cannot be approximately accurately with an equation of the first degree.
I therefore attempted to derive the series of data obtained twice, to be able to write a quadratic equation.
It is therefore difficult to implement only a partial discharge and it would be complicated to apply this approach in the field, which is why I considered other techniques to determine the state of health of the battery.

Diagnosing state of battery life

<u>Problem</u>

A good quality electric power supply is essential to ensure reliable operation of a measurement station. Technicians therefore change the batteries every five to ten years, without knowing the state of health of the battery, to avoid losing data. Is it not possible to carry out verifications in the field or when the battery is returned to the lab to be able to keep or reuse certain batteries? This is one of the most important questions for laboratories.

<u>Protocol</u>

Here, we applied the same discharge protocol at C/20 as that used previously but focusing more on the impedance, which gives an estimation of the state of battery life. I collected around ten identical old *Sonnenschein* 12V 60Ah batteries, which had not been subjected to the same conditions and whose dates had not been monitored.

The impedance value used was that measured after the rest period of the battery charged in a repeatable manner. Full discharge enabled calculation of the battery SoH to be compared with battery impedance.

Results

I only had time to conduct tests on a sample of six batteries at a temperature of 20°C, but, as shown on Figure 111, they did not behave at all in the same manner.

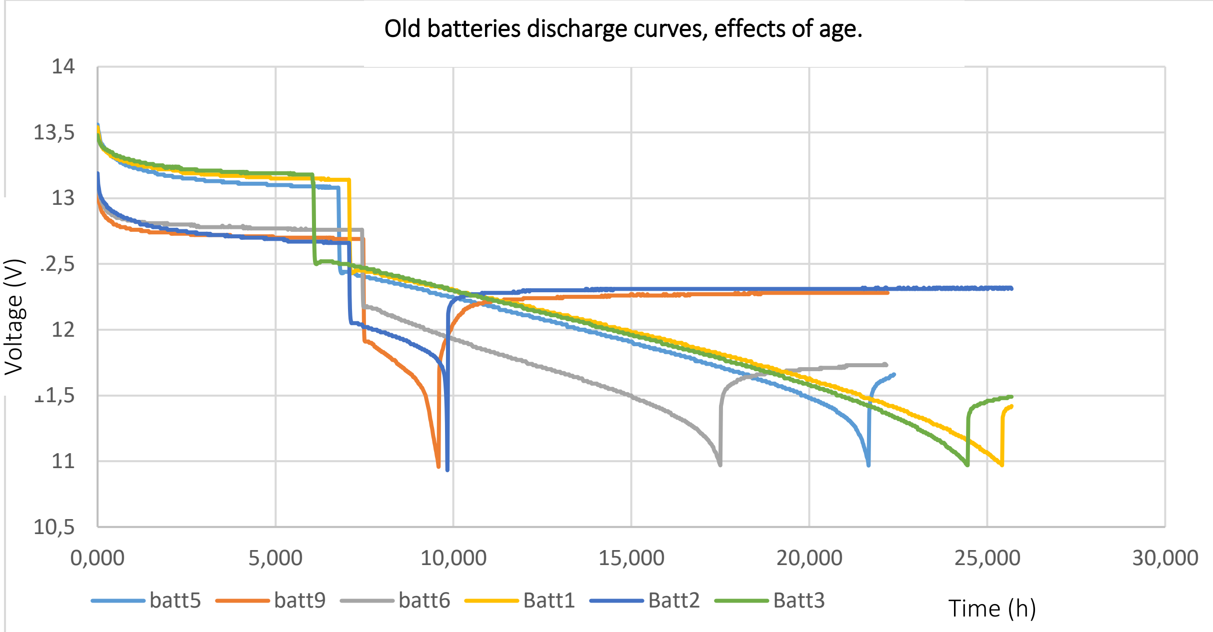

Figure 111 - Old battery discharge curve.

Using a well-completed monitoring form and continuous acquisition, I was able to observe different characteristics according to the SoH. Firstly, Figure 112 shows that impedance certainly appears to evolve according to battery ageing: the older the battery, the higher its internal impedance. By monitoring impedance as of battery reception, we could therefore examine this curve to find out its state of health. However, a calibration curve would be required for each different battery reference, since they probably do not respond in exactly the same way, and temperature would have to be regulated during the tests. Temperature has a strong effect on impedance, Figure 112. This experiment would not therefore be relevant to field use, but could be applied when the batteries are returned to the lab.

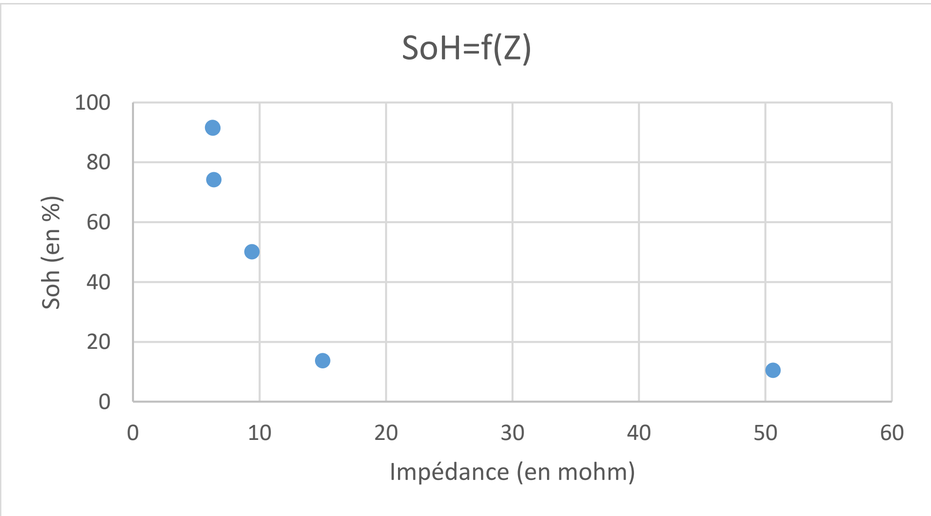

Figure 112 - Graph showing battery state of health according to impedance.

After discussion with the manufacturer *YUASA*, they proposed the following protocol, implemented empirically by their technicians: simply recharge the batteries to 100% and leave them to rest for 4 hours before measuring their voltage. This technique appears to provide a good representation of battery ageing. Again, voltage varies with temperature, and this since this operation involves opening the circuit, it would not be easy to use in the field. However, it remains useful to find out quickly if the battery voltage remains above 13 volts, and if it can be reused or not.

This experiment allowed me to observe that the final value of the voltage drop[21] during discharge appeared to define the discharge time and therefore capacity. Indeed, this is flagrant on new battery tests, since the curves appear to be parallel, the value of the "*coup de fouet*" effect can indicate battery capacity, and therefore state of health. The R^2 of this last method is the most precise but this would require more tests to ensure total control over this method as a function of discharge current, and to see if it actually works for all lead technologies.

This final method remains to be explored. I think that monitoring impedance could provide information on the state of battery health, but a simple full charge followed by a rest period would suffice to provide a good estimation. If after a rest period the battery voltage is above 13V, it is in good condition, if not, care must be taken. The technique of measuring voltage after a full charge and a 4-hour rest period appears to be the method best suited to our situation. It requires little in terms of equipment, is rapid and, although it only affords a rough approximation, the researchers would have this information when their batteries are returned from the field.

[21] This is the "*coup de fouet*" effect

E. Technical summarize: data sheets for a direct on-site use.

Purpose:

The following data sheets have been design to help potential users for a quick and easy use.
They summarize the mains information gathered in the previous chapters.

I. Photovoltaic solar panels

Solar panels

Technical advices summary for on-site direct use

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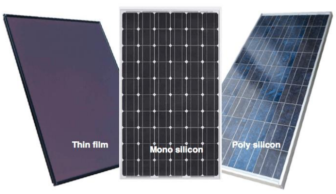
In 2017,the most common technologies available on market are: (source EPIA: European Photovoltaic Industry Association, and NREL: National Renewable Energy Laboratory, USA)

- Silicon-crystals (≈ 90% of worldwide market): mono or polycrystalline. Typical efficiencies goes from 12 to 18%.
- Thin film: Silicon or Cadmium Tellure (Cd-Te), copper indium gallium selenide (CIGS), … Typical efficiencies goes from 5 to 12%.
- Multi-junction cells: like Indium gallium arsenide, Germanium,… Typical efficiencies goes from 25 to 45% (but most of them are still in R&D process).

Most terrestrial and oceanic scientific stations used **silicon-crystals technologies**. In this case, better choose **monocrystalline** technology rather than polycrystalline.

Photovoltaic cell technology	Typical efficiency of commercial solutions (2017)	Available on market ?
Silicon-crystals	12 to 18%	Easy (90% of world market)
Thin film	5 to 12%	Yes
Multi-junction	25 to 45%	Depending: No, or not easily.

- For high mountain alpine (45° latitude) sites with regular snow deposition, put them in **vertical** :
  - To avoid snow deposition, dust, falling rocks,…
  - Differences in terms of produced power between vertical and “annual optimized” tilt are small as solar arrays are usually oversized. Moreover, you will benefit from a higher albedo effect (snow light reflexion on snow) in winter where you will have less sun.



- Use a double independent batteries block:
  - 1 for acquisition (priority)
  - 1 for transmission (secondary)

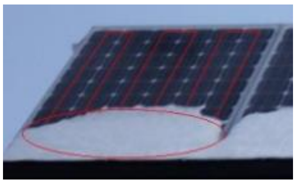
- Prefer **MPPT** charge controller rather than PWM ones. Essentially for > 100 Wp installation.

- **Sizing**: The bellow table is a suggestion for a “classic” 10 W consumption 24h/24h with the following restricts:

Your constrains are:	Suggested solar array sizing

• Scientific acquisition ≈ 5 W
• Transmission ≈ 5W
• Sun light ≈ 1000W/m2 (average in France metropolitan, adapt for your country) and 3 hours of efficient sun per day (as a minimum for winter time).
• 5 days autonomy wanted.
• Discharge batteries rate = 70% (eg: for a 100Ah, count on 70Ah)
	• 150 W solar panels
	• 160 Ah batteries:
	  ○ 80 Ah for acquisition
	  ○ 80 Ah for transmission
	• Charge controller: Max current = 10A (generally in 12VDC)

- Shadows/Snow:



PV Cells are in series ! Be careful to avoid any shadows (tree, rock, building etc…) or snow deposition even on a single cell. Total production will dramatically drop down. Like for a water tube, a single "pinch" will affect the entire rate of flow.

- Mechanics:

Pay attention to your fixation system, a solar panel is like a sail for the wind. Mechanicals forces could be strong.

- Example of sizing calculation

Scientific devices consumption balance			
Element	***Description***	***Maximum consume power (W)***	
Datalogger A	A…	1,00	
Sensor B	B…	2,00	
C	C…	3,00	
	Total Psci :	***6,00***	

Annexe devices consumption balance			
Element	***Description***	***Maximum consume power (W)***	
Modem E	E…	4,00	
Switch F	F…		
G	G…		
H	H…		
	Total Panx :	***4,00***	

Estimation of daily needs (Watts.hours/day)			
Total P	**Total P(j)**	*Total Psci(j)*	*Total Panx(j)*
10,00	**240**	*144*	*96*

Available hours of sun in winter	3
DNI Irradiance estimation in winter Wh/m2/j	1000

Valeurs pour dimensionnement groupe solaire	
Daily power of scientific devices (PSCI(j))	144
Daily power of annexe devices (PANX(j))	96
Majoration coeficient (for meteorologic variations), Km	1,2
Majoration coeficient (for solar charge controler yield) Kc	1,2
Majoration coeficient (for solar panels yield), Kp	1,25
Majoration coeficient (for batteries yield), Kb	1,25
Maximum batteries discharge (between 80% and 40%), Db	1,3
Nominal batteries voltage (V), Uc	12
Wanted days of autonomy, Nja	5
Normalized Irradiance solar power, Pdni, h/j	3

Batteries capacity for scientific acquisition (Ah)	
	97,5

Batteries capacity for annex elements (Ah)	
	65

Solar array power estimation (Wp)	
	144

CAUTION : You need to choose the appropriate charge controler regarding solar panels maximum current: I(A) = P(W)/U(V)	12

Excel file can be download from the ENVRI Community website. http://envri.eu/

II. Wind turbines

Wind turbines (WT)

Technical advices summary for on-site direct use

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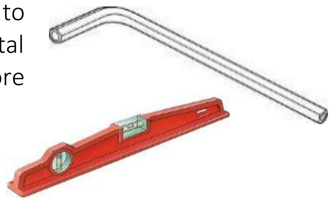
- Examples of used small horizontal or vertical axis WT for scientific stations (non exhaustive list)

Horizontal axis	Vertical axis	
		
Primus AIR 30	Forgen Antarctica	Forgen Ventus 70

- **Be careful with sizing:** On site wind is turbulent, as in laboratory conditions wind is laminar. There is a gap regarding production. On-site: **oversize** wind turbines that you will not have the power you were supposed to find. If you can: **double with parallel WT.**
  As examples: For < 10 W consumption and 100 Ah batteries: Two Forgen Ventus 70 vertical axis or one Primus AIR 30 horizontal axis.

- **Combine wind turbines + solar panels**: Small wind turbines should be coupled with solar panels to ensure power charging. Or any other parallel source like fuel cell,etc…

- **Check screwing and vibrations**: To prevent from an early usury, try (as you can) to strongly fix the WT, and stabilized as much as possible both vertical and horizontal axes. Furthermore, a wind turbine leads inevitably to vibrations. You should therefore come from time to time (typically a month or two) to check screwing.
  Vibrations waves may interfere with particular measurement such as seismology…



- **AC/DC**: To check with manufacturer: most of the time the regulator is internal to the wind turbine. Indeed: wind turbines first produced alternative 3 phases electricity that has to be redress as a direct current. AC -> DC. 12/24/48 has to be chosen regarding batteries and devices you are using.

AC/DC

- **Ideally: Monitor your production.** Produced current in A or just battery voltage. Try to find a wind speed forecast model available on your site. This will help to schedule intervention if needed, as a long period without wind.

Methanol Fuel Cell

Technical advices summary for on-site direct use

Example of the EFOY methanol fuel cell, used by different laboratories:

- Commercialized power: from 25 to 100 W.
- Methanol must be handled carefully: can be toxic if breathe.
- Reject H_20 and CO_2:
  - Ventilation needed (for CO_2 safety reason)
  - Must be adapted (ventilated and warmed) for negative temperature use.
- Relative long autonomy for small electrical consumption needs (W). Typically 1 L of Methanol for 1 000 Wh produced = 100 hours for a 10W consumption. It exist 28L tanks for the tested model



Advantages	Disadvantages
Constant: Provide current all day long, 24/24. No intermittence as from the wind or the sun…	Reject gases: H_2O, CO_2,… Impossibility to be use on some atmospheric measurement. Ice can appears under zero °C. Must be placed in a ventilated enough site.
Relative long autonomy for small electrical consumption needs (W). Typically 1 L of Methanol for 1 000 Wh produced = 100 hours for a 10W consumption. It exist 28L tanks for the tested model	Fuel can be hazardous for transportation: ➔ H_2 ➔ Methanol: CH_3OH Involving serious precautions for its manipulation.
Where there is no other energy sources. Light and compact system.	Much more expensive than solar panels
	Limited running hours because of internal membranes state of health. Typically 3000 to 6000 hours with an EFOY 1600 depending on using temperatures, from -20°C to +40°C

IV. Lead-acid batteries

Batteries

Mainly on lead-acid ones, with few advices for Lithium based.

Technical advices summary for on-site direct use

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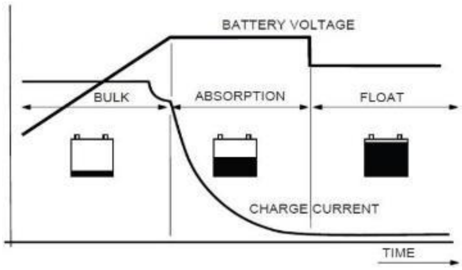
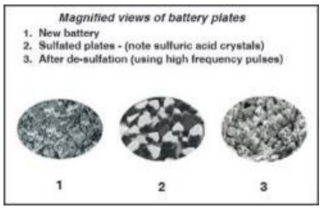
Lead-acid batteries:

- What does C10, C20, C100 means ?
  - Example: C10 = 50 Ah means that the battery can delivers 50 Ah if you fully discharge it in 10 hours. C20 = 90 Ah means can delivers 90 Ah in 20 hours. C20 is the common standard to talk about battery capacity

- Charge:
  - **If possible**: use a 10% to 25% C20 current charger available. Better use an intelligent 3 steps charger (or more steps)
  - **Example**: for a 80 Ah battery, charge with 8 to 20 A current



- Discharge:
  - **Do not discharge more than 50% of C, or under 10,5 V** : To keep your batteries in a good state of health (SoH) for years. For a 80 Ah, consider 40 Ah available for your installation sizing. This will highly influence on its life time: from a hundred available cycles, to a thousand for its full capacity
  - When voltage decrease, acid will be change in water. Sulfate crystals will be formed thanks to this water, and will blocked electron movement possibilities in the electrolyte. Enhancing loss of capacity. This is the main reason for a battery to be harmed / over used.
  - To avoid this sulfatation phenomenon, batteries need to be recharge at least every 6 month, and every time voltage will drop under 12 V.



- **Short test** for internal SoH (State of Health):

  This short and empirical test allowed you to have a global overview of the internal battery SoH (State of Health). That represents its internal use due to sulfatation. After a complete charge and a 4h00 rest: measure battery voltage. Refers to the table beside.

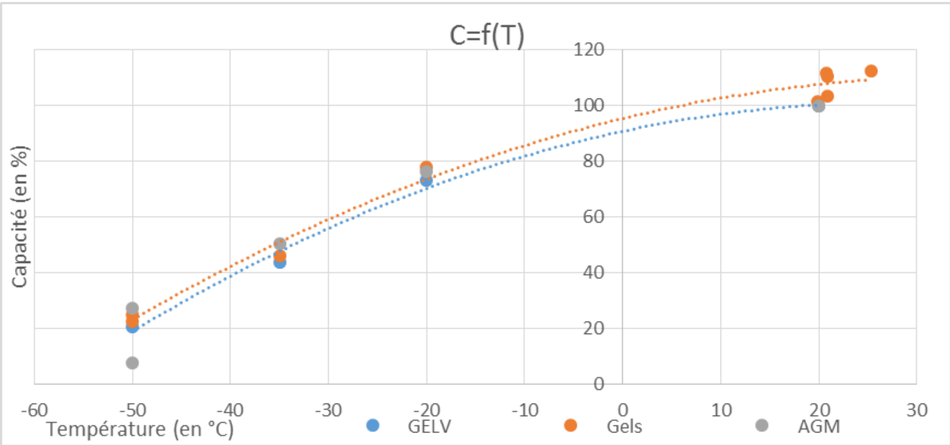
U(V)	Battery State of Health (%)	Comments
≥ 13,0 V	100%	Ok for fieldwork use.
12,5 V	50%	To be use in laboratory
12,0 V	0%	End of life

Date	Voltage (V) after charge + 4h00 rest
01/2015	13,2
06/2015	13,1
04/2017	12,6
≥ 13,0 V = 100% of SoH	
12,5 V = 50% of SoH	
≤ 12,0 V = 0% of SoH	

Suggestion for a ready to print and useful label for battery management

- Storage/maintenance:
  - Stored fully charged. As they always have an internal self-discharge. Light, but still a continuous loss of current (that is the reason why you should regularly start your car when it is not been used for a long).
  - In a fresh and ventilated room. Warm temperatures will catalyze discharge chemical reaction: $H^+ + e^- + SO_4^{2-} \rightarrow H_2SO_4 + H_2O$, so better keep them in a fresh room. Of course, to avoid corrosion on batteries lugs, better avoid humidity too. Charge produce small quantity of water + sulfuric acid vapors. Have a ventilated room.

- Effect of temperature:



Effects of temperature on batteries capacity. Results obtained by Bastien Bourjaillat, Institute of External Geosciences, Grenoble) 2017.

<u>Lithium batteries:</u>
Density energy (rough estimation):

- Wh/kg: ≈ 10 times more than lead acid
- Wh/L: ≈ 3 times more than lead acid

For low current consumption (e.g: < 1 A) : Li-FePO_4 is one of the most developed and used technology. It is also one of the most secured one in terms of fire hazards.
Pay attention on:

- Need a special Li-ion battery charger (voltage and current are needs are different from lead-acid)
- Difficult to be charged under 0°C. Discharge can goes down to -20°C (approximation for common Li-FePO_4 batteries market available)

V. Power regulation and control

Power regulation: from production to storage

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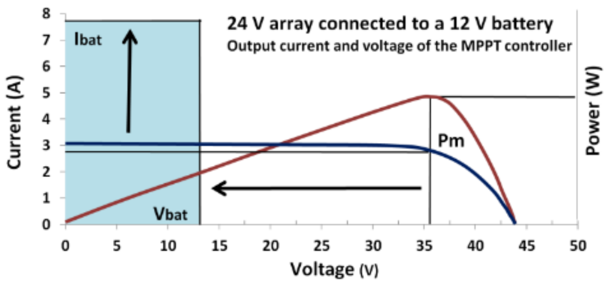
- Solar regulator/controllers:
  - For > 100 Wp solar arrays: better use a **MPPT** charge controller (except on polar region: Zener diodes could be better to prevent from electronic failures and minimize night internal consumption)
  - Global gain is about 30% in comparison to an equivalent PWM solar charger.



Graphical representation of the DC to DC transformation as performed by an MPPT controller. Source: Victron energy

  - Beware of the maximum accepted current from the charge controller
  - When connecting your charge controller: First connect batteries, then production, to avoid electric arch if production already arrive when connecting batteries. Or cover solar panels to erase production.
  - If possible (usually in PWM) use “duo” charge controllers that can manage two batteries rack (one for acquisition, one for telecommunications) or battery separator.

- Wires:
  - Try to minimize wires length, for power loss (Joule effect).
  - Maximum wires cross section regarding power and length:

Puissance max en fonction de la longueur et de la section des câbles (12V)										
Câble (mm2)	Longueur des 2 câbles (AR)									
	2	4	6	8	10	12	14	16	18	20
1,5	103	51	34	26	21	17	15	13	11	10
2,5	171	86	57	43	34	29	24	21	19	17
4	274	137	91	69	55	46	39	34	30	27
6	411	206	137	103	82	69	59	51	46	41
10	686	343	229	171	137	114	98	86	76	69
16	1097	549	366	274	219	183	157	137	122	110
25	1714	857	571	429	343	286	245	214	190	171
35	2400	1200	800	600	480	400	343	300	267	240
50	3429	1714	1143	857	686	571	490	429	381	343
70	4800	2400	1600	1200	960	800	686	600	533	480
90	6171	3086	2057	1543	1234	1029	882	771	686	617

Wire Gauge and Current Limit Table						
AWG gauge	Diameter Inches	Diameter mm	Ohms per 1000 ft	Ohms per km	Maximum amps for chassis wiring	Maximum amps for power transmission
0	0.325	8.2525	0.098	0.3224	245	150
1	0.289	7.3482	0.124	0.4064	211	119
4	0.204	5.1892	0.249	0.8151	135	60
6	0.162	4.1148	0.395	1.2959	101	37
8	0.129	3.2639	0.628	2.0605	73	24
10	0.102	2.5883	0.999	3.2764	55	15
12	0.081	2.0523	1.588	5.2086	41	9.3
14	0.064	1.6281	2.525	8.2820	32	5.9
16	0.051	1.2903	4.016	13.1725	22	3.7
18	0.040	1.0236	6.385	20.9428	16	2.3
20	0.032	0.8128	10.150	33.2920	11	1.5
22	0.025	0.6452	16.140	52.9392	7	0.92
24	0.020	0.5105	25.670	84.1976	3.5	0.577
26	0.016	0.4039	40.810	133.8568	2.2	0.361
28	0.013	0.3201	64.900	212.8720	1.4	0.226
30	0.010	0.2540	103.200	338.4960	0.86	0.142

  - Between batteries in series or parallel: Try to keep same length and cross sections wires. To homogenize current transportation

VI. A typical daily battery cycle for isolated stations, powered by solar panel.

Typical battery + solar panel daily cycle

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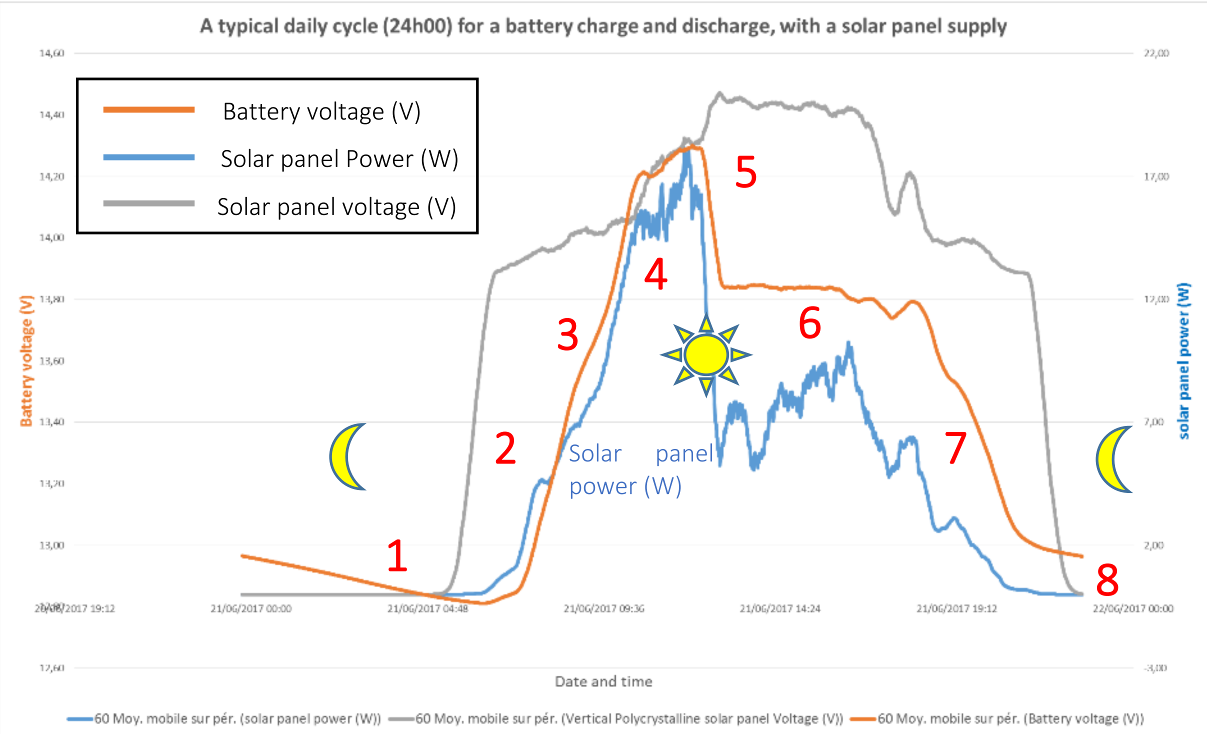
For a better understanding of physical phenomenon that occurred in an isolated scientific site powered by solar panels and batteries, the following diagrams present the typical steps for a 24h00 battery charge and discharge cycle.



Step	What does happen ?
1	Night, the battery voltage decrease as it's the only power source for consumption.
2	Daylight arrives (as the solar panel voltage shows on the grey curve), solar panel voltage quickly jumps to a running level.
3	When solar panel voltage is high enough (for this 100 W panel, around 14,00 V), with sun striking hard enough, electrical current will be produced. Until the battery is fully charged, the solar charge controller will allows solar panel to transmit current. This is called the "bulk mode".
4	Battery charging. Voltage and current are regulated to correctly fits the battery level.
5	The battery is fully charged. Solar charge controller will switch to a "floating mode"
6	The solar charge controller remain in the floating mode, to maintain optimal battery voltage (here around 13,8V), without damaging it. Additional produced current will power the electrical charges, as scientific sensors, data-logger, transmission modem, etc.
7	Sun starts decreasing, solar panels start to be too wick to provide enough energy for both electrical charges and to maintain battery levels. Batteries will so take place instead of solar energy. Thus battery voltage will start to decrease.
8	Until next sunny day…

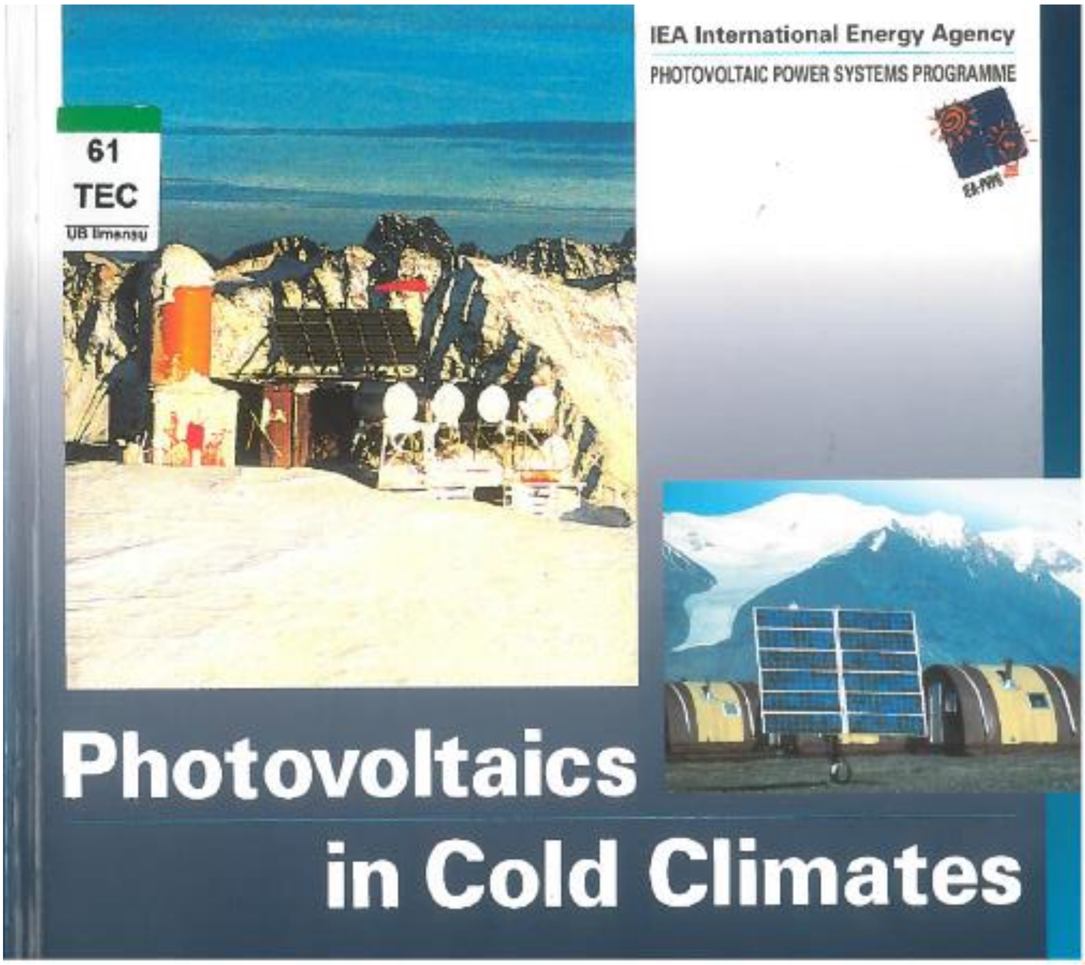
F.Glossary

A (unit)	Ampers
CNRS	National Scientific Research Center (French)
Energy	Energy = electrical energy (language abuse)
FluxAlp	Measurement station for carbon flux exchanges in the Alps (soil, air, rain).
I (unit)	Intensity, Current in Ampers
IFSTTAR	French Institute of Science and Technology for Transport, Development and Networks
IGE	Institute of External Geosciences
ISTerre	Institute of Earth Sciences
OSUG	Univers Sciences Observatory, Grenoble
PAR	Photosynthetically active radiation: designates the spectral range (wave band) of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis (https://en.wikipedia.org/wiki/Photosynthetically_active_radiation
PV	Photovoltaic solar panel
SAJF	Station Alpine Joseph Fourier: The site evaluate for energy production systems. At the “Col du Lautaret” (Lautaret pass), 2100m height, French Alps. Between Grenoble and Briançon. Part 1: Common knowledge on energy for isolated sites
SoH	State of Health
U (unit)	Voltage
V (uint)	Volts
W (unit)	Watt
Wh (unit)	Watt.hour
Wp (unit)	Watt Peak: optimum power production for solar panel in laboratory conditions: 25°C, 1000 $W.m^{-1}$, and determined air density (which vary with pressure/altitude, and so with the available quantity of solar radiation on the solar panel).

G. List of figures

H. Annexes

Annex A: PV in cold climate, International Energy Agency editions.



Can be interesting. Only rare available document about energy in cold climates

Annex B : Technical guide for solar + batteries sizing

Scientific devices consumption balance			
Element	***Description***	***Maximum consume power (W)***	
Datalogger A	A…	1,00	
Sensor B	B…	2,00	
C	C…	3,00	
	Total Psci :	***6,00***	

Annexe devices consumption balance			
Element	***Description***	***Maximum consume power (W)***	
Modem E	E…	4,00	
Switch F	F…		
G	G…		
H	H…		
	Total Panx :	***4,00***	

Estimation of daily needs (Watts.hours/day)			
Total P	**Total P(j)**	*Total Psci(j)*	*Total Panx(j)*
10,00	**240**	*144*	*96*

Available hours of sun in winter	3
DNI Irradiance estimation in winter Wh/m2/j	1000

Valeurs pour dimensionnement groupe solaire	
Daily power of scientific devices (PSCI(j))	144
Daily power of annexe devices (PANX(j))	96
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Majoration coeficient (for solar panels yield), Kp	1,25
Majoration coeficient (for batteries yield), Kb	1,25
Maximum batteries discharge (between 80% and 40%), Db	1,3
Nominal batteries voltage (V), Uc	12
Wanted days of autonomy, Nja	5
Normalized Irradiance solar power, Pdni, h/j	3

Batteries capacity for scientific acquisition (Ah)	
	97,5

Batteries capacity for annex elements (Ah)	
	65

Solar array power estimation (Wp)	
	144

CAUTION : You need to choose the appropriate charge controler regarding solar panels maximum current: I(A) = P(W)/U(V)	12

Batteries test and stock management
(returning from the field)

1 : Put them in charge.

Ideally with a 10% to 25% current of the C20 battery capacity (capacity for a 20hours use, usually written on it by manufacturer).
As an example for a 70 Ah battery => current of 7 A.
If the charger can only deliver a 1 A current, it will takes you 70 hours to charge it (if it was totally empty) and moreover: this will not be an optimal charge.

2 : Test them:

Protocol: (Ideally: everything is done around a 20°C)

1. **Fully charge the battery**
2. **Wait for 4 hours after disconnecting the charger.**
3. **Measured voltage U(V), refers to the bellow table**
   Option : If you can : also check the impedance (Z in Ω)
4. **Note U(V) (and Z as an option) on its label, added on the battery.**

U(V)	Battery State of Health (%)	Comments
≥ 13,0 V	100%	Ok for fieldwork use.
12,5 V	50%	Better use in laboratory
12,0 V	0%	End of life

Note on the impedance Z(Ω)
Typical new lead-acid battery impedance = from 5 to 10 mΩ.
When Z(Ω) is doubled : the battery starts to be seriously harmed, used enough.
If Z(Ω) > 30 mΩ : battery end of life. Go for recycling or de-sulfatation (which is another story: refers to professionals).
Ideally: Write battery Z on it when take its delivery (new battery).

3 : Store it in a fresh, not too humid and ventilated place.

4 : Waiting for its next use :

- A battery has to be stored in a fully state, because of internal self-discharge.
- Has to be refuel every 6 months at least, or if voltage < 12V
- A battery self-discharge will increase with warm temperature than with fresh ones.
- Battery charge: can reject water + sulfuric acid: need a ventilated place.

Annex D: Typical prices to power a ≈ 10W station. (with 5 days autonomy)

Estimations of global prices of several power sytems for a typical 10W consumption scientific measurement station				
It is not relevant to estimate €/Wh for the following reasons: 1: productions (Wh) are very fluctuating for solar and wind, very different from one site to another. 2: Fuel cells are too new tec				
Solar pannels	Quantity	Typical price per unit (2017) €	Total price (€)	
Solar pannels 100 Wp	1	150	150	
MPPT Power controler 20V - 10 A	1	150	150	
Battery protect (cuts off under a determined voltage)	1	50	50	
Lead -acid battery 50 Ah	3	200	600	
Mechanical parts for attachment	1	200	200	
Wires and other electrical options (fuses, breaker,...)	1	200	200	
	Wh			
Produced power at the "Col du Lautaret" 2016				
TOTAL			1350	**≈ 1000 € (for a typical 10W station)**
			1000	
Wind turbines				
AIR 30 Primus Wind turbine ≈150W with internal regulator	1	800	800	
Battery protect	1	50	50	
Lead -acid battery 50 Ah	3	200	600	
Mechanical parts for attachment	1	200	200	
Wires and other electrical options (fuses, breaker,...)	1	200	200	
TOTAL			1850	**≈ 1500 € (for a typical 10W station)**
			1500	
Fuel cell				
EFOY Pro 800 Duo Fuel cell, 45 W	1	3500	3500	
Insultated box	1	1900	1900	
Methanol tanks	2	150	300	
Battery protect	1	50	50	
Lead -acid battery 50 Ah	3	200	600	
Mechanical parts for attachment	1	200	200	
Wires and other electrical options (fuses, breaker,...)	1	200	200	
TOTAL			6750	**≈ 6000 € (for a typical 10W station)**
			6000	
Others informations:				
LiFePO4 battery 60 Ah				

(2017 prices, global average for estimation. Ask sellers for up-date quotation)

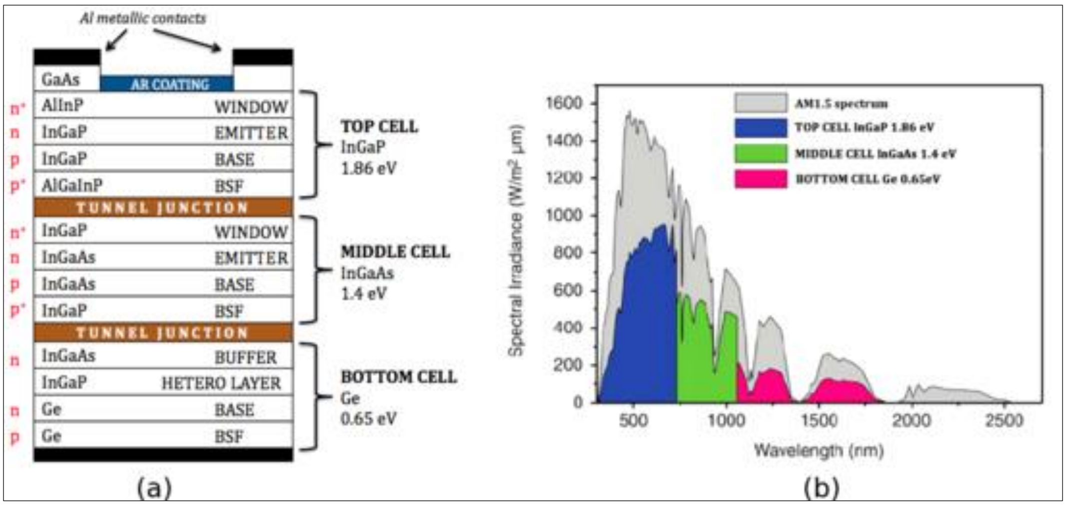
Annex G : Wind speed conversion units: m/s <=> km/h <=> mph

Wind speed units conversion		
m/s	km/h	mph
1	3,6	2,2
2	7,2	4,5
3	10,8	6,7
5	18	11,2
10	36	22,4
15	54	33,6
20	72	44,8
30	108	67,2
50	180	112,0

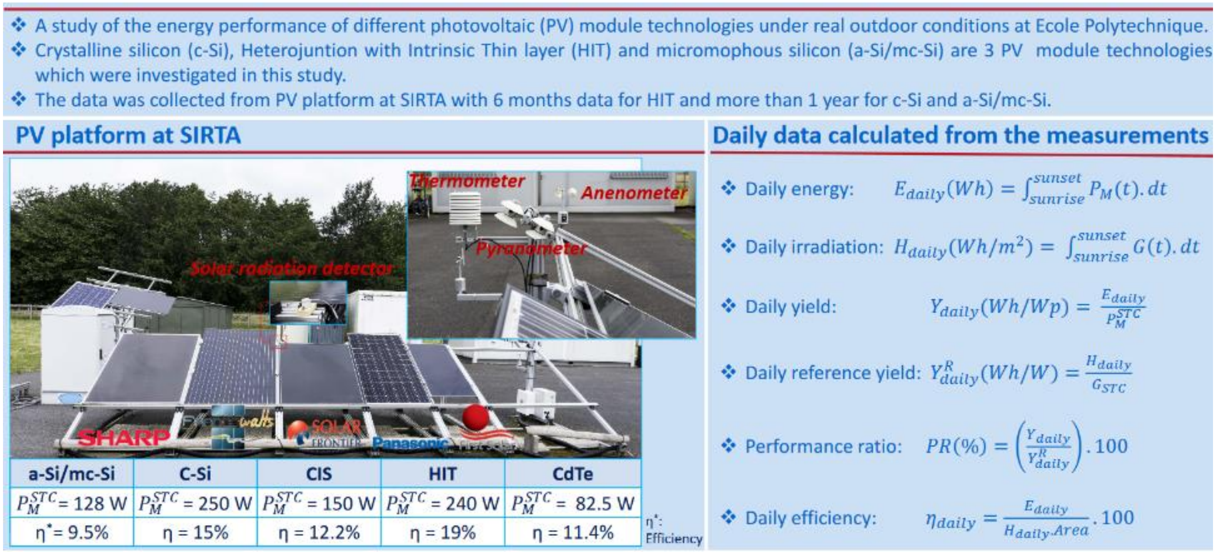
Figure 113 - Wind speed conversion units: m/s <=> km/h <=> mph

Annex H: Others evaluations on photovoltaic technologies.

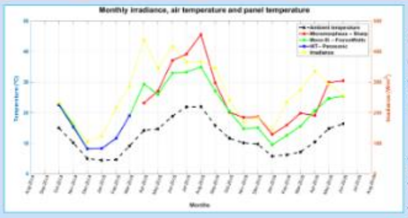
Others technologies could be useful on-site, especially to maximize production if you only have very few hours of sun. The actual most commercialized one is silicon crystals cells. Its efficiency varied from 15 to 20% approximatively (in 2017).
Others technologies use most efficient compounds as multi-junction cells (as displayed in figure bellow). Prices are proportional to production, and for that time (2017), multi-junction solar panels are still difficult to found on market.



For more details on multi-junction evaluate on efficiency, refers (as an example) to the SIRTA evaluations (Site Instrumental de Recherche par Teledetection Atmospherique) as displayed in next figure.



Monthly mean daytime temperature and irradiance

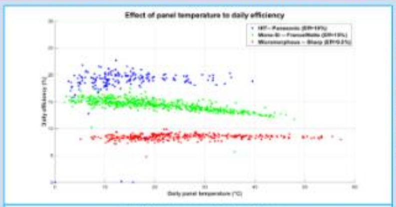


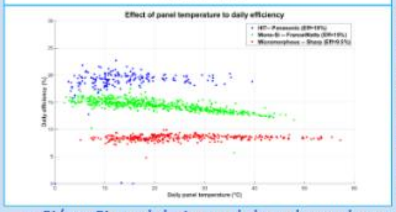
Overall, there is a similar fluctuation of irradiance, air temperature and PV temperature.

The ambient temperature varies from 3ºC in winter to 22ºC in summer.

PV temperature of a-Si/mc-Si module is higher than HIT and c-Si.

Effect of temperature and irradiance



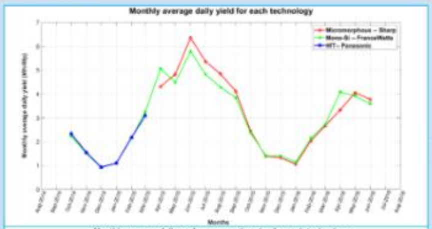


The daily efficiency is strongly dependent on the temperature for the c-Si module and lower dependence in the case of HIT.

All the modules have greater daily efficiency at low irradiance than the high ones due to the effect of temperature that is correlated with irradiance.

a-Si/mc-Si module is much less dependence on the temperature and irradiance.

Energy performance results



Although the monthly average daily yield is very similar for all modules (follow the trend of irradiance), their performance ratio (PR) are very different.

HIT and c-Si modules have higher PR values for winter months, while a-Si/mc-Si module has higher PR values for summer months.

In spite of having lower efficiency than c-Si and HIT modules, the obtained result illustrate that a-Si/mc-Si module performs better under real outdoor conditions.

Conclusion

The comparative energy performance was studied with 3 different PV module technologies under the same conditions at Ecole Polytechnique.

Under real conditions, the daily efficiency is strongly dependent on temperature and irradiance for c-Si, lower in the case of HIT and a-Si.

Moreover, with these conditions, c-Si and HIT modules present better performance for winter months while a-Si module performs better in summer and it shows the best energy performance in this study.

References

C. Cañete, J. Carretero, M. Cardona, "Energy performance of different photovoltaic module technologies under outdoor conditions"

End of report.
December 2017