ENVRI[plus] DELIVERABLE

D3.1
Report on the use of energy units in extreme environments

WORK PACKAGE 3 – Improving measurement networks: common technological solutions

LEADING BENEFICIARY: CNRS

Author(s):	Beneficiary/Institution
Olivier GILBERT	CNRS EPOS
Mickael LANGLAIS	CNRS EPOS
Franck DELBART	CNRS ANAEE
Bastien BOURJAILLAT	CNRS ACTRIS
Luc PIARD	CNRS ACTRIS
Loic Dussud	IFREMER
Laurent Delauney	IFREMER

Accepted by: Helle Pedersen (WP 3 leader)

Deliverable type: Report

Dissemination level: Public

Deliverable due date: 29.5.2019

Actual Date of Submission: 13.03.2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654182

ABSTRACT

The ENVRI community (Environmental and Earth System Research Infrastructures) covers multiple scientific domains, such as oceanography, atmosphere, geophysics and biology. Whilst very different in terms of scope and technology, the research infrastructures and their personnel face common technical challenges related to the fact that field equipment is often installed in remote sites. Specifically, a large proportion of field equipment needs to be autonomous and sometimes operates in extreme conditions.

Theme 1, "Technical innovation", aims to provide and improve the technology used by environmental RIs by developing internal cooperation synergy and by collaborating with the industries that propose solutions for RIs. WP3, "Improving measurement networks: common technological solutions", is focused on energy issues (WP3.1: Enhancing observation capacity in remote sites: improving energy production) and data transmission (WP3.3: Robust data provision: data transmission and near real time QC) in extreme environments (WP3.2: Testing robustness towards extreme conditions).

This report deals with the work for WP3.1, which was conducted between 2015 and 2018, as a collaborative project involving CNRS EPOS, ANAEE and ACTRIS.

The main questions for Task 3.1 were:

- What is needed to provide energy to isolated scientific stations?
- What are the most sustainable technical solutions regarding the specific needs of RIs?
- What do RIs actually use?
- How to improve RI use of these systems?

The report gathers information on energy production and storage using land-based instruments. It contains advice for potential non-specialist users, with technical abstracts and data sheets on each technology. The report is the main outcome of Task 3.1, and is attached as **ANNEX I**.

This deliverable has also benefitted from interaction with other ENVRI+ partners, and IFREMER's contribution concerning energy solutions in marine environments, which can be found in **ANNEX II**.

The report in ANNEX I is composed of five main chapters:

Chapter A: General knowledge on energy for isolated stations

This chapter describes the "minimum knowledge" concerning energy for isolated stations: photovoltaic solar panels, small wind turbines, hydro-turbines and fuel cells for production, batteries (lead-acid, lithium and others) for storage, power regulation and management.

Chapter B: A catalogue of isolated, operational stations

This chapter presents a summary of an ENVRI+ wide survey (conducted in collaboration with WP3.2 and WP3.3) on "Who is using what?" in terms of energy and data transmissions in extreme environments.

Chapter C: Energy production system evaluations

Following the ENVRI+ WP3 survey on energy for isolated stations, this chapter presents tests conducted the most commonly used power production solutions (i.e. photovoltaic, wind turbines and regulation systems). These were evaluated in extreme conditions: cold, snow and strong winds.

The Joseph Fourier alpine station research site (at an altitude of 2,100m, managed by ENVRI SAJF-ANAEE), in the heart of the French Alps, was chosen for this purpose. A sustainable research facility was set up (CNRS ISTerre - EPOS and SAJF - ANAEE), offering all the logistics (access, energy and communication) required for technical tests as well as scientific measurements.

Chapter D: Energy storage system evaluations

Energy storage is another critical issue for autonomous scientific equipment in the field.

Using the IGE-ACTRIS laboratory facility (a climate chamber allowing cooling to -70°C), the energy storage system most commonly used throughout ENVRI+ RIs, the lead-acid VRLA battery, was tested in a controlled cold environment. Several tests were carried out to test potential technical improvements and better management of the equipment with a view to improving the performance of this type of equipment in cold conditions.

Chapter E: Technical summary

Finally, all previous knowledge was summarised into an A4 recto-verso "ready-to-print" format enabling easy use for fieldwork or in laboratory conditions. This part of the report is intended to offer practical advice for non-specialist technical and scientific staff installing isolated scientific stations.

Internal project reviewer(s):

Internal project reviewer(s):	**Beneficiary/Institution**
Philippe Gueguen	IFSTTAR EPOS
Helle Pedersen	UGA EPOS
Paolo Laj	UGA ACTRIS
Jean Daniel Paris	CEA ICOS
Philipp Kozin	CEA ICOS
External project reviewer(s):	**Institution**
Olivier Charade	CNRS DT-INSU

Document history:

Date	**Version**

From 06/2017 to 01/2018	Draft for comments (Mickael Langlais, Philippe Guéguen, Helle Pedersen, Jean-Daniel Paris)
20/01/2018	Corrected version
October 2018	Inclusion of Annex II
October 2018	Review by Philipp Kozin
January 2019	Review by Philippe Guéguen
February 2019	Review by Olivier Charade
February 2019	Validation by Philippe Guéguen

DOCUMENT AMENDMENT PROCEDURE

Amendments, comments and suggestions should be sent to the author: Olivier GILBERT, Olivier.gilbert@univ-grenoble-alpes.fr or Olivier.gilbert.fr@gmail.com

TERMINOLOGY

A complete project glossary is provided online here: https://envriplus.manageprojects.com/s/text-documents/LFCMXHHCwS5hh

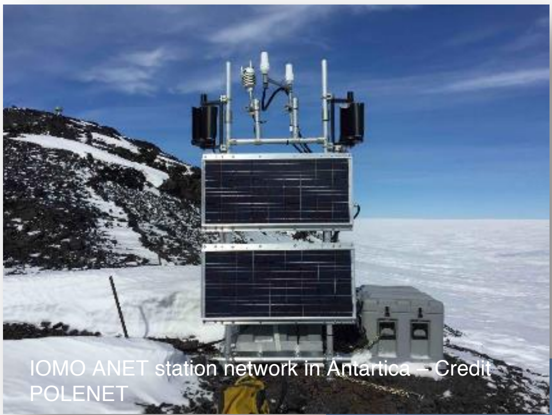
Annex I
Energy for isolated scientific stations

Contents

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

Annex I
Energy for isolated scientific stations

A contribution to a shared knowledge


IOMO ANET station network in Antartica – Credit POLENET


Kerguelen *Monts de l'Atmosphère* Credit: IPGP


AGO Seismic station – Credit OPGC

Authors:

- Olivier GILBERT (EPOS-ACTRIS/CNRS-ISTerre)
- Mickaël LANGLAIS (EPOS/CNRS-ISTerre)
- Franck DELBART (ANAEE/CNRS-SAJF)
- Bastien BOURJAILLAT (CNRS/ISTerre-IGE)
- Luc PIARD (ACTRIS/CNRS-IGE)

Reviewers:

- Jean Daniel PARIS (ICOS, CEA-LSCE)
- Philipp KOZIN (ICOS, CEA-LSCE)
- Paolo LAJ (ACTRIS/CNRS-IGE)
- Helle PEDERSEN (EPOS/UGA-ISTerre)
- Philippe GUEGUEN (EPOS/IFSTTAR-ISTerre)
- Olivier CHARADE (CNRS/DT-INSU)

Contacts :
olivier.gilbert.fr@gmail.com
mickael.langlais@univ-grenoble-alpes.fr

Grenoble, 2019

ENVRI+ WP3.1 project on 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 specialised technical 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 researchers to address specific challenges within their own scientific fields. However, to tackle the major challenges facing human society (e.g. climate change, natural disasters, loss of biodiversity, etc.), scientists must collaborate across the traditional fields. The earth system is highly interlinked and therefore environmental research must focus on the planet as a whole.

Collaboration within ENVRIplus will enable the multidisciplinary earth system sciences to cross the traditional scientific borders. This is of the greatest importance in addressing today's global challenges. Cooperation will avoid the fragmentation and duplication of efforts, making the products and solutions proposed by Research Infrastructures easier to use with one other, improving their innovation potential and the cost/benefit ratio of Research Infrastructure operations.
Collaboration is the only way forward to address the global changes facing today's society.

This report addresses a common technical issue of relevance for most ENVRI+ RIs:

"Energy for isolated scientific stations"

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

Aims of this report:

This report provides **guidelines** and **technical advice** on operational solutions to power remote scientific measurement stations.

- This report aims to help technical staff to choose the most suitable solutions to bring energy to their autonomous sites and to save time.
- This report is not an ISO/AFNOR standard reviewing the energy efficiency of different power systems. Evaluations have been conducted on site to ensure the practical relevance of the document with regard to Research Infrastructure (RI) needs.

Document structure:

This report is composed of five stand-alone chapters:

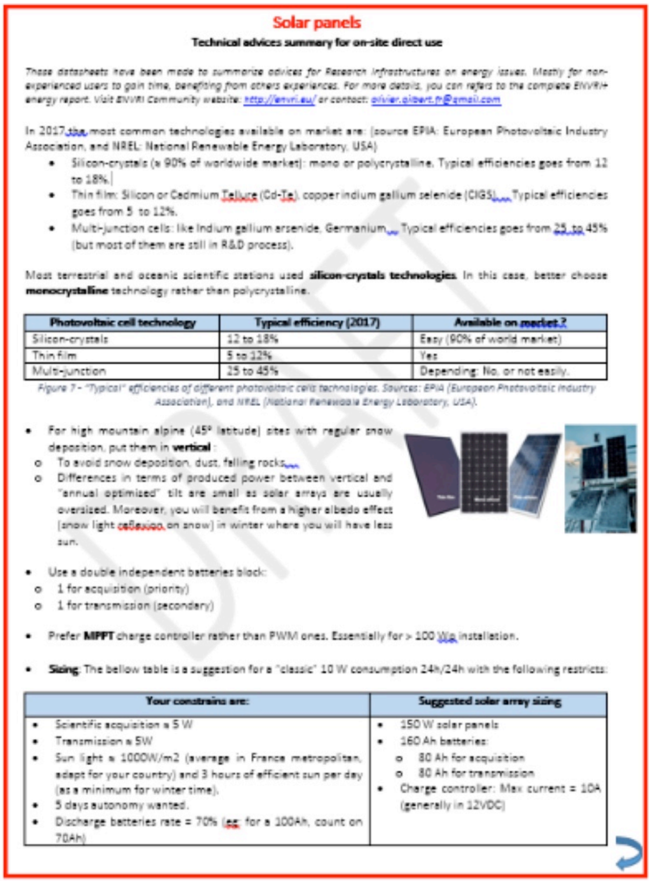
Chapter A: General knowledge on energy for isolated stations
This chapter provides a quick overview of the minimum knowledge required concerning energy systems for isolated sites.

Chapter B: A catalogue of isolated, operational stations
Thanks to the ENVRI+ RI community in the fields of oceanography, biology, atmosphere and geology, this chapter gives examples of operational stations, their energy sources and data transmission. Contacts are provided if more detail is required.

Chapter C: Energy production system evaluations
With regard to RI needs and following the ENVRI+ survey, this chapter presents evaluations of the most commonly used power systems.

Chapter D: Energy storage system evaluations
With regard to RI needs and following the ENVRI+ survey, this chapter presents evaluations of the most commonly used power storage systems (lead-acid batteries).

Chapter E: Technical summary
Finally, all previous information has been summarised on technical data sheets for direct on-site use. These data sheets are presented in chapter E as a technical summary 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 direct on-site use. See chapter D.

Comments and additional knowledge will be welcome for future updates.

Contact: olivier.gilbert.fr@gmail.com or mickael.langlais@univ-grenoble-alpes.fr

A. General knowledge on energy for autonomous sites

A.I. General information on energy

A.I.1. Definition

The scientific definition of energy reads as follows "energy is the physical quantity that characterises a system state change". In others words, energy is the capacity to change the state of matter, i.e. to move a physical material from one place to another, to vaporise it, to make it move in a living body, to transform matter into heat, to create light, etc.

A.I.2. Context and major challenges

Energy is everywhere and we need energy for everything: to build our houses, to move our cars (burning fuel such as petroleum), to grow food (chemical energy from the ground, physical energy of the sun via photosynthesis), to warm rooms (thermal energy), to run our electrical devices (electrical energy), to make our muscles work (caloric energy).

Energy has thus become one of the major challenges facing humanity. Worldwide individual energy consumption has grown significantly over the last century (Figure 3). As populations have grown, the total consumption of energy has grown too, as shown in Figure 4. Moreover, 80% of this energy results from burning fossil fuels containing carbon (oil, coal and gas), which represent an additional source of atmospheric CO_2, contributing to global warming.

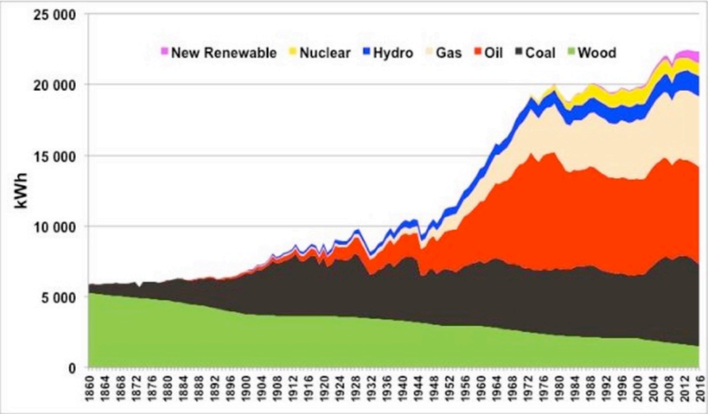


Figure 3 – Average worldwide energy consumption per person. Source: Jean Marc Jancovici, adapted from Shilling et al. 1977, BP Statistical Review 2016, Smil 2016.

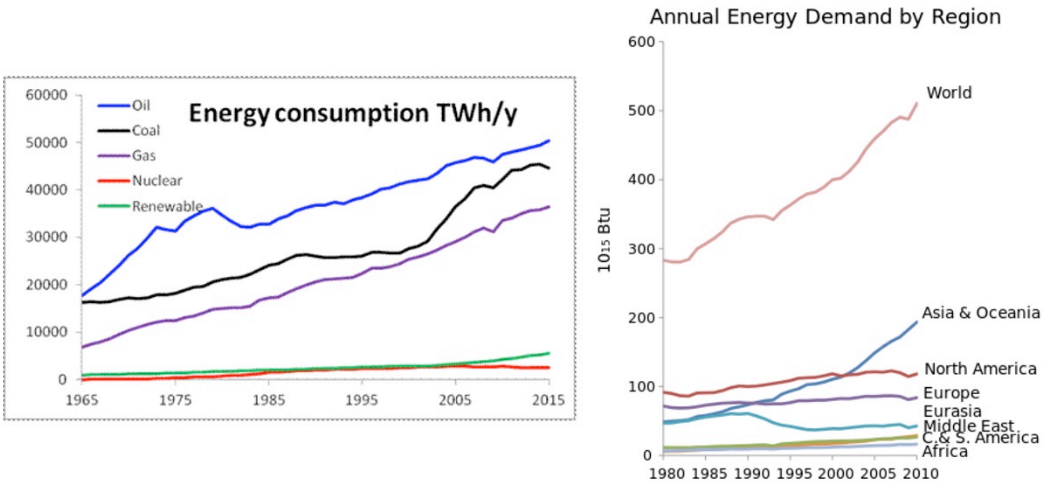


Figure 4 - World energy consumption by source and region. Credit: BP Statistical Review of World Energy 2014 and International Energy Agency (IEA).

A.I.3. Units

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

Table 1 - Energy units. Source: ISTerre.

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

A.I.4. Differences between primary and final

We rarely consume a cup of diesel for breakfast, nor do we inject methane. Engines (and human effort) consume "primary" energy (wood, petroleum, radioactive fuels, wind, sun, water, kinetic energy, coal) to produce the services we need, such as food, transport, heat, electricity, etc. As final consumers, we use this "final" energy.

The difference between final and primary energy is the “intra-system loss”. Based on the global average, electrical losses in France between production (nuclear power plant) and final user (as electrical heat) represent about 70% throughout the whole system[1]. Most energy losses happen within the power plants in the form of thermal dissipation and mechanical losses (e.g.: loss of mechanical effort) and approximately 10%[2] comes from energy transport (Joule effect).

A.I.5. ENVRIplus isolated scientific stations and energy

Far from world energy issues and global consumption, isolated scientific stations are tiny players in terms of consumption. Typically, their consumption is equivalent to or less than one light bulb, i.e. 2 to 100W.

However, with no energy supply, no measurements can be taken. This is a critical issue for all scientific measurements and particularly for isolated sites, which are not connected to the national electrical grid.

In this report, for the sake of simplicity, “energy” refers to “electrical energy”, the only form of power discussed herein (as opposed to thermal energy or transport energy, for example).

A.II. Energy production

To produce energy autonomously to supply isolated sites, naturally available energy flows (sun, wind, water) can be converted into electricity, or primary energy can be stored in tanks in the form of fuel (gas, alcohol, oil, etc.), which are primary energy chemical compounds.

A major installation constraint is the minimal maintenance of energy supply systems. If fuel is used to obtain energy, refuelling must be organised, which might be complicated if the site is difficult to access. In this sense, it is better to use natural energy flows, but this brings the problem of intermittence.

This “energy production” chapter briefly describes the most common naturally available energy flows used to produce electrical energy: sun, wind and water (e.g.: as opposed to thermal energy which often uses geothermal flows). A short paragraph has also be added about an emerging but still relatively new technology (in 2017): fuel cells, focussing on the fuel cells that use methanol as their primary energy. The methanol is stored in tanks, which implies refuelling constraints, but the period of autonomy can be long, typically between 2 and 6 months, for common ENVRI RI needs, representing a consumption of 10 Watts. (See description in chapter B: ENVRI+ survey on energy “Who is using what?”).

Note: Only “general knowledge” (main technical specifications) is presented and discussed in this report to provide users with a brief overview of each technology.

A.II.1. The sun: Photovoltaic (PV)

Figure 5 shows an example of an scientific station powered by photovoltaic solar panels.

[1] Source: BP statistical review and International Energy Agency. Data from 2010
[2] Sources: RTE (French electricity transportation network, ERDF (electricity network distribution France).

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

A.II.1.1 Operating principle

Devices based on photovoltaic effects (solar panels) use particle energy proprieties to turn photons into electrons, which is what happens if the radiating light energy is enough to overcome the energy barrier of electron excitation in the atom, thus “freeing” the electron from the atomic structure.

If a voltage difference is applied to the conductive matter, an electrical current will appear due to electron movement, as shown in Figure 6.- Illustration of photovoltaic effects. Copyright University of Calgary.

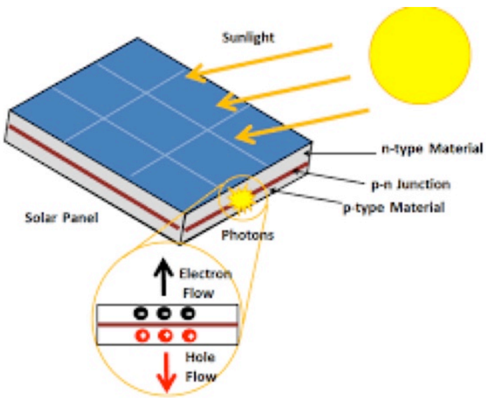


Figure 6 - Illustration of the photovoltaic effects. Copyright University of Calgary.

A.II.1.2 Technologies

Technologies can differ in terms of the efficiency of electricity production compared with light radiation (sunlight spectrum available).

Figure 7 shows the efficiency of some common photovoltaic technologies within the wavelength range from 0 to 1,200 nm.

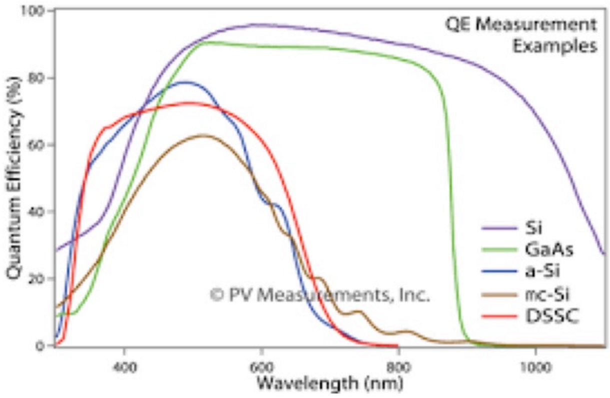


Figure 7 - Some common photovoltaic technologies efficiency for a 0 to 1200 nm wavelength range. Source: PV Measurements, Inc. 2014 (Si: Mono crystalline silicon; GaAs: Gallium arsenide junction; a-Si: Amorphous silicon; mc-Si: Multi-crystalline silicon (also names Polycrystalline); DSSC: Dye sensitized solar cells).

Other technologies include cadmium-telluride (CdTe), Heterojunction with Intrinsic Thin-layer (HIT), etc. "**Si**" (**silicon)** technology is currently the most developed, affordable, and commonly used solar cell technology. It is widely used as a solar power source for scientific stations, and is therefore the only technology discussed in this report.

Photovoltaic silicon technology is developed in three different ways: monocrystalline, polycrystalline or thin film amorphous (deposited without any crystalline structure) solar panels. The visible differences are shown in Figure 8.

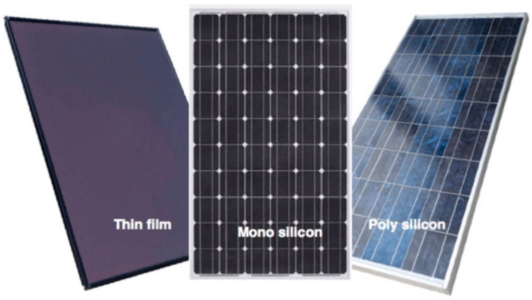


Figure 8 – Representation of the visible differences between mono, poly and thin film (amorphous silicon) solar panels. Source: newsouthernenergy.com

Thin film deposition (made using paper printer type technology) offers the possibility of flexible solar panels.

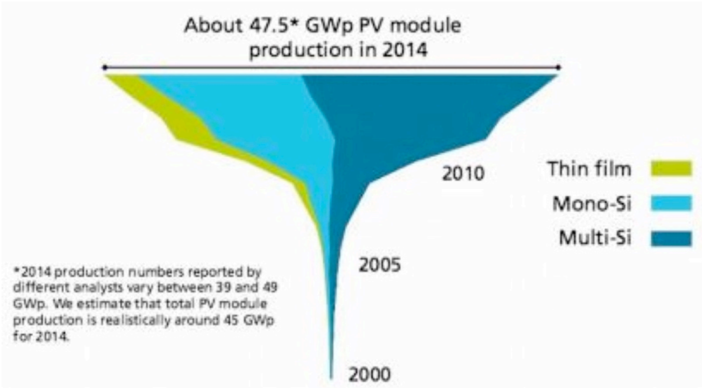


Figure 9 - PV production 2014 by technology. Source: Fraunhofer ISE, Photovoltaics Report. Adapted by www.photovoltaique.info

A.II.1.3 Technical specification 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

A.II.1.3.1 Efficiency

The solar energy industry is one of the most dynamic in the world (in 2017) in terms of research and development (R&D). Consequently, there are major differences between market products and the highest efficiency rates in R&D.
In 2017, the most common technologies available on the market (sources: EPIA -European Photovoltaic Industry Association- and NREL -National Renewable Energy Laboratory, USA) are:

- Silicon crystals (≈ 90% of worldwide market): mono or polycrystalline. Typical efficiencies range from 12 to 18%.

- Thin film: silicon or cadmium telluride (Cd-Te), **copper indium gallium selenide (CIGS).** Typical efficiencies range from 5 to 12%.

- Multi-junction cells: such as indium gallium arsenide, germanium. Typical efficiencies range from 25 to 45% (but most are still in the R&D phase).

Most terrestrial and oceanic scientific stations use silicon crystal technologies. Monocrystalline technology has certain advantages over the polycrystalline version.

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

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.

Figure 10, produced by NREL (National Renewable Energy Laboratory, USA), shows the evolution in efficiency for several solar photovoltaic technologies over the last decades. This information can be used as a reference to help technical staff to choose solar panels for very shaded sites, if only few hours of sun are available. As shown in the figure, the efficiency of the 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.

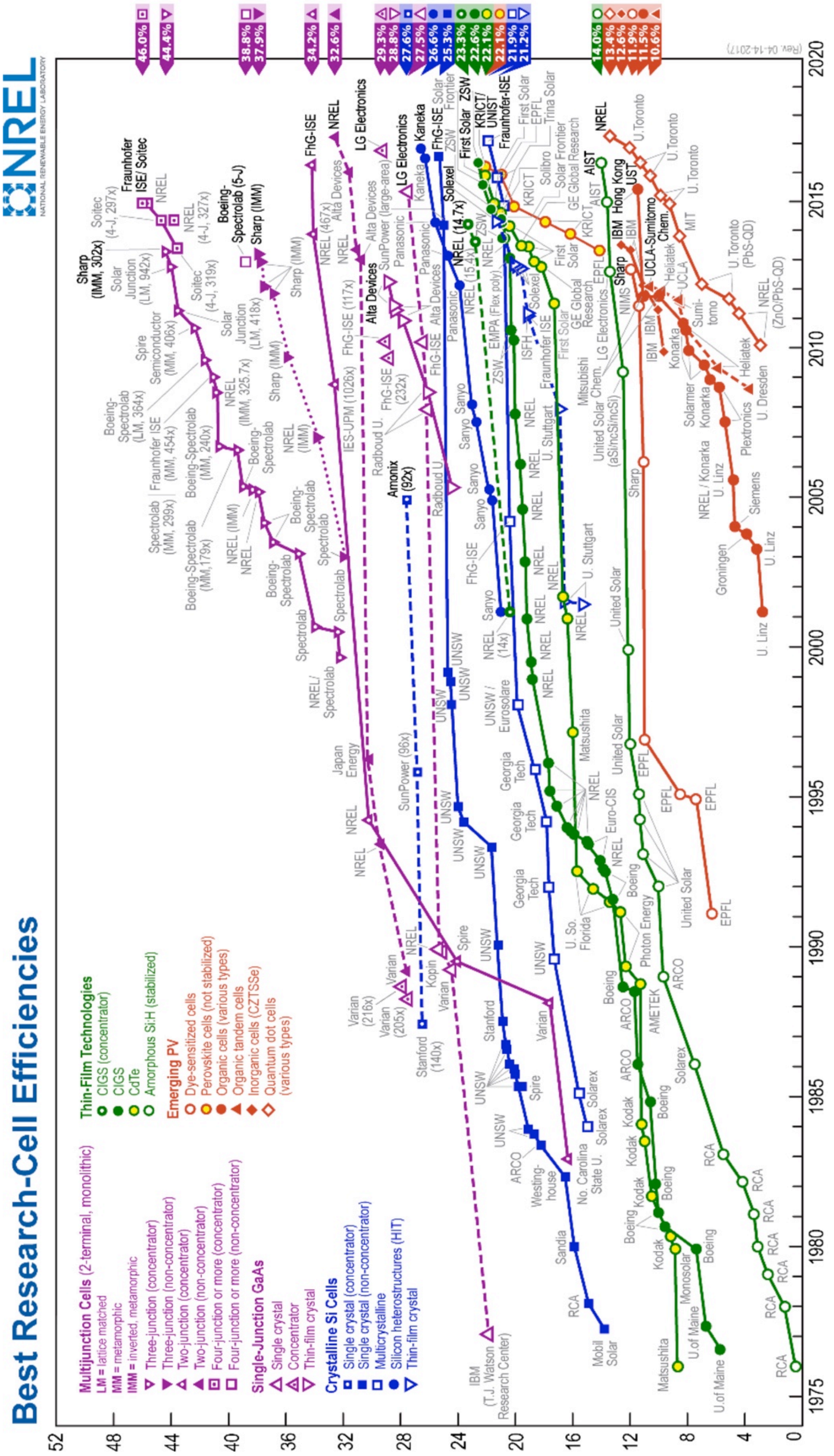


Figure 10 - Best research cells efficiencies. Source NREL. https://www.nrel.gov/pv/

A.II.1.3.2 Energy Production

The current *I(A)* produced by solar panels will of course be highly influenced by the incoming solar energy (irradiance), as shown by Figure 11. Voltage will also be affected, but not to the same extent as current production. The Maximum Power Point (named MPP) represents the optimum combination between voltage and current to maximise power production with respect to solar irradiance (W/m^2): *P(W)=U(V).I(A)*

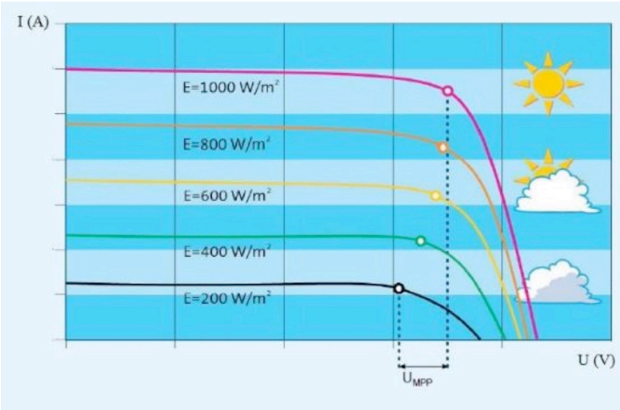


Figure 11 - Influence of light on solar panel voltage and current. Position of MPP - Credits: http://www.photovoltaique.guidenr.fr/III_2_effet-eclairement-module-photovoltaique.php

Total power production will be influenced by:

- Southerly orientation.
- Tilt (angle) above the horizon.
- Internal temperature: efficiency decreases as temperature rises.
- Dirt (dust or snow).
- Manufacturing quality.

A.II.1.3.3 Influence of orientation (to the south) and tilt (above the horizon)

The southerly orientation and tilt angle (above the horizon) have a major influence on production, as shown in Figure 12. The blue circle represents the optimum (maximum = 100% production) for a 45° latitude site for annual production. In this case, it means 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), because the sun is lower.

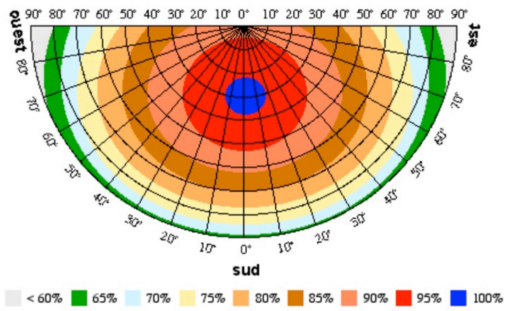


Figure 12 - Effects of southerly orientation and tilt deviation (above the horizontal) on solar panel efficiency. Source: dualsun.fr

A.II.1.3.4 Tracking technology

Solar panels can also be mounted on a tracker, offering the possibility of tracking the sun's position and following it all day long.

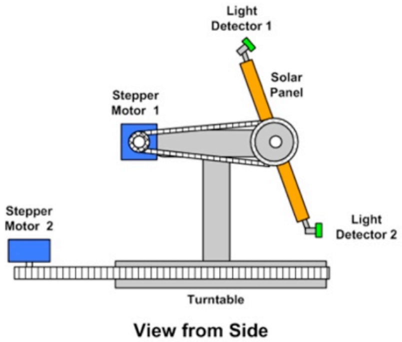


Figure 13 - Illustration of solar tracker systems.

Figure 14 - Illustration of solar tracker systems

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

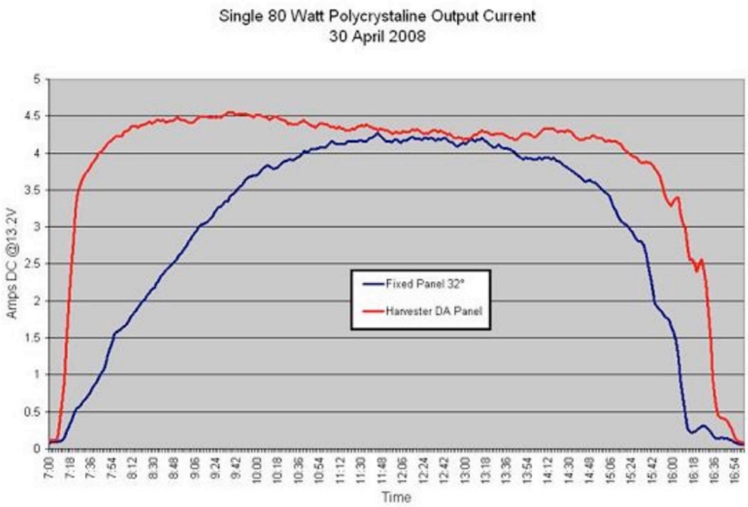


Figure 15 - Comparative production of solar tracking system and fixed solar panels in Australia. Source: www.solarchoice.net

However, trackers consume some of the energy produced by the solar panels to move. For large solar arrays, such as "solar farms", the overall increase in terms of power production can be significant. It is also important to bear in mind that the more technically sophisticated the installations, the higher the possibility of technical failure.

Such installations might therefore not be ideal for RI use because of:

- Weakness against strong winds.
- Overall construction weaknesses due to the large number of details.

Moreover, for most ENVRI RI sites, fixed solar arrays are oversized to ensure autonomy even on cloudy days, so they do not need further yield optimisation.

In the entire ENVRI community, not one example of tracker use was observed. As this technology does not meet RI requirements, it will not be developed in this report.

A.II.1.3.5 Temperature effects

A solar cell works better at cold rather than hot temperatures. Power production drops when the temperature increases, as can be seen in Figure 16 below. Temperature influences voltage more than current.

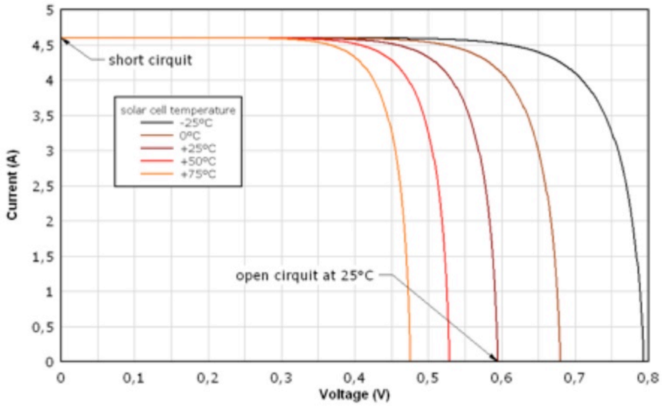


Figure 16 - Solar cell characteristic temperature dependency. Source: pvresources.com

A.II.1.3.6 Solar photovoltaic array sizing

It is important to size the solar installation appropriately for the following main reasons:

- Size depends on the average solar potential of the site.
- Logistics constraints, such as weight and space, are crucial.
- Battery capacity must be adapted to an appropriate charge current (see paragraph A.III for more details on batteries) and the required autonomy if there is no sun.

To help users to select the right size, the two following items will be developed:

- Item 1 - How to estimate your site's solar potential.
- Item 2 - How to estimate energy storage (batteries) based on the worst period (without sun).

Item 1 - Solar potential estimation:

One of the most widely used tools is the European JRC (Joint Research Centre) webpage: "PVGIS", for PhotoVoltaic Geographical Information System. It helps to evaluate the solar potential of specific sites (latitude/longitude).
Link: http://re.jrc.ec.europa.eu/pvgis/

This site provides an estimation of average irradiance for specific latitude and longitude coordinates. The model does not take into account potential shade due to natural relief (mountains), trees, or buildings. Available sunshine hours will therefore have to be estimated independently at the site, particularly for the annual worst period, the winter solstice: 21 December in the northern hemisphere, 21 June in the southern hemisphere.

Another useful tool is provided by the French National Institute on Solar Energy (INES).
INES has 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 monthly production with respect to the tilt of the solar array. To illustrate the importance of ground reflection at a snowy mountain site: production is lower with a 36° (rather than 70°) tilt above the horizon in winter when the albedo effect is strong and the sun is low (see chapter C.III.1 Evaluation results, photovoltaic for more details).

Item 2 - Solar array (and battery) sizing:

Ing. Mickaël LANGLAIS, at the Institute of Earth Sciences (ISTerre) in Grenoble, has aggregated a step-by-step methodology for their own needs. It determines:

- Production needs (W): sizing of the PV installation.
- Storage needs (Ah): sizing of batteries.

Using the following inputs:

- Total installation energy consumption (W).
- Required autonomy (days).
- Worst available irradiance (average daily hours of efficient irradiance).

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

A.II.1.3.7 Effect of snow deposition

As the PV cells in a solar panel are connected in series, it is important to anticipate possible snow deposition and to think about how to install the solar panel, with electrical connection lines parallel or perpendicular to potential snow accumulation. The effects on production are significant, as shown on Figure 17. If a single cell is shaded, all the others, even if they are perfectly lighted, will have the same low passing current as the shaded panel (the effect is similar to that of pinching a garden hose).

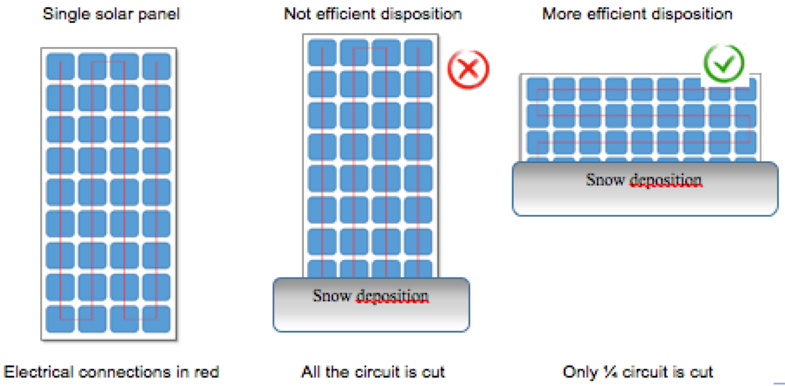


Figure 17 - Effects of snow deposition on the electrical connections of photovoltaic cells. Source: ISTerre

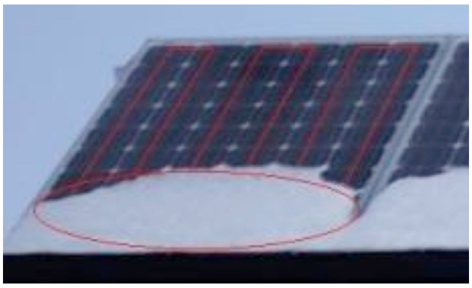


Figure 18 - Effects of snow deposition on electrical cell connection. Source: Norusk.com.

By-pass diodes are often inserted in the cells' sub-circuits to shunt the potentially shaded part of the solar panel.

A.II.1.4 Advantages & disadvantages of photovoltaic solar panels (not exhaustive list)

Table 3 - Advantages & disadvantages of photovoltaic solar panels

Advantages	Disadvantages
Mechanically strong	Intermittence, only with sun !
1m² ≈ 100 Wp (Watt peak)	1m² ≈ 100 Wp
Very low needed maintenance	great surfaces = sails to winds
Works better in cold than warm environments	Works better in cold than warm environments
Easy to use	

A.II.2. The wind: Wind turbines

A.II.2.1 Operating principle

Wind turbines (WT) use electro-mechanical engines to transform mechanical energy (rotating axis) into electrical energy, using a rotor and stator: a rotating magnet versus a fixed magnet coupled to a conductor coil.

It produces alternating current (AC) which, for most of our applications, must be transformed into direct current (DC). This is done by a rectifier and a regulator, which are usually part of the WT. Most small, modern and efficient WTs use neodymium magnets, while their blades are made from a mix of plastic (for flexibility) and carbon fibres (for rigidity and lightness).

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

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

where:

- C: power coefficient
- ρ: Air density
- A: Area swept by the rotor
- W_s: Wind speed

This equation highlights the critical aspects of the location and height of the WT, which are not the main selection criteria for most scientific sites.

A.II.2.2 Technology

“Classic” wind turbines use the horizontal axis. For small wind turbines (e.g. 10 to 1,000W production), vertical axis turbines also exist (Figure 19).

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

Three WTs were evaluated on-site for this project:

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

Only information that is important to on-site use will be summarised here. Vertical twisted WTs (Figure 20) also exist, but were not tested for this project.

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

A.II.2.3 technical specifications

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

The reality is quite different from laboratory wind tunnel evaluations. Technically, “theoretical” power characteristics are often different from the power actually produced on site, especially for vertical axis turbines. In laboratory wind tunnels, winds are laminar and perpendicular to the WT, with equal speed throughout the stream and constant flux through the height.

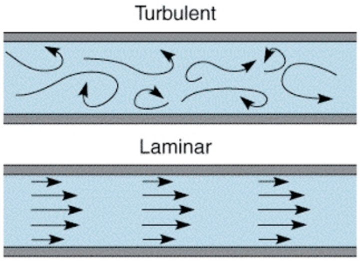


Figure 21 - Representation of laminar and turbulent winds. Source: University of Liverpool

On site and particularly in mountain regions, winds are usually turbulent, not laminar. This means that the wind sometimes reaches the WT at a significant tilt angle. This factor has a greater impact on vertical axis turbines than on horizontal ones.

Electricity produced on site by a vertical axis WT can be dramatically lower than the power level expected. This type of wind turbine is considered more useful on ships, where they generally face laminar winds.

For horizontal axis WTs, turbulent winds are still well absorbed and used thanks to long and sometimes twisted blades.

A.II.2.4 Mounting

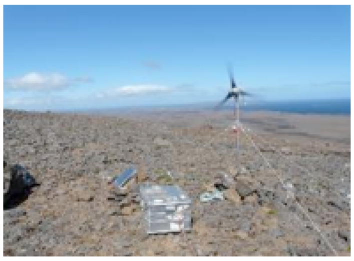
Wind turbine fixture is crucial at isolated sites, particularly in polar regions and high mountains, where the winds can be violent and maintenance interventions are infrequent.

Horizontal axis turbines are obviously “pole mounted”, i.e. on top of a mast.

Vertical axis turbines can also be “side mounted”, like a staple, secured at the top and bottom. This installation necessarily induces a loss of power because the wind is blocked on one side (by a wall, rock, the side of a mast), but it also greatly strengthens the assembly, preventing vibrations, and will not have a huge impact on production during strong wind events.

It is important to check that all the mechanical parts of the horizontal and vertical axes work properly.

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

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

A.II.2.5 Advantages & disadvantages of small wind turbines (not exhaustive list)

Table 5 - Advantages & disadvantages of small wind turbines

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.

A.II.3. The water: hydro turbines

Very few examples of scientific stations using hydroelectricity were found among ENVRI+ RIs. However, some micro hydro turbines could be used in special conditions. Figure 22 offers a global overview of such systems.

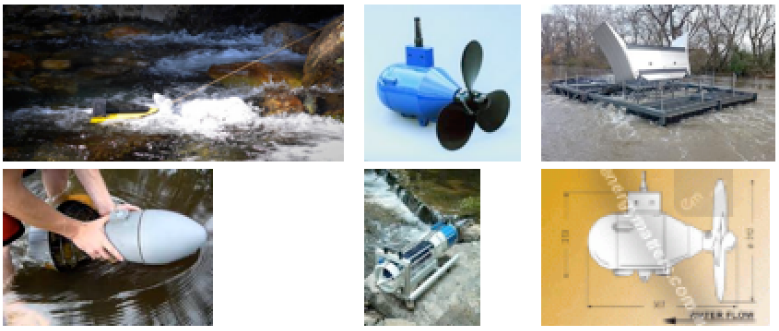


Figure 22 - Examples of micro hydro turbines.

For example, the CNRS/ANAEE "Nouragues" station in French Guiana (a station for tropical ecological research) uses a 10kW hydroelectric "pelton" turbine, similar to the one below (Figure 23).

See website for more information: http://www.nouragues.cnrs.fr/spip.php?rubrique4

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

Other hydro turbines, as small as 100W (Figure 24), can provide constant power to small devices, as long as flowing water is available.

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

A.II.4. Chemistry: fuel cells

A.II.4.1 Operating principle

Fuel cells produce electricity by electrolysis not combustion: energy is gathered from molecule separation.

Several technologies exist, two of which are advanced enough to be commercialised:

- Hydrogen: H_2
- Methanol: CH_3OH

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

Fuel cell technology is still relatively new (at the time of writing this report, 2017), but huge efforts are being put into research and development in this area. Fuel cells offer a number of interesting advantages for scientific research sites.

A.II.4.2 Technical specifications

Tab. 6 is an example of a technical specification for a methanol fuel cell.

Table 6 - Example of a technical specification for a methanol fuel cell. Source: EFOY.

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

A.II.4.3 Application examples

Methanol fuel cells (on-site use) were evaluated by technical staff from laboratories. The potential issues identified by these evaluations are:

- Water vapour emission, causing the set-ups to switch to safe mode when temperature drops below 0°C. This is unacceptable for "cold" outdoor scientific stations. Insulated and/or heated casings could be used to avoid this issue.

- CO_2 emission: harmful in terms of GHG levels and the fuel cells must be placed in a ventilated area to ensure personnel safety.

- Methanol represents a hazard for logistics operations. Toxicity is relatively high, and precautions must be taken.

Figure 26 - Example of a methanol fuel cell.

One advantage of the methanol fuel cell system is its autonomy: 2 months with a 10L tank, for consumption of ≈ 8W. Methanol tanks exist in 5, 10, 28 and 60 litre capacity.

Manufacturers now sell adapted heated and insulated boxes, with fuel tanks that are large enough to supply both heating and battery/direct consumption. These models are intended to operate at temperatures as low as -40°C.

Hybrid systems also exist, combining fuel cells with lead-acid or Lithium $FePO_4$ batteries. They can also be linked with solar panels, wind turbines, etc.

A.II.4.4 Advantages & disadvantages of methanol fuel cells (not exhaustive list)

Table 7 - Advantages & disadvantages of methanol fuel cells.

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 (separators) state of health.

A.III. Energy storage

Electricity has to be stored for unproductive periods: night, no wind, no fuel, etc. Batteries are the most widely used technology to store the electricity produced directly, compared with other secondary physical storage solutions, such as water tanks -using the potential energy of gravity-, or chemical compounds like H_2, compressed air, etc. Batteries are the only storage technology that will be discussed here.

There are two main families of batteries:

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

We will concentrate mainly on the type most used by scientific research laboratories, "secondary" rechargeable batteries: [4]

- Lead-acid batteries
- Lithium-ion batteries.

However, we will add a few words on primary non-rechargeable batteries.

Note: *Only "common useful knowledge" (main technical specifications) is presented and discussed in this report to provide users with a brief overview of each technology.*

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

A.III.1. Lead-acid batteries

A.III.1.1 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 mixture of sulphuric acid and water (Figure 27). This set-up represents a single battery cell. Its nominal voltage ranges from about 2.1 to 2.2 Volts. A "12V" battery is made from six cells in series, producing a nominal voltage of **12.6 to 13.2 Volts**. If cell voltage drops below 2V, the battery must be recharged. Thus, for a 12V battery, if voltage drops below 12V, it must be recharged.

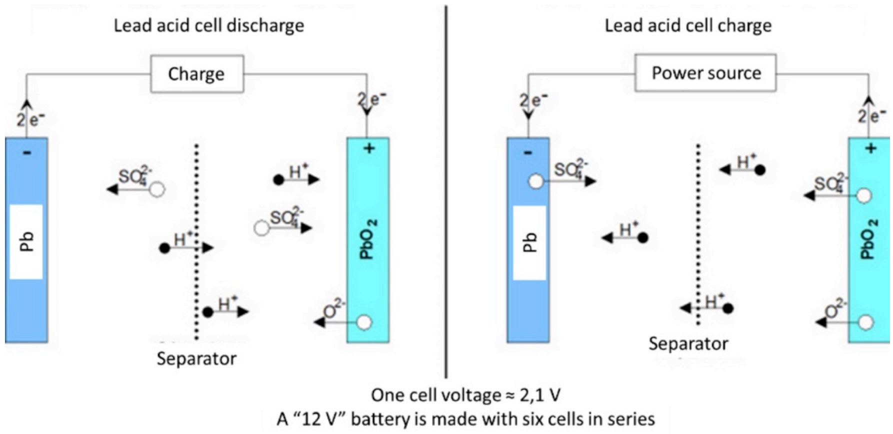


Figure 27 – Operating principle of lead-acid batteries. Source: Batterie-solaire.com

Three major technologies for lead-acid batteries are available:

- Open liquid: sulphuric acid + water
- Sealed with AGM (Absorbent Glass Mat)
- Sealed with gel inside

Sealed batteries are called VRLA, for "Valve-Regulated Lead-Acid". They are the batteries most used by scientific research infrastructures and the subject of the following paragraphs.

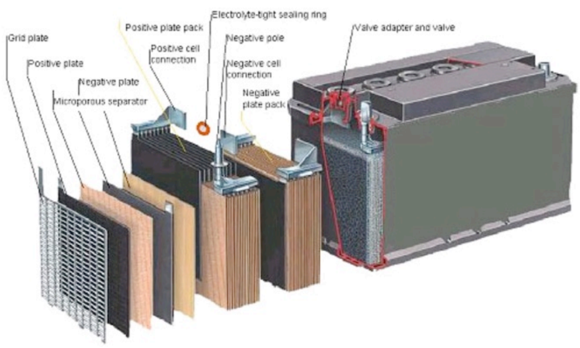


Figure 28 - Schematic of a typical lead-acid VRLA battery. Source: http://barden-uk.com/info/

Open liquid batteries were used in cars for a while, but nowadays they have been replaced by VRLA batteries. Large photovoltaic solar arrays still use tall open liquid batteries for two reasons: 1) they can provide higher current, and 2) they cannot be removed from the energy storage building.

A.III.1.2 Valve Regulated Lead-Acid (VRLA) batteries

Sealed batteries are called VRLA for “Valve-Regulated Lead-Acid” batteries because they have closed boxes, secured by pressure valves. They can operate in an inclined position, and do not need regular maintenance, unlike open batteries, whose water has to be refilled regularly due to evaporation during charge and discharge cycles.

Gel and AGM batteries use two different technologies to store the mixed acid and water electrolyte. Their characteristics differ depending on how and why they were built: high current for cars, large number of cycles available, etc.

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

- Low current consumption: approximately 1 Ampere.
- Charged by photovoltaic solar panels, so needs a high number of available cycles (sometimes called “cycling batteries”).

For example, in the YUASA range, cycling batteries are the REC and NRC products: they are AGM VRLA batteries. When the technology first came out, gel (which is newer than AGM) was reputed to work better in cold conditions. However, it seem that the new AGM manufacturing technique, with improved quality glass material, has reduced this difference. Once again, it is important that requirements are clearly explained to battery suppliers: low current and solar charge.

Another less known and much more expensive technology (e.g.: €330 for one 50Ah battery, compared with approximately €150 for a typical VRLA AGM or gel battery) is thin plate pure lead: TPPL.

This technology is expected to have a longer life and to work at lower temperatures. A case study in an Antarctic seismology measurement station is presented in chapter B II “Catalogue of operational isolated stations” (this station was set up by the French Institute of Earth Globe Physics in Strasbourg). This technology will not be discussed in this report, but should be considered for polar installations.

A.III.1.3 Technical specifications

A.III.1.3.1 Capacity

The capacity is the amount of electricity the battery is able to store. It is expressed in Ampere hour: Ah.

For example, a 50 Ah battery is supposed to be able to supply 5 A for 10 hours, 2 A for 25 hours or 10 A for 5 hours.

A lead-acid battery is able to send more current with a lower amperage than with a higher amperage, e.g.: nominal battery capacity will be higher with a 100 mA current than with a 10 A current, which would severely reduce battery capacity. Nominal battery capacity is therefore usually expressed as the optimal current for a 20-hour discharge, noted “C20”.

C20 = X Ah = battery capacity with constant consumption of a X/20 Ampere current.

For example:
C20 = 50 Ah: the battery will supply 50/20, i.e. 2.5 A current continuously for 20 hours.
Some batteries indicate C10 or C100. C100 = current for 100 hours' use. C10 = current for 10 hours' use. If C20 = 50Ah, C10 will be < 50 Ah, and C100 will be higher.

A.III.1.3.2 Charge

Battery capacity depends on how the battery is charged. It is more efficient to use a charge current of between 10% and 25% of nominal capacity (at C20) than a lower one (and a higher current will cause damage due to high temperatures).

For example, if C20 = 50 Ah, use a charge current of between 5 and 12.5 A.

Furthermore, it is better to charge with a "multiple step" charge process. Although usually comprising 3 steps, chargers are also available with 7 or 8 steps. Each step adapts the voltage and current to the battery's state of charge. If battery charge is very low, a high current will be used with a high voltage. This is called the "bulk" step. When the battery reaches its nominal charge, current will be reduced to the "floating" step level.

Between the two, are the "absorption" steps, as shown on Figure 29.

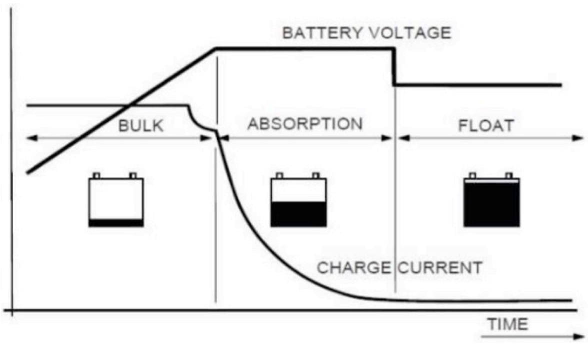


Figure 29 - Ideal 3-step battery charge process. Source: Batterie-solaire.com

"Internal" battery chargers for office use generally propose this multi-step technology, but this is not always the case with the kind of cheap solar chargers used in isolated stations.

If charge voltage and current are too high, hydrogen will be formed. Valve regulated (VRLA) systems reduce gas to threshold pressure. Such scenarios must be prevented and avoided. Furthermore, charging rooms must be properly ventilated.

A.III.1.3.3 Discharge

Manufacturers usually provide certain instructions, such as do not discharge to less than 1.8V per cell. That means that a 12V battery should not be discharged below 10.8 V. Below this threshold, there is more water in the electrolyte (sulphuric acid + water mix). This will enhance the formation of sulphur crystals, causing the potential (voltage) and therefore electricity storage capacity to decrease.

It is recommended not to use the battery to more than 50% of its nominal capacity. This means that when sizing installations, 80 Ah batteries should be used as if they were 40 Ah batteries. The less the battery is discharged during each cycle (one cycle = one charge + one discharge), the longer the battery will last.

This advice is for optimal battery use and to make the batteries last longer. In very remote sites, where every available Ah is necessary, it makes sense to use more of the total battery capacity even if this means replacing the batteries every three years instead of every six.

When batteries are stored and not in use, they also suffer **internal self-discharge** over time. Generally speaking, it is recommended to store them in a cool (and ventilated) room to slow down this process. On Figure 30, the lead-acid battery lost 0.07 V per cell over 6 months at +40°C (i.e. ≈ 0.5 V for a conventional 12 V battery made with 6 cells in series), while it lost the same voltage over 48 months at +10°C. This tendency has been also confirmed by another battery manufacturer (YUASA).

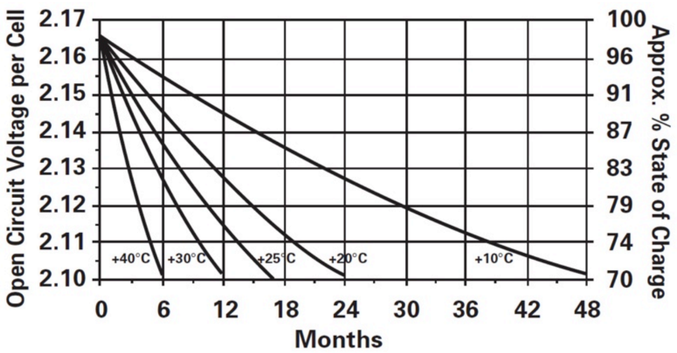


Figure 30 - Example of self-discharge rate for a range of temperatures. Source: EnerSys-emea.com

A.III.1.3.4 Other information

Storage while batteries are not in use:
Batteries must be recharged when voltage U < 12 V, or every 6 months.
A discharged battery has more water in its electrolyte. This encourages the growth of sulphate crystals, resulting in irreversible deposition on the lead plates, severely reducing battery capacity.

Capacity and temperature:
Actual battery capacity is proportional to temperature:

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

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

There is little information available on capacity at temperatures under -10°C, but this is often the case for the scientific measurements conducted by the Grenoble laboratory community, working in high mountains and/or polar regions. Tests were therefore conducted using a climate chamber, where temperatures can be brought down to -50°C. These results are presented in chapter D “Evaluation of energy storage in a laboratory climate chamber”.

A.III.1.3.5 A quick test for battery state of health

As previously mentioned, sulphate crystals will appear due to the water in the electrolyte when discharge is too deep and too long, seriously damaging nominal battery capacity. Checking voltage while the battery is in use can indicate its state of charge, but not its internal SoH.

If you fully charge an empty battery, a few seconds after disconnecting the charger, a voltmeter is likely to display voltage of approximatively 13V. This suggests that the battery is in good health. However, it is only possible to check its “true” voltage at least two hours after the end of charging (ideally four hours). This value will correlate with the battery’s internal SoH (see chapter D for more details).

This quick empirical battery test proposed by the manufacturer YUASA can be used as a good approximation for internal battery SoH, having been tested and validated several times during this project.

Note that an impedance-meter will offer a more precise diagnostic based on the impedance Z(Ω) measurement, but such devices are quite expensive “just for battery users”, and similar results can be achieved using a regular, affordable voltmeter.

Protocol (ideally, everything should be done at a temperature of 20°C):

1. Fully charge the battery
2. Wait 4 hours after disconnecting the charger.
3. Measure voltage U(V), in reference to the table below.
   Option: If possible, check impedance too (Z in Ω)
4. Note U(V) (and Z if measured) on the label, and affix to the battery.

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

≥ 13,0 V	100%	Ok for fieldwork use.
12,5 V	50%	Temporary use only
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	

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

Precisions concerning impedance Z(Ω): if the value has doubled, battery is at the end of its life (Figure 32). Rough estimate of nominal impedance in new lead-acid battery ≈ 5 to 10 mΩ

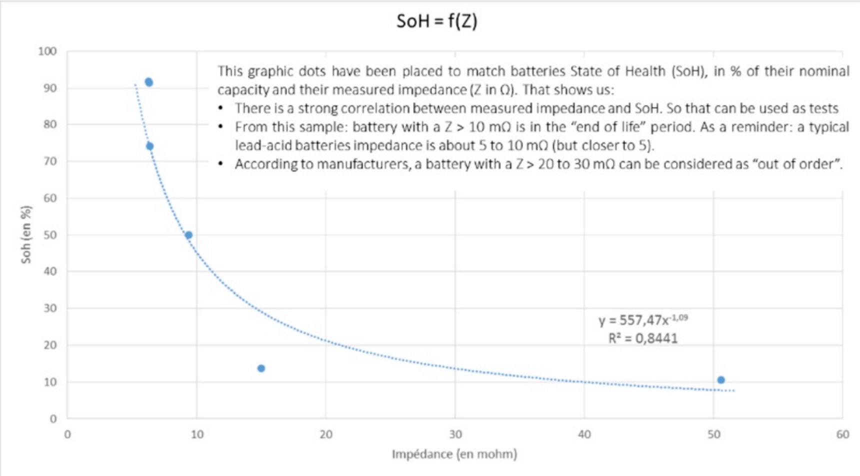


Figure 32 - Link between battery impedance (Z) and State of Health (SoH).

A.III.2. Lithium batteries

A.III.2.1 Technologies

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

Lithium-metal batteries: non-rechargeable (primary batteries)
These have a lithium plate as the anode, and another metal as the cathode, e.g. the Li (anode) and MnO_2 (cathode) battery, Figure 33.

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

Some Research Infrastructures working in marine environments use primary lithium-metal batteries.
Specific energy: 150-800 W·h/kg

Lithium batteries such as the lithium sulphuryl chloride cell, are mainly used in the oceanic domain (see Figure 34), in buoys or deep ocean profiling floats. Primary lithium batteries will be installed at the time of launch and changed when the device returns.

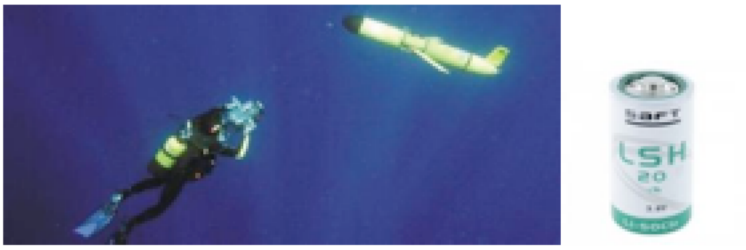


Figure 34 - An example of use of lithium sulphuryl chloride (primary non-rechargeable) cells in the oceanic domain, RI survey feedback.

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.

Figure 35 - Example of a 1,5 Ah Li-ion battery.
Source: https://en.wikipedia.org/wiki/Lithium-ion_battery

Figure 36 - Example of a 60 Ah Lithium-ion battery used by a research infrastructure

Lithium-polymer batteries (Li-Po): rechargeable

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

Figure 37 - A lithium-ion polymer battery used to power a mobile phone. Source: https://en.wikipedia.org/wiki/Lithium_polymer_battery

Lithium-ion and lithium polymer batteries are those most commonly used for mobile devices, such as laptops, smartphones, tablets, etc.

A.III.2.2 Advantages and disadvantages of lithium batteries compared with lead-acid batteries (non exhaustive list)

Table 10 - Advantages & disadvantage of lithium batteries compared with lead-acid batteries.

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). 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	Need others special chargers than “common” lead-acid ones. Voltage and current variation (minimum and maximum) are different, such as charging steps.
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.	

A.III.3. Other battery technologies

Other battery technologies exist that could be used for some specific installations, but they are not included in this report as they are not representative of the types most commonly used in isolated scientific stations.

Some examples are:

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

Current research and development (R&D) projects include:

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

To conclude, Figure 38 presents the main differences between the most commonly 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 – Comparison of battery technologies - Source: homepower.com

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

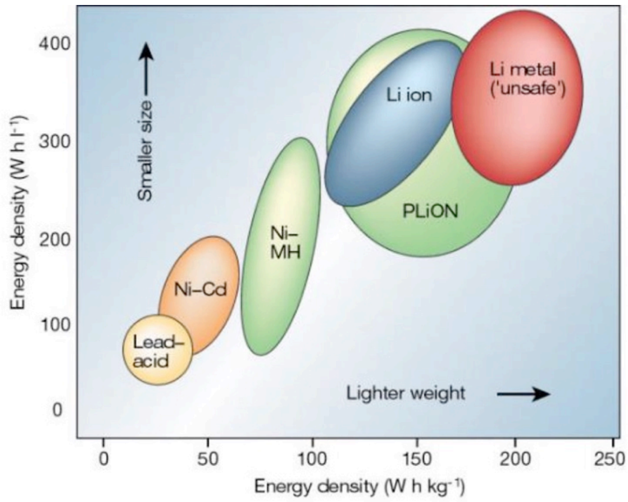


Figure 39 - Energy density comparison - Sources: JM Tarascon & M Armand, http://www.nature.com

“Comparison of the different battery technologies in terms of volumetric and gravimetric energy density. The share of worldwide sales for Ni–Cd, Ni–MH 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.

A.IV. Power regulation/control

***Note:** Only "general knowledge" (main technical specifications) is presented and discussed in this report to provide users with a brief overview of each technology.*

A.IV.1. General concepts

Between production and storage systems, current must be regulated to maximise efficiency.

For example, in a car, current from an engine generator is regulated by the alternator, producing direct current (DC) for 12V batteries and electrical devices. Primary energy comes from the engine's circular mechanical force and an alternating current (AC) is produced.

Regulation is necessary because production systems can sometimes provide voltages that are quite different from the voltage levels actually required. For example, a wind turbine usually produces a 3-phase alternating current (AC) that must be transformed into direct current (DC) to supply standard electronic 9-36 VDC devices. For industrial wind turbines, the situation is different: they produce AC that "just" has to be adapted to the electric grid voltage, for example, from 400,000 VAC for long distance transportation to a final 220-240 VAC for distribution.

The DC produced by solar panels also has to be modified before being used to charge batteries or to operate devices. It is important to set both values to the appropriate voltage to avoid causing damage, according to the number of photovoltaic cells composing the solar panel. Voltage usually ranges from 20 to 40 VDC with maximum irradiance, and must therefore be adapted to suit 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 controllers to cut off overvoltage in order to minimise internal consumption during winter (when every mA counts), because during sunnier periods, there will be enough time to recharge batteries, even if the sun is low and weak, and even if power regulation is not at its most efficient. Furthermore, use of electronics is kept to a strict minimum as such parts are weak at temperatures under -50°C.

A.IV.2. Special cases for solar panels: PWM or MPPT

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

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

A PWM charge controller can be likened to a switch that connects the solar panels to the battery. It reduces the panel voltage to be close to the battery voltage and enable charging without causing damage. Time pulsations adapt the current to the battery.

MPPT charge controllers constantly try to target the most efficient ratio between voltage and current in order to maximise battery charge.

For scientific applications, particularly in isolated, unmanned stations, MPPT systems are recommended, particularly for high power solar panels[5]. A 250 Wp solar panel is composed of 60 photovoltaic cells, 0.5 V each, reaching approximatively 30 VDC. A PWM charger will reduce this

[5] Latest update: After winter 2017-2018 evaluations of MPPT versus PWM, we strongly recommend systematic use of MPPT, even for "small" (e.g. 50 to 100 Wp) solar panels. See details in chapter C.III.3.

voltage to the voltage of the battery, i.e. 14 V for a 12 V battery. This results in a significant loss of efficiency, as P(W)=U(V).I(A).

Conversely, an MPPT charge controller constantly adapts total power using the “Most Power Point” value of the solar panel, as illustrated in Figures 40 and 41, to maximise available current.

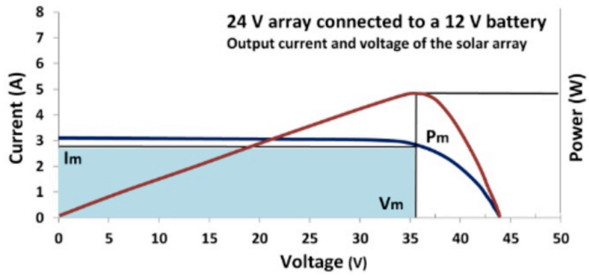


Figure 40 - Example of a large number of cells wired in series to produce 36 volts. Source: Victron energy.

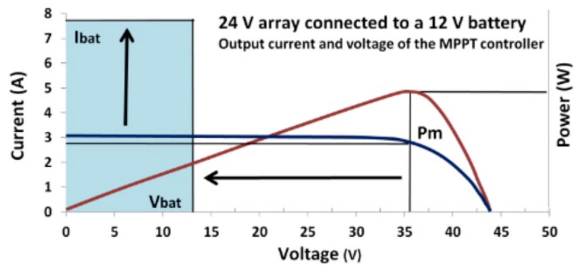


Figure 41 - Graphical representation of the DC to DC transformation performed by an MPPT controller. Source: Victron energy

Moreover, an MPPT regulator will optimise solar panel performance when cell temperature is too low or too high, and when irradiance is low. This is a major advantage in places with low solar irradiance, which can be the case for RI applications.

It is also recommended to have a “duo” regulator or a battery separator system that can manage two battery packs: one for scientific acquisition, the other for data transmissions. This allows charging priority to be given to the scientific acquisition battery pack.

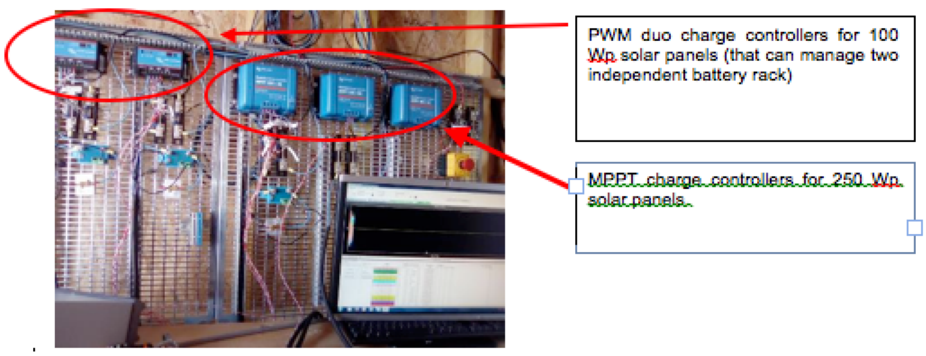


Figure 42 - Examples of current regulators for solar panels. Source: ENVRI+ WP3.1 bench test at Col du Lautaret (see chapter C).

A.IV.3. From production to storage: the importance of wires

As wires have their own electric resistivity, the current carried inside will generate a voltage drop (= power line loss). Wire cross section must be carefully selected with respect to wire length and current value.

Power loss is due to the Joule effect (Joule Heating) as follows:

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

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's resistance R results from this equation:

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

where:

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

For the same material (e.g. same ρ) and same length (L), a larger cross section will reduce Joule losses. Table 11 shows a few examples of material resistivity.

Table 11 - Material resistivity values. Source: ISTerre.

Material	Resistivity (x10^{-8} Ω.m)
Copper	1,7
Iron	10
Carbon	3500

Solar and battery systems in isolated scientific stations generally use 12 V devices. Remember that a higher voltage will allow a smaller cable cross section (for the same power level) or a higher current with same cables.

Figure 43 (French for metric system and English for AVG correlations) shows maximum available power or current as a function of wire length and cross section.

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. A catalogue of isolated, operational isolated stations

B.I. Purpose

The purpose of the ENVRI+ (WP3.1) survey was to find out who is using which energy solutions to power their isolated stations. The survey was conducted from March to June 2016 and, at the time of writing this report, had gathered about 25 examples of isolated, operational stations in very different scientific domains: oceanography, biology, atmosphere, geology, etc. These stations are representative of larger networks.

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

The chapter comprises two main parts:

- The actual “Who is using what?” survey, which aggregates statistics on the answers provided by RIs.
- The catalogue of operational solutions based on the survey’s findings.

B.II The survey on energy: “Who is using what?”

B.II.1 Construction

B.II.1.1 Purpose

The title of this questionnaire was: “**Energy and data transmissions for isolated scientific stations: Who is using what?**”

The aim of this questionnaire (and of the resulting database - catalogue -) was to aggregate as many examples as possible of site conditions regarding energy and data transmission systems, from all over the world and from different scientific domains (solid earth, atmosphere, oceanic, etc.).

The overall guideline that motivated this report is: **The more we share, the better we are.**

This quote particularly applies to isolated technical installations in extreme conditions. Only general information was requested concerning the technologies used for energy and data transmission systems in the RIs’ isolated scientific stations. For information on directly operational solutions and case studies on energy and data transmission, please refer to the catalogue (second part).

B.II.1.2 Question

The ENVRI+WP3 questionnaire comprised the following questions concerning just one isolated station per answer:

On energy:

- What is the approximate 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, etc.)
  - Other:
- Could you please specify the model you are using?
  - For 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)
  - For 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?
  - For example: 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)
  - For example: We didn’t have a choice: only satellite works where we are. We have several remote stations on this site, we built a WIFI "bridge" network, etc.

General information:

- Could you please describe your station briefly?
  - For example: Seismological station in the Alps, powered by 200 W solar panels, lead-acid batteries, 3G communication. CO2 measurement in forest, powered with lithium batteries designed to last for at least 1 month.
- Email address for contact (if agreed)
- Name of your station and research infrastructure:
  - For example: ARGG from RESIF, XXXX from ACTRIS, etc.

Figure 44 - Illustration of the ENVRI+ WP3.1 survey: “Energy and data transmissions in isolated scientific stations: Who is using what?”

A first general questionnaire was distributed from February to June 2016. A second simpler and shorter questionnaire (described in this report) was published on-line in June 2016, and is still running.

Standard legal information

The questionnaire aims to provide technical information (on energy and data transmission in remote stations) on European public Research Infrastructures (RI): Answering the questionnaire is voluntary. You have been selected to answer the questionnaire in your professional capacity as a representative of the RI with which you are working.

All data will be stored securely on the servers of University Grenoble Alps (France, WP3 leader) and will only be used for the ENVRIplus project. The technical results of the questionnaire and the conclusions deducted from the results might be published as 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 provide contact information, you can also request copies of the reports and documents generated from the information collected in this questionnaire.

B.II.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 domains (See Tab. 12).

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

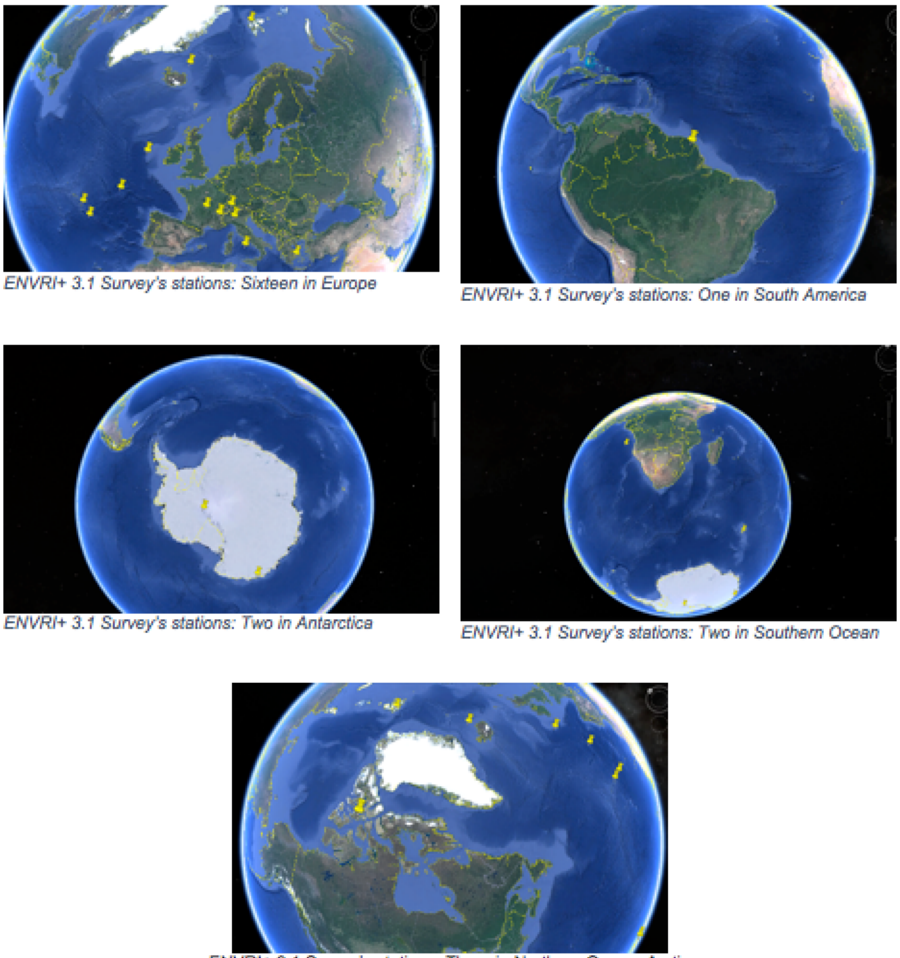
Scientific domain	Answers to questionnaire
Ocean	10
Atmosphere	3
Biodiversity-ecosystem	1
Solid Earth	10
TOTAL	24

When talking about energy systems and data transmission, it is important to keep in mind that certain technical solutions might be available for terrestrial use (14 answers to questionnaire, i.e. 58%), but not for oceanic applications (10 answers to questionnaire, i.e. 42%). They have therefore been separated to ensure a more relevant comparison.

Glaciology (polar stations in this case) is included in the "Solid Earth" category (as GPS reference stations are usually placed on surrounding rocks).

Where are the recording stations located?

Station locations are voluntarily shown to cover a wide area. The following maps only present their global location to help users to find the most appropriate solutions (depending on their needs: oceanic, polar, forest, etc.).



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 station locations. Maps powered by Google Earth.

B.II.3 Details on energy systems

B.II.3.1 - What is the approximate total energy consumption of the isolated measurement station? (total: sensors + communication + heating + alarm + etc.)

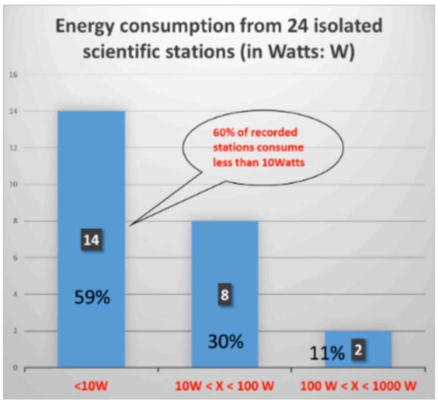


Figure 46 – Survey: Energy consumption from 24 isolated scientific stations. Source: ISTerre

One of the most useful pieces of information obtained from this questionnaire to help us work on common solutions, is that **60% of isolated scientific stations consume less than 10 Watts**.

The questionnaire did not try to highlight other consumption categories up to 1kW. We considered (and knew) that for higher levels of energy needs, most scientific stations would be supplied by gasoline power engines, which are not suitable for unmanned stations.

Differences were obviously expected between **oceanic and terrestrial uses**, Figure 47.

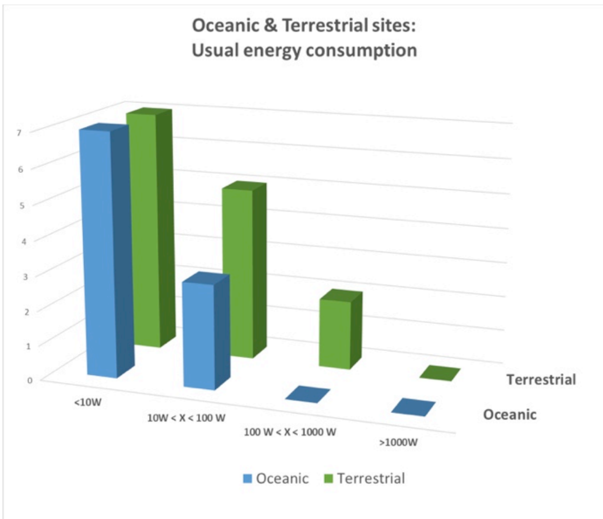


Figure 47 - Survey: Oceanic vs Terrestrial typical energy consumption. Source: ISTerre

Oceanic stations usually have a lower level of consumption than terrestrial stations. The energy source issue is even more critical under water.

B.II.3.2 - What technology do you use to provide the energy you need?

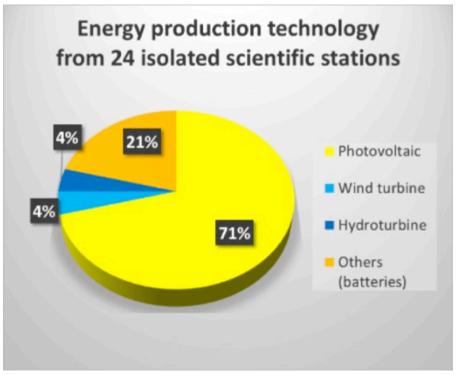


Figure 48 - Survey: Energy production technology used in 24 isolated scientific stations. Source: ISTerre

Photovoltaic is by far the main source of electrical energy in isolated scientific stations: more than 70% of recorded isolated scientific stations use solar panels. Indeed, this technology does not require regular, complex on-site maintenance, unlike wind turbines which are more sensitive to cold temperature (because of oil and mechanic parts). For examples and case studies, please refer to the catalogue (second part).

No feedback was provided on the use of fuel cells. This topic is of interest because fuel cells are being used (2017) increasingly as energy sources in isolated sites (fuel cell using H_2 made from methanol or H_2O). If you know of any such examples, please contact us using the questionnaire or via email (mickael.langlais@unvi-grenoble-alpes.fr).

Another interesting (but of course expected) result is that most oceanic applications only use batteries that have to be replaced regularly, and have no source of energy production. The reasons are obvious for underwater profilers, unlike surface buoys (which generally use small photovoltaic solar panels).

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

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

B.II.3.3 - What kind of batteries do you use?

Lead-acid batteries are still (2017) the most widely used technology for storing energy in isolated scientific stations.

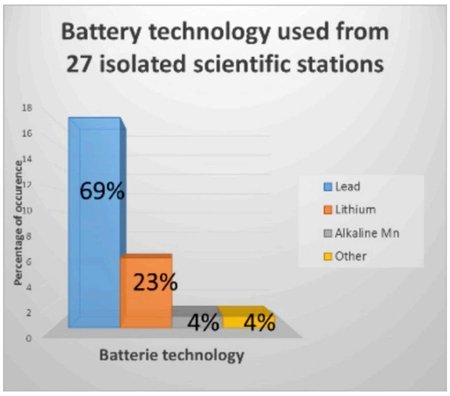


Figure 49 - Survey: Battery technologies used in 24 isolated scientific stations. Source: ISTerre

Lithium batteries are also used (according to the responses to the questionnaire), mostly for oceanic underwater applications. No drone applications have been recorded as isolated scientific stations; they are known to use lighter batteries.

Regarding the current state of the art of this technology, lead-acid batteries offer better performance than lithium batteries in cold conditions.

Lithium batteries involve logistics problems, although certain technologies (such as $FePO_4$) have made improvements to safety issues.
For examples and case studies, please refer to the catalogue (second part).

B.II.3.4 - Please indicate the model (brand, specifications) of these batteries.

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

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

B.II.4 Details on data transmission systems

B.II.4.1 - What technology do you use for data transmission?

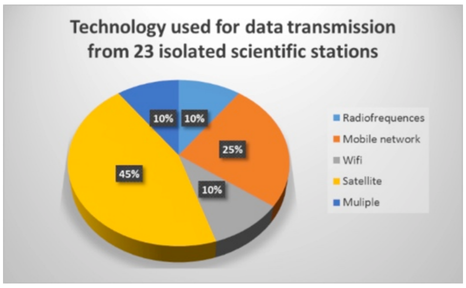


Figure 50 - Survey: Technologies used for data transmission in 24 isolated stations. Source: ISTerre.

Satellite communication is the most commonly used data transmission system in isolated sites. In fact, the Iridium satellite constellation is the only system that covers polar regions.

However, satellite systems are quite expensive, which is why mobile networks (GSM, GPRS, 3G, EDGE, 4G, etc.) come in second place for data transmission.

There are of course differences between terrestrial and oceanic requirements: satellite systems are obviously the most commonly used technologies for oceanic connections.

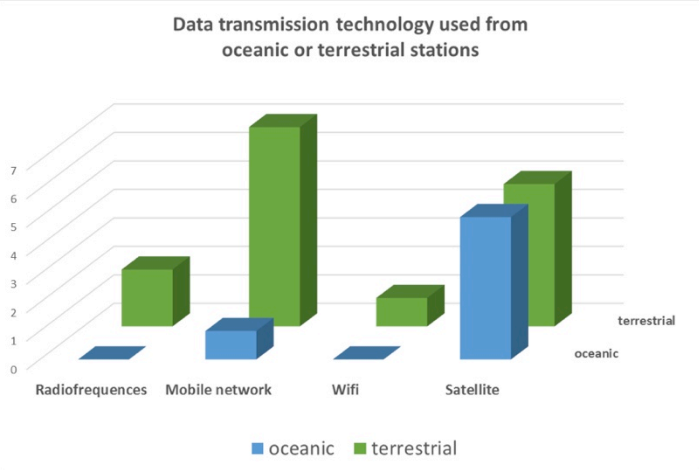


Figure 51 - Survey: Data transmission, differences between Oceanic and Terrestrial stations

WiFi as a local multiple point network (many measurement stations are in a defined area) is regularly used for data transmission, working in parallel with a mobile network modem to aggregate all the station's data and send them to datacenters.

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

B.II.4.2 – Data transmission summary

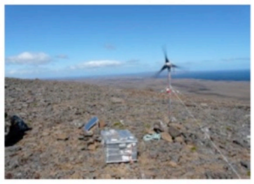
Table 15 - ENVRI+ WP3.1 survey: summary on data transmission. Source: ISTerre. (see next page)

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)

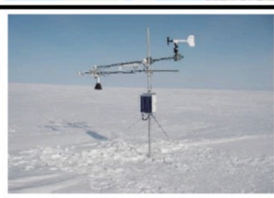
B.III – The ENVRI+ catalogue of operational isolated stations

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

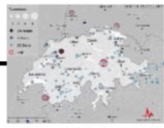
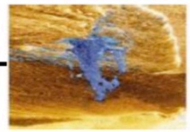
B.III.1 – Terrestrial stations

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.



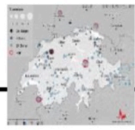
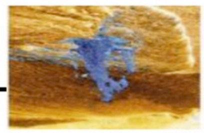
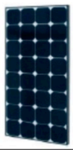




General informations:	
Name of the scientific station:	SBLM
Research infrastructure/laboratory :	nc
Measured parameters:	nc
Localization :	nc
Contact (email):	nc
Website:	nc
Energy supply:	
Energy consumption:	10W < X < 100 W
Energy production:	Photovoltaic 4 poly crystalin solar panel "sun modules" 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)



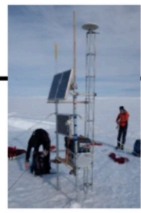
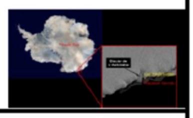
General informations:	
Name of the scientific station:	PREO from SED
Research infrastructure/laboratory :	EPOS/ Swiss Seismological Service (SED)
Measured parameters:	Seismic
Localization :	Alps mountain
Contact (email):	lukas.heiniger@sed.ethz.ch
Website:	http://www.seismo.ethz.ch/en/home/
Energy supply:	
Energy consumption:	10W < X < 100 W
Energy production:	Photovoltaic 2 x Sun Peak PN-SPR of 100W
Energy storage:	Lead-acid 100 Ah < X < 500 Ah SWISSsolar compact 270Ah
Telecommunication:	
Network architecture:	Mobile network
Modem:	Cabtronix AnyRover Communication is fast and reliable and we can control the modem by SMS is everything else fails.
Others informations:	Semi-Permanent Seismological station in southern Switzerland, powered with 200W of solar panels and a large battery. 4G (LTE) communication.

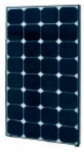




General informations:	
Name of the scientific station:	TOMO from ANET network in Antarctica
Research infrastructure/laboratory :	POLNET
Measured parameters:	GPS
Localization :	Antarctica
Contact (email):	kendrick.42@osu.edu
Website:	http://polenet.org/?page_id=176
Energy supply:	
Energy consumption:	<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.

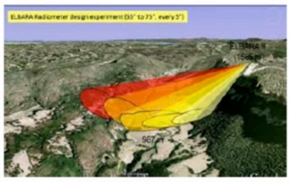
General informations:	
Name of the scientific station:	Automatic weather station
Research infrastructure/laboratory :	ACTRIS
Measured parameters:	Meteorological parameters (P, T, U, wind)
Localization :	Antarctica
Contact (email):	luc.piard@ujf-grenbole.fr
Website:	http://www.ige-grenoble.fr/
Energy 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

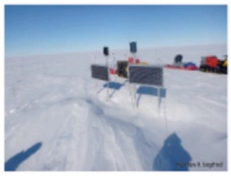
General informations:	
Name of the scientific station:	RIPLE
Research infrastructure/laboratory :	IGE (Institute of External Geosciences, Grenoble, France)
Measured parameters:	2 turbidimeters, 1 hydrophone, 2 radars (water level and speed), conductivity probe, echo sounde
Localization :	
Contact (email):	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 optimized (6W

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 Inselberg 10KW (hydroturbine) + 2KWh solar panels / Saut Pararé 10KW generator + 1,5 KWh 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)

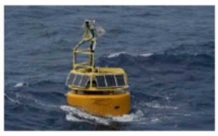
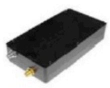
General informations:	
Name of the scientific station:	ELBARA
Research infrastructure/laboratory :	IGE
Measured parameters:	Sol humidity with radiometer measurements
Localization :	Vercors mountain
Contact (email):	bernard.mercier@univ-grenoble-alpes.fr
Website:	http://pp.ige-grenoble.fr/pageperso/pellarin/Radiometrie_montagne.htm
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



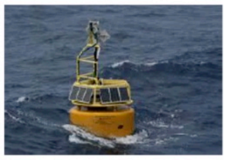
General informations:	
Name of the scientific station:	S2 from NIVO-IPEV-IGE
Research infrastructure/laboratory :	IGE
Measured parameters:	Meteo
Localization :	Antarctica, eastern plateau
Contact (email):	laurent.arnaud@univ-grenoble-alpes.fr
Website:	
Energy supply:	
Energy consumption:	<10W
Energy 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).

General informations: Name of the scientific station: Research infrastructure/laboratory : Measured parameters: Localization : Contact (email): Website:	WISSARD SALSA (Subglacial Antarctic Lakes Scientific Access) matthew.siegfried.phd@gmail.com https://salsa-antarctica.org/subglacial-hydrology-2/ brad_lipovsky@g.harvard.edu SUBGLACIAL ANTARCTIC LAKES SCIENTIFIC ACCESS
Energy supply: Energy consumption: Energy production: Energy storage:	5 W 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 
Telecommunication: Network architecture: Modem:	nc 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

B.III.2 – Oceanic stations

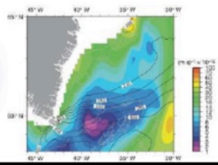
General informations: Name of the scientific station: Research infrastructure/laboratory : Measured parameters: Localization : Contact (email): Website:	EMSO Azores Relay buoy (BOREL) EMSO/IFREMER nc Oceanic, Azores julien.legrand@ifremer.fr http://www.emso-fr.org/EMSO-Azores/Infrastructure
Energy supply: Energy consumption: Energy production: Energy storage:	<10W Photovoltaic, 80W 4 mono-cristallyne solar panels of 20 W = 80 W <100 Ah Lead-acid 
Telecommunication: Network architecture: Modem:	Satellite (Iridium RUDICS) Global coverage, low cost, correct baudrate (2400 bits/sec) 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

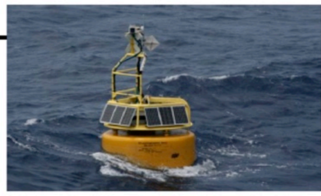


General informations:	
Name of the scientific station:	Poseidon System, HCMR
Research infrastructure/laboratory :	HCMR
Measured parameters:	temperature, salinity, waves
Localization :	Hellenic sea
Contact (email):	mntou@hcmr.gr
Website:	http://www.hcmr.gr/en/ 
Energy supply:	
Energy consumption:	10W < 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:	ISTITUTO NAZIONALE DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE
Name of the scientific station:	E2M3A from INOGS - TRIESTE
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.

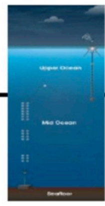
General informations:	
Name of the scientific station:	DELOS A (Deep-ocean Environmental Long-term Observatory System)
Research infrastructure/laboratory :	DELOS
Measured parameters:	sonar, hydrophone, oxygen sensor, conductivity sensor, pressure sensor, current meter, fluorometer and turbidity sensor, ADCP, 2x digital still
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 production

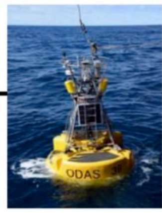
General informations:	
Name of the scientific station:	EMSO Azores surface buoy
Research infrastructure/laboratory :	EMSO/IFREMER
Measured parameters:	communication relay for oceanic stations
Localization :	ocean, azores
Contact (email):	julien.legrand@ifremer.fr
Website:	http://www.emso-eu.org/site/
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 by
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)

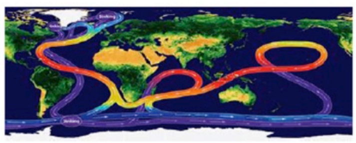
National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL





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:	

Ifremer



C. Energy production system evaluations

C.I Aim

The purpose of the ENVRI+ on-site energy bench test was to evaluate several available systems to optimise them for RI needs and particularly extreme terrestrial conditions like those faced by scientific stations in high mountains or polar regions:

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

The SAJF (Joseph Fourier alpine station) site (Col du Lautaret, Alps, 2,100m) was chosen for the test. It is briefly described in the first paragraph (C.I.1).

Adaptation and learning evaluated technologies for RI use is the matter. The aim is to provide technical staff with recommendations for on-site use.

The test focusses on the most common power supply technologies used by RIs, according to the ENVRI+ energy survey (WP3.1, see chapter B):

Solar panels - Two main technologies: monocrystalline vs polycrystalline.

Tilt angle - Vertical (to avoid snow deposition or to catch very low sun in polar regions) or 36° (optimum for 45° latitude sites).

Bifacial (east-west orientation) vs **monofacial** (south orientation).

Wind turbine solutions - to evaluate and optimise a few small wind turbine models for RI use.

Solar charge controllers: MPPT or PWM.

The protocol compares total power produced (Wh) by each circuit system:

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

i.e. monitoring of U(V) and I(A).

As well as electrical characteristics, mechanical resistivity, weight, size, transport constraints, and required maintenance were all considered. All these factors are important in isolated stations where equipment is transported by people.

The technical specifications of the bench test are described in chapter C.II.2 and the results are presented in C.II.3

The evaluations below are not ISO standard characterisation tests. This report does not intend to conclude on the efficiency of one technology compared with another. ISO standard tests are conducted in laboratories under identical conditions according to a standard protocol, e.g.: 25°C, 1000 W/m^2, laminar flow, etc.

These evaluations were carried out to help RIs to improve their understanding and use of the systems they are already familiar with, i.e. to optimise them for their own, very specific needs.
Solar panels: the aim was to compare different solutions facing the same environmental conditions, but not to calculate absolute efficiency, which is why no radiometer was used.

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

C.II.1 Joseph Fourier Alpine Station (SAJF) test site

The Joseph Fourier Alpine Station (SAJF) is located in Col du Lautaret, in the French Alps. It is at an altitude of 2,100m, and within two hours' driving distance of Grenoble, or 30 minutes of Briançon (Figure 52). SAJF watches over a 100-year old Alpine garden, offering a technical platform facility in high mountain conditions: the TETRA hut (TEst Technologiques pour la Recherche Alpine).

More information: https://www.jardinalpindulautaret.fr

Figure 52 – Geographic location and view of Joseph Fourier alpine station (SAJF). Source: SAJF.

The **TETRA hut** (Figure 53) was installed by ENVRI+ SAJF as a testing and measurement facility for technical solutions and scientific measurements in high mountain conditions. It is a 10m² wooden hut, equipped with 220 VAC and a mobile internet connection. A wired Internet connection (University network) is planned for 2018.

Logistics: cars and trucks can access the site in summer. The car park is 100m below the site during winter. There are facilities to enable work at the site in pleasant conditions (dormitories, kitchen, warm refuge).

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

C.II.2 The ENVRI+ bench test

Using SAJF facilities, we installed our bench test to evaluate the following energy production systems:

- Photovoltaic solar panels
- Wind turbines
- PWM or MPPT solar charge controllers

With the:

- Acquisition system

C.II.2.1 Photovoltaic solar panels

The following devices were used for the photovoltaic evaluations:

Solar panels:

- Two 100 Wp monocrystalline panels
- Two 100 Wp polycrystalline panels
- One 240 Wp monocrystalline bifacial panel
- One 250 Wp monocrystalline monofacial panel (same manufacturer and technology as the bifacial panel)

Regulators:

- Same PWM duo for all 100 Wp panels
- An additional MPPT to compare with PWM (all other equipment equal)
- Same new MPPT for 250 and 240 Wp panels

Batteries:

- Same single 90 Ah gel lead-acid battery

The photovoltaic (PV) solar panels were evaluated comparatively for our specific use cases:

- Impact of tilt angle: vertical (to avoid snow accumulation) vs optimal tilt [6].
- The two major technologies: monocrystalline vs polycrystalline (silicon). Is there a significant difference in our case?
- Bifacial east-west orientation vs monofacial south orientation. This could be of interest in polar regions where the sun moves in circle, at a low angle above the horizon.

[6] 36° above the horizon for a 45° latitude position to maximize annual production, or 78° to maximise winter production.

The results from the first two evaluations (vertical vs tilted and poly vs monocrystalline, Figure 54) were put together as the solar panels have a similar nominal power of 100Wp (Watt peak).

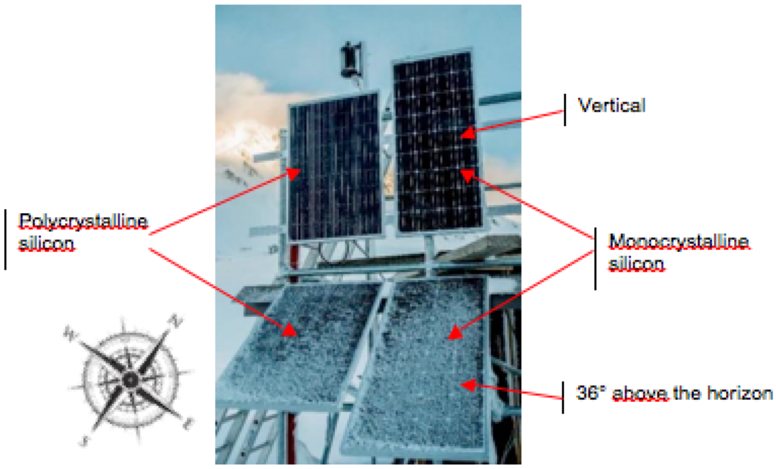


Figure 54 - The four 100 Wp solar panels evaluated. Source: ISTerre.

- Bifacial east-west orientation vs monofacial south orientation (Figure 55 and Figure 56):

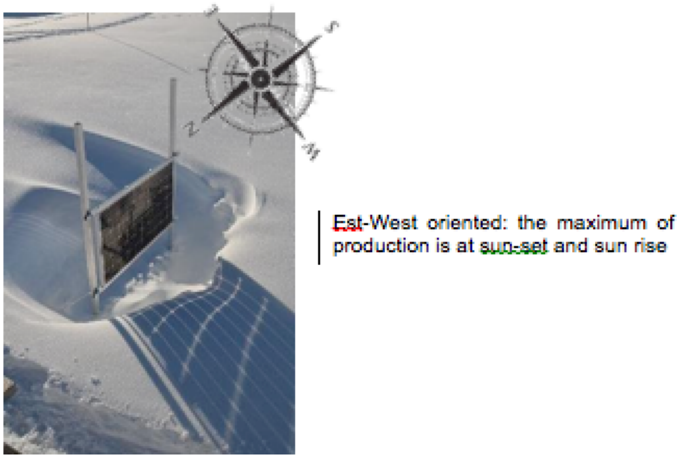


Figure 55 - The 270Wp bifacial solar panel evaluated. Source: ISTerre.

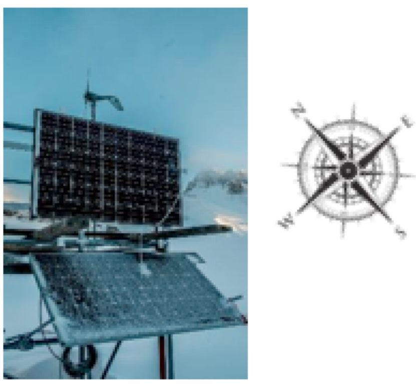


Figure 56 – The two monofacial 250Wp solar panels evaluated (here during installation). Source: ISTerre.

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

Table 16 – System of solar panels evaluated. Source: ISTerre.

Solar panel	Used abbreviation	Certificated power (from manufacturer) in W [7]
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

C.II.2.2 Wind turbines

Three wind turbines were evaluated for our specific use cases.

Two vertical axis turbines of 20 Wp and 70 Wp, respectively named:

- VAWT A: Vertical Axis Wind Turbine "A": 30 Wp
- VAWT B: Vertical Axis Wind Turbine "B": 70 Wp

One horizontal axis turbine of 400 Wp:

- HAWT: Horizontal Axis Wind Turbine: 400 Wp

C.II.2.2.1 Technical specifications - VAWT "A":

Table 17 - VAWT "A", vertical axis wind turbine. Source: FORGEN, adaptation ISTerre

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

Energy production(Figure 57):

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

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

- Max: 30Wp
- Start at ≈ 12 km/h

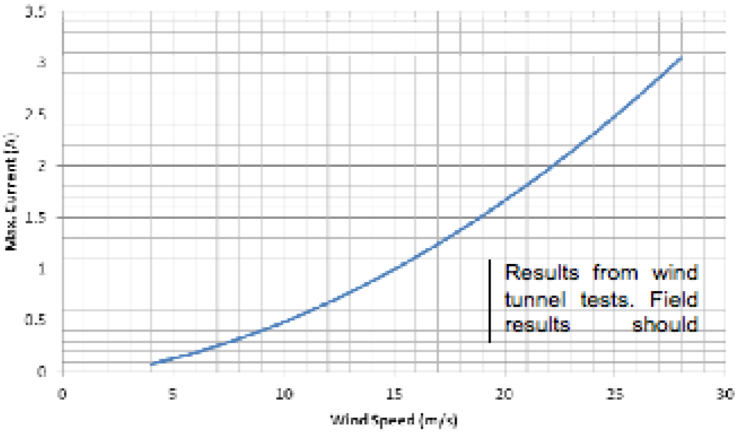


Figure 57 - Theoretical production of "VAWT A".

Electrical installation:

- The wind turbine is directly connected to a 90 Ah battery, with an AC-DC regulator inside.
- Electric charge of consumption of 200 mA (3 W).
- Battery protection able to open the charge circuit, configured to open the circuit at 10.5 V.

C.II.2.2.2 Technical specifications - VAWT "B":

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

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 @ $20ms^{-1}$

Energy production (Figure 58):

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

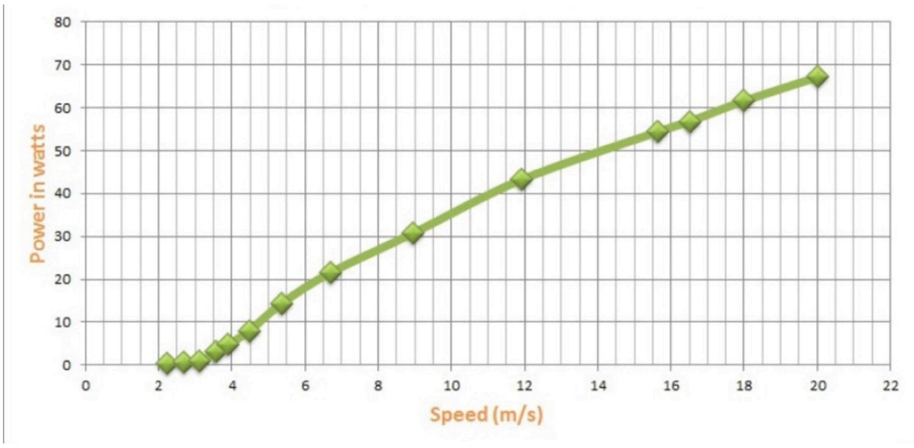


Figure 58 - Theoretical production of the "B" wind turbine

Electrical installation:

- The wind turbine is directly connected to a 90 Ah battery with an AC-DC regulator inside.
- Electric consumption load of 200 mA (3 W).
- Battery protection able to open the charge circuit, configured to open the circuit at 10.5 V.

C.II.2.2.3 Technical specifications - Horizontal axis wind turbine: “HAWT”

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

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)

Energy production (Figure 59):

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

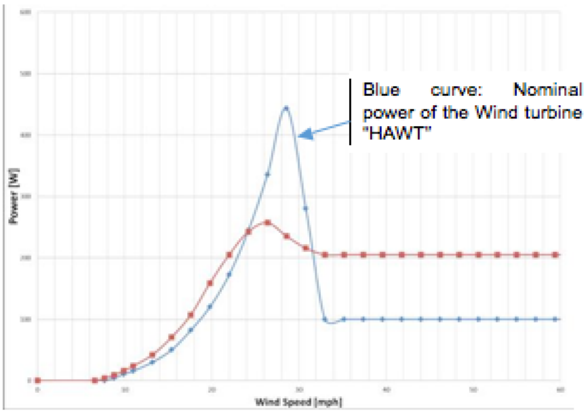


Figure 59 – Specification for the "HAWT" wind turbine (blue curve).

Electrical installation:

- The wind turbine is directly connected to three 90 Ah batteries in parallel with an AC-DC regulator inside.
- Electric charge of consumption of 200 mA (3 W).
- Battery protection able to open the charge circuit, configured to open the circuit at 10.5 V.

C.II.2.3 Solar panel charge controllers

The two main technologies used as solar panel charge controllers were compared.

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

The differences between the two are described in the technical chapter A: "general knowledge on energy".

The technical specifications of the selected regulators are given in Table 20.

Table 20 - Solar panel power regulators evaluated (MPPT and PWM)

	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

The PWM and MPPT lines comprise the same elements, except for the actual charge controller (Table 21).

Table 21 - Specifications of each electrical circuit for the solar panel regulator evaluation.

	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 equipment	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.

C.II.2.4 Data acquisition system

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

Figure 60 - Acquisition multiplexer card

Figure 61 - Acquisition data logger

The main specifications of the data logger are:

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

Synoptic of acquisition of the electric parameters of the solar panels, Figure 62 (similar to the wind turbine and charge controller evaluations, except for the actual device under evaluation):

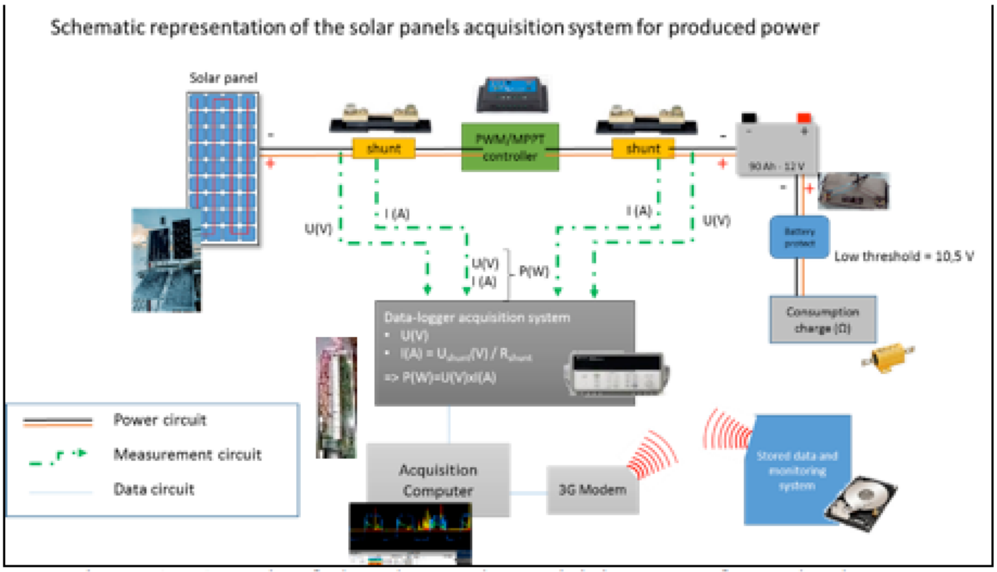


Figure 62 – Synoptic of the solar panel acquisition system for power production.

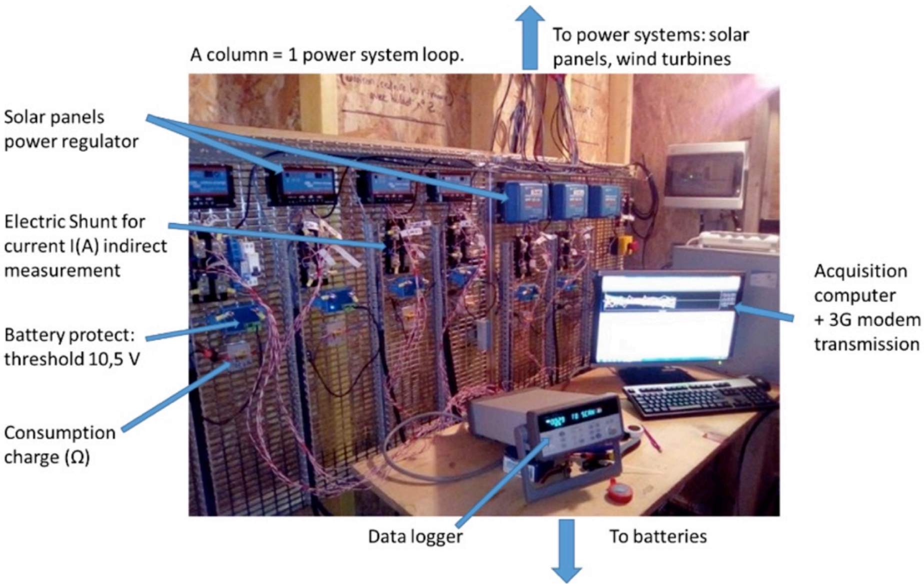


Figure 63 – ENVRI+ bench test solar panel acquisition system for power production.

As previously mentioned,

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

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

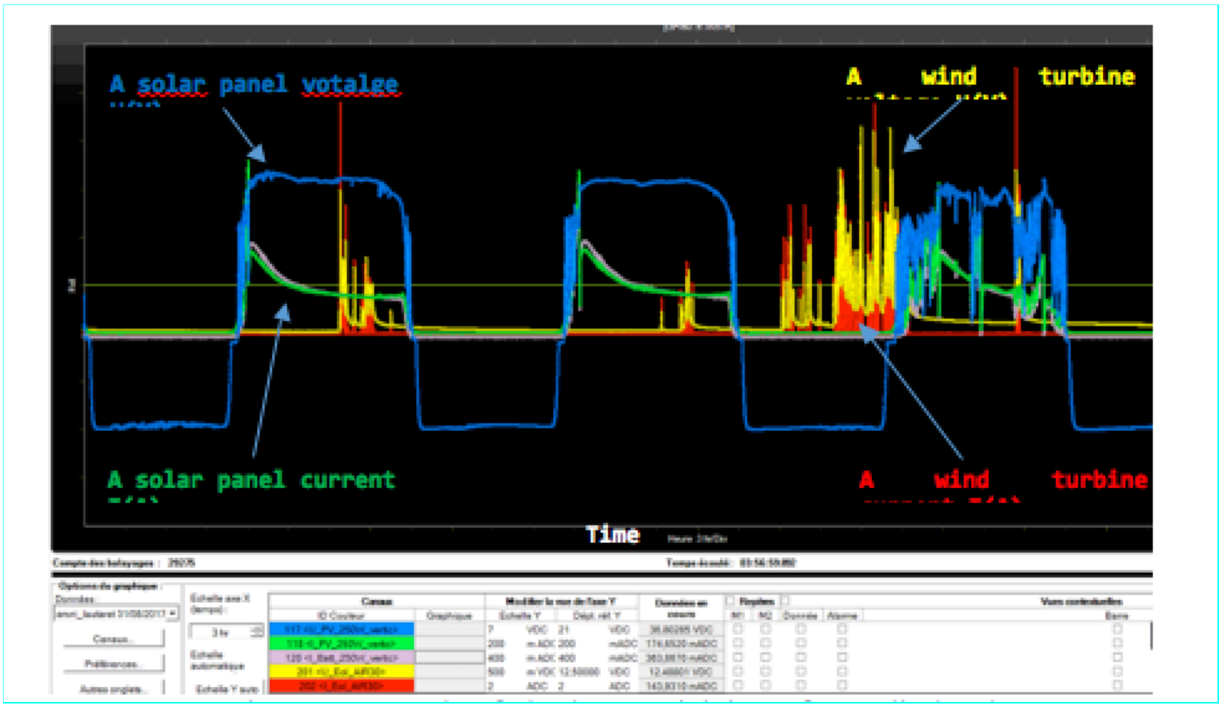


Figure 64 – Example of the data acquisition software displayed

The challenge was to set up a system similar to the one used in the field for scientific measurements (i.e. the whole system made with power production + storage) to evaluate the fit between power production systems and research infrastructure needs (see ENVRI+ RIs Survey on energy, chapter B).

Each power system circuit was therefore equipped with the same elements, except for the power production part (e.g.: solar panel, wind turbine).

Details of the identical equipment used on each power circuit:

- Power circuit wires: multi strand similar in diameter for each equal device (from 1.5mm² to 6)
- Acquisition wires: equal lengths of twisted electric pairs to avoid uncertainty as we are measuring from mV (1.10^{-3}) to µV (1.10^{-6}).
- Batteries: VRLA Gel 12 V, 90 Ah (see chapter A for battery details)
- Solar panel power regulators:
  - PWM Duo for ≤ 100 Wp solar panels
  - MPPT for > 100 Wp solar panels
- Consumption loads: 2 W (R=75 Ω ± 5%) for the measurement campaign (March to November 2017), then 12W (R=12 Ω ± 5%) from November 2017 to the end (still running at the time of writing this report, December 2018), to maximise solar panel production.

***Note**: Herein, "power production" is used to refer to the power sent from the solar panels to power resistors to be consumed via the batteries. "Energy consumed" would have been an alternative, as solar panels rarely reach their maximum nominal power, just producing the energy required to recharge the batteries and to provide the energy consumed on-line.*

C.III Evaluation results

C.III.1 Photovoltaic

C.III.1.1 Usual 100 Wp solar panels: vertical or 36° tilted, poly or monocrystalline.

Note *: Remind that100 Wp solar panels are those "usually" employed for fieldwork measurements, since they offer a good compromise between sufficient power and an appropriate size to be transported by people. 100 Wp solar panels were chosen for this work.*

C.III.1.1.1 Overall results

Figure 65 presents data recorded between June and December 2017 on cumulated power produced by the four[8] 100 Wp solar panels.

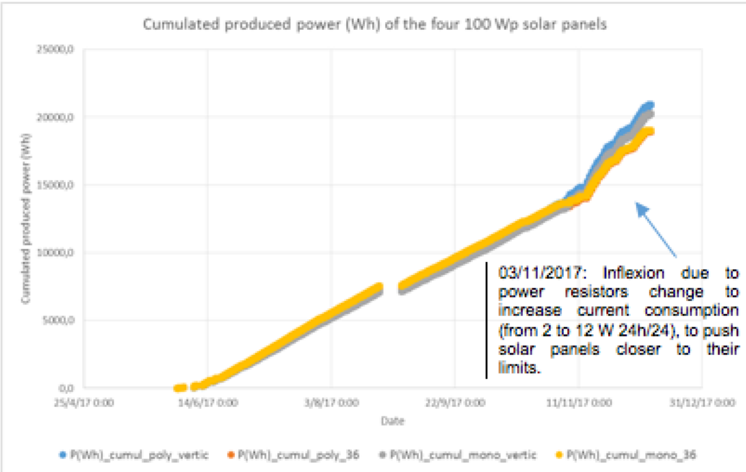


Figure 65 - Cumulated power produced (Wh) by the four 100 Wp solar panels (June to December 2017).

Data acquisition actually started in March 2017 but previous data are not displayed here as the frequency acquisition changed in June from T=5min to T=30s to improve recording of the pulsation change in the solar panel power regulators. To keep things simple, only T=30s data were used. Earlier data from March to June do not change the overall results.

The inflection point on the curve on 3 November 2017 corresponds to modification of materials. The power resistors were changed to consume more power, thus pushing the solar panels closer to their limits to be able to highlight their potential differences. Power charges were initially only consuming about 2W (75Ω in 12V, I ≈ 166 mA), which is representative of a typical seismograph or a weather station, but not enough to force the solar panels to produce power (Wh) all day long because the connected batteries are not sufficiently discharged during the night or even after a few days without sun. The power resistors were replaced: R=12 Ω (I=U/R=12/12=1A. $P=RxI^2=12x1^2=12W$) for the 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 the 250 Wp solar panels.

With regard to total power production (Figure 65), the recorded data shows two main facts:

[8] Vertical or 36° tilted, monocrystalline or polycrystalline. See chapter C.II.2 for more details.

- There are significant differences between the vertically aligned panel and the 36° tilted panel: vertical solar panels clearly produced more than panels tilted 36°.
- There is not much difference between monocrystalline panels and polycrystalline panels: the power produced is very similar.

The next part of the report focusses on these two aspects.

C.III.1.1.2 Vertical panel versus 36° tilted panel

The histograms below (Figure 66) present the same results as Figure 65, but clearly highlight the difference in power produced by vertical vs. 36° tilted solar panels.

The comparison must be relative and not based on absolute production, which is only representative of total operating hours (which are of course the same).

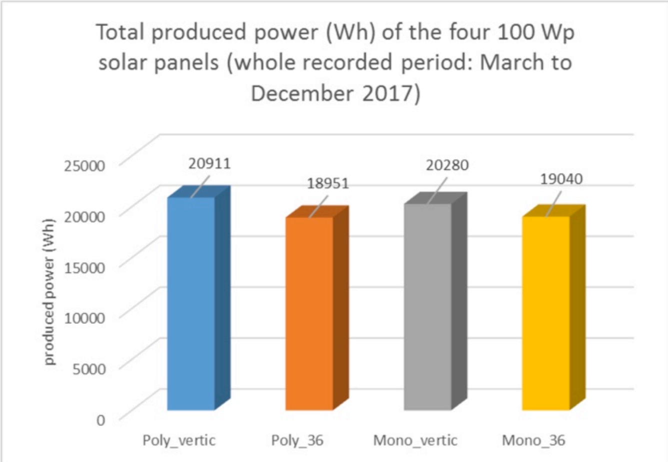


Figure 66 - Total power produced (Wh) by the four 100 Wp solar panels (entire recorded period: March to December 2017).

Averaging the production of the vertical and 36° solar panels gives the figure below (Figure 67), showing this difference: +8% from vertical to 36° tilted

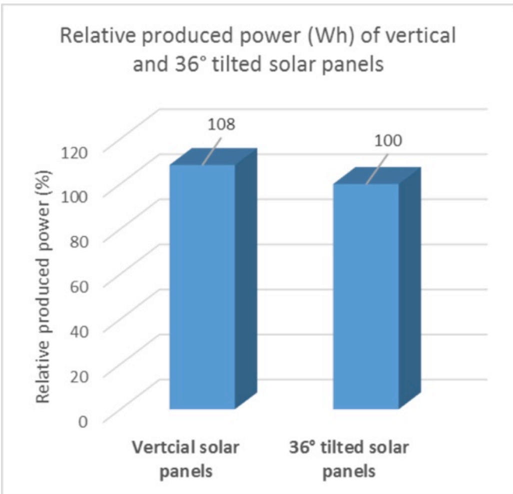


Figure 67 – Difference between vertical and 36° tilted solar panels in terms of power produced (Wh) over the entire recorded period.

The main reasons for this difference have already been cited: i) in winter, the sun is lower in the sky and ii) the albedo effect (ground light reflection) is more pronounced, which both favour vertical solar panels. Looking at the second period (after the power resistor change on 03/11/2017) when the current consumption level increases, production differences appear between the types of panel alignment. Furthermore, there was snow on the ground during this period, and snow can, of course, cover a 36° tilted solar panels whereas it cannot cast shade over a vertical one.
The winter results are shown in Figure 68 below.

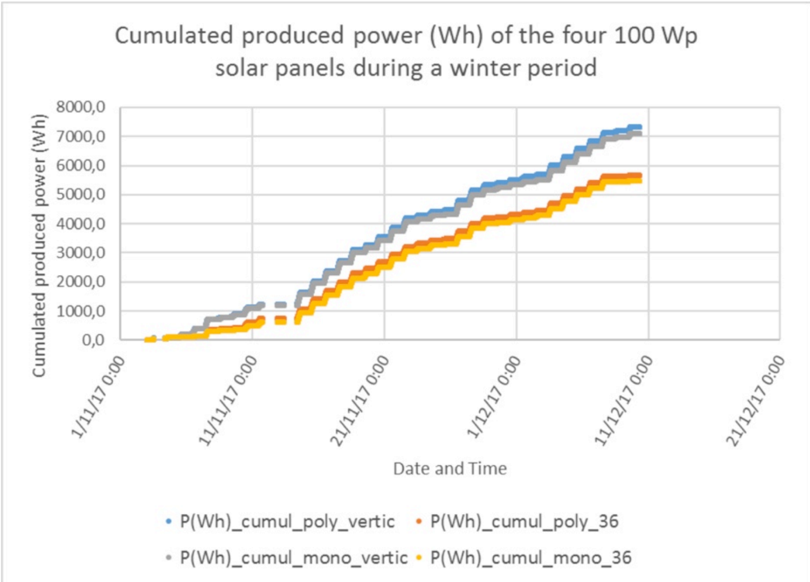


Figure 68 - Cumulated power produced (Wh) by the four 100 Wp solar panels during the winter period (3/11 to 11/12).

The difference in power production is quite clear, with the vertical panels producing **29.5%** more than the 36° tilted panels (base 100 = 36°), as shown on the histogram below: Figure 69.

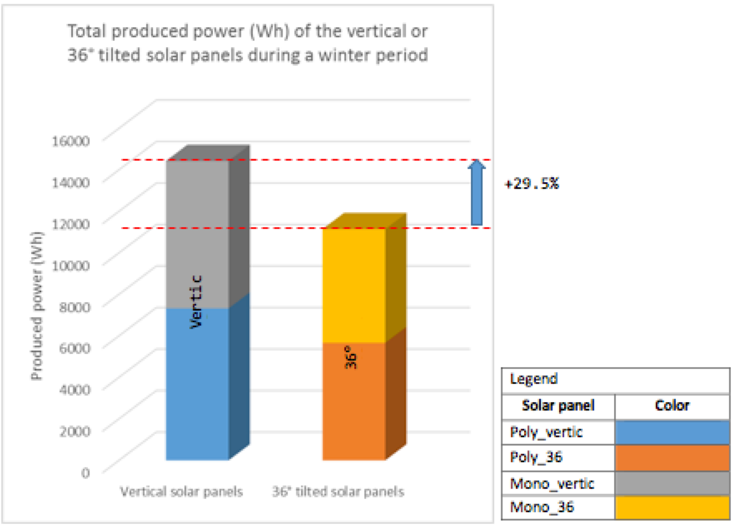


Figure 69 - Total power produced (Wh) by the vertical and 36° tilted solar panels during the winter period (3/11 to 11/12).

In an attempt to further improve understanding of these interesting differences for our specific fieldwork requirements, the data was analysed to establish the main reasons:

- The sun is lower in the sky during winter time, which favours vertical solar panels more than 36° tilted panels to maximise production.
- Snow effects: deposition is avoided for vertical solar panels (as shown on Figure 72) and the albedo effect, caused by the snow reflecting light, is more pronounced.

The sun is lower in the sky during winter time, which favours vertical solar panels, or panels tilted more than 36° for maximum production.

In the northern hemisphere (Figure 70), the sun is lowest on 21 December, the winter solstice. At this time, the optimum angle for solar panel production at a 45° latitude site (such as Grenoble) would be: 45° + 23.5° = 68.5° (0°=horizontal). A vertical solar panel (which is also better for avoiding snow deposition) will have a higher yield at this time.

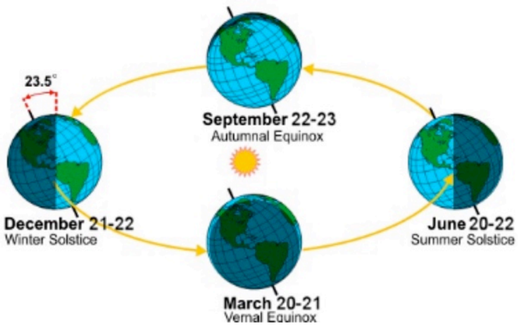


Figure 70 - Incident Sun light on Earth surface at Equinox and Solstice.

Conversely, at the equinox (half way between the zenith to the nadir) at a 45° latitude site, the 36° angle will be optimal.

The table below (Figure 71) shows total power produced and the maximum rated power of the four solar panels during these two major periods.

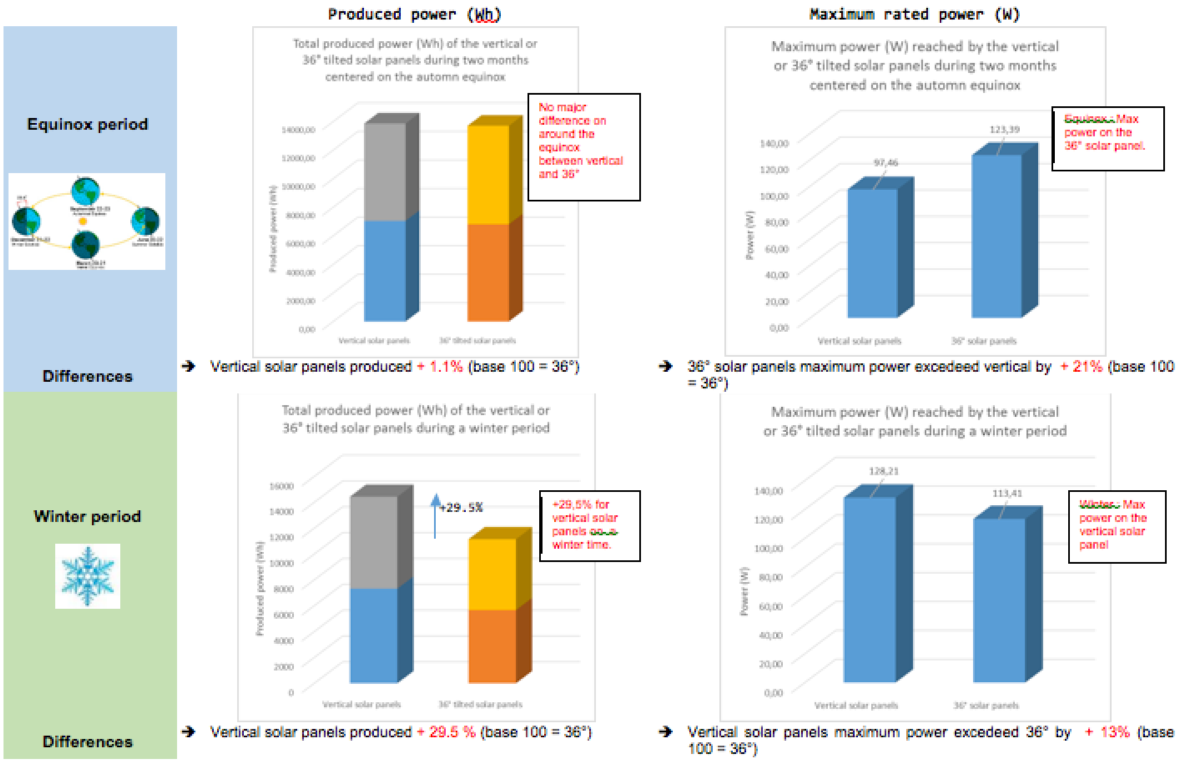


Figure 71 - Comparison of solar panel power produced (Wh) at the Equinox and at the Winter solstice`

Deposition is avoided for vertical solar panels and the albedo effect, due to light reflecting on the snow, is more pronounced.

The albedo effect is the reflection of incoming solar light, i.e. irradiance. It is represented by a value between 0 and 1.

- 0 corresponds to a perfect black surface that could (theoretically -in physics we talk about a perfect "black body") absorb all incident electronic radiation.
- 1 corresponds to a perfect mirror that could reflect 100% of incoming light.

Table 22 shows the values for common ground coverings.

Table 22 - Some albedo values. Source: CNRS

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

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

On a snowy day, snow deposition on the 36° tilted panel will combine with its reduced capacity (due to the tilt) to benefit from the albedo effect.

On 29/11/2017, the 36° tilted solar panels were covered with snow, as shown on Figure 72.

Figure 72 - Snow deposition on 36° tilted solar panels

The cumulated power production (relative, in %, base 100 = vertical solar panels of each technology type, i.e.: poly or monocrystalline) is presented for this day in Figure 73.

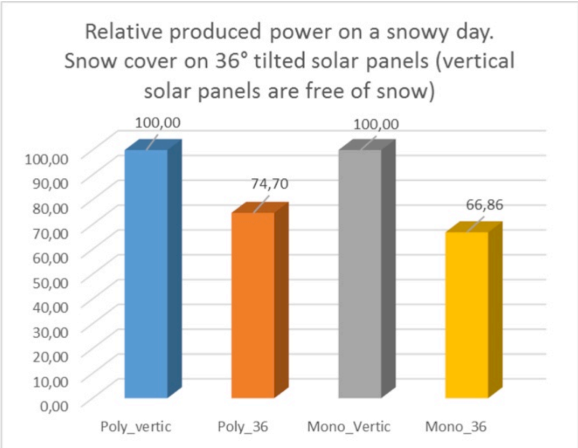


Figure 73 – Relative power production on a snowy day. Snow cover on 36° tilted solar panels (vertical solar panels are free of snow)

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

Remark: one explanation for the production difference between Mono_36 and Poly_36 could be a difference in snow quantity. As shown on Figure 72 (poly on the left, mono on the right).

These initial findings could be confirmed with more data on snowy days, but this is an overall trend.

In conclusion, regarding the vertical versus 36° tilt angle, users are strongly advised to install solar panels vertically (particularly in high mountains and polar regions).

C.III.1.1.3 Polycrystalline versus monocrystalline

Table 23 (total cumulated power produced by the four 100 Wp solar panels) shows the power produced by monocrystalline and polycrystalline solar panels.

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

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

Averaging poly and mono production gives 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

Production only differs by 1.4% (base 100 = polycrystalline), with polycrystalline performing better.

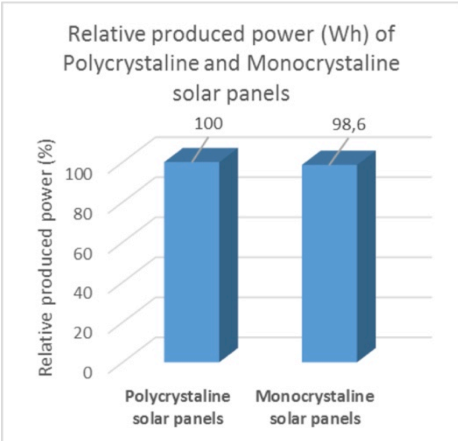


Figure 74 - Relative power (Wh) produced by polycrystalline and monocrystalline solar panels

The four solar panels were certified by the same manufacturers as having a nominal production of 100.3360 Wp. The only characteristic that determines their yield differences is size, as shown in Table 24.

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

	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

The polycrystalline technology appears to need a larger surface area to produce the same amount of energy as its yield is generally lower than that of the monocrystalline technology (i.e.: chapter A, Figure 10 – Efficiency of research cells. Source NREL. https://www.nrel.gov/pv/). However, for our needs (isolated stations, approximately 2 to 50 W), it does not matter whether the panel is 1 or 1.05m².

It could be an important issue for people planning to produce and sell electricity from a roof whose surface area is of course limited: they will try to find the best surface yield to maximise production from every square metre.

In our case, the polycrystalline solar panels are approximately 4% larger, as calculated from table 24 above, leading to a difference of 4.15% in terms of relative yield (base 100 = polycrystalline solar panels).

Table 25 - Estimated yield differences between poly and monocrystalline solar panels based on our evaluations.

	Area (cm^2)	Produced power (Wh/cm^2)	Yield (Wh/cm^2)	Relative yield (%, base 100 = poly)
Polycrystalline solar panels	5859	19931	3,407	100
Monocrystalline solar panels	5625	19660	3,548	104,15

This is not an important issue for on-site power supplies in scientific stations. Furthermore, there is a certain level of intrinsic uncertainty in our bench test (Col du Lautaret), which is a fieldwork evaluation, due to the changing environment (although this is true for all solar panels). It is therefore difficult to draw conclusions from such a small yield difference of 4.15%.

However, based on these results, correlated with the information in chapter A “general knowledge on energy”, monocrystalline technology is still recommended as its yield is typically about 5% higher.

As we have already established, it is more important to position the solar panel vertically to avoid snow deposition and to maximise the albedo effect (resulting in a production difference of about 30% for the vertical position compared with the 36° tilt position), than to focus on the difference between poly or monocrystalline, which only represents about ± 5%.

The overall conclusions for our specific use of solar cells are thus:
- Vertical installation (for high mountains and polar regions).
- Monocrystalline rather than polycrystalline technology.

For more information on photovoltaic solar cell yield for other technologies, see Annex I, the SIRTA bench test, or the national research centre on solar energy (INES in France, NREL in the USA).

C.III.1.2 Bifacial east-west vs monofacial south orientation solar cells

Figure 76 represents the cumulative total over time of power (Wh) produced by both bifacial and monofacial solar panels during a snowy period, with the albedo effect.

Production capacity is 250Wp for the monofacial panel, and 270Wp for the bifacial panel. A coefficient of 270/250 = 108 was applied to monofacial production figures to enable comparison with figures from the bifacial panel.

Reminder: the bifacial panel is east-west oriented, and the monofacial panel is south oriented (Figure 75).

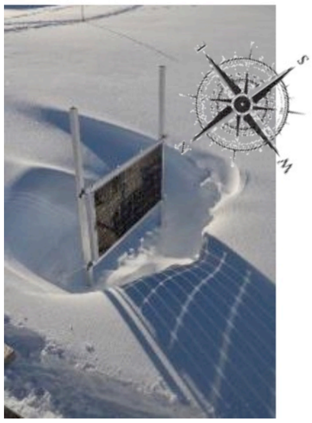


Figure 75 – Picture of the bifacial solar panel. Est-West oriented, and vertically tilted.

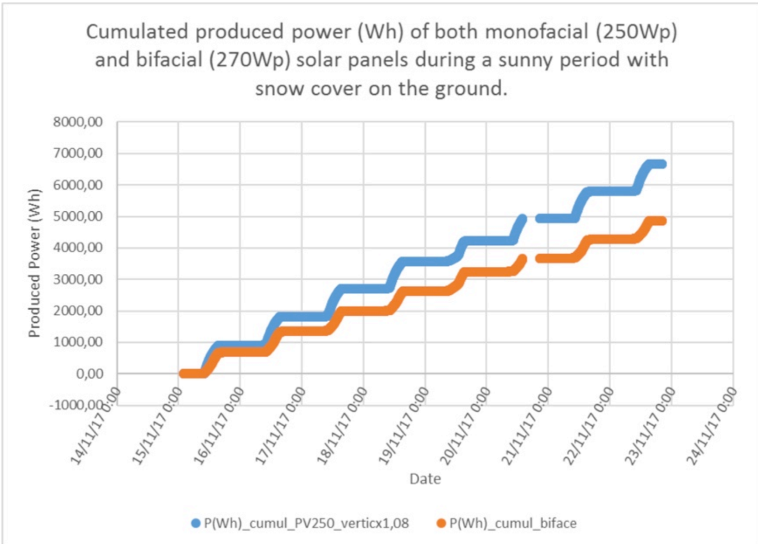


Figure 76 - Bifacial and monofacial power production for a sunny period with snow cover.

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

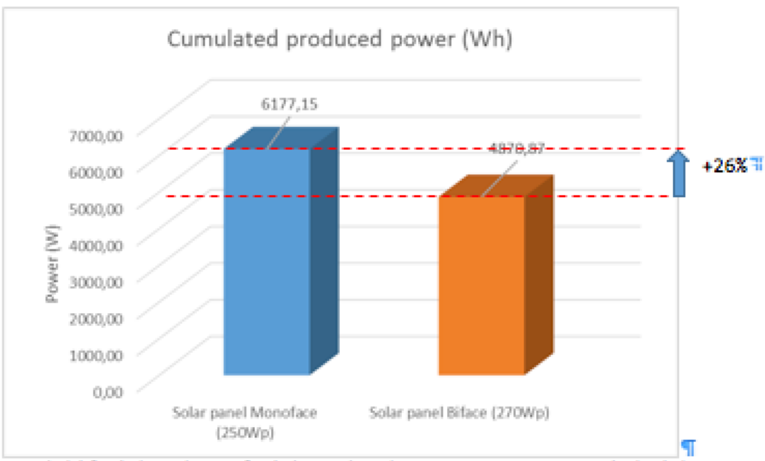


Figure 77 - Total bifacial and monofacial power production for a sunny period with snow cover.

Bifacial solar panels that turn all day long in sunny periods are expected to offer an advantage in winter in polar regions where the sun is very low. However, in the Alpine case described, where the sun is higher around midday, the production increase is much greater than the gains in the morning and in the evening of the east-west oriented bifacial solar panel. Voltages are higher at the beginning and at the end of the day for the east-west oriented bifacial solar panel, as shown on the Figure 78.

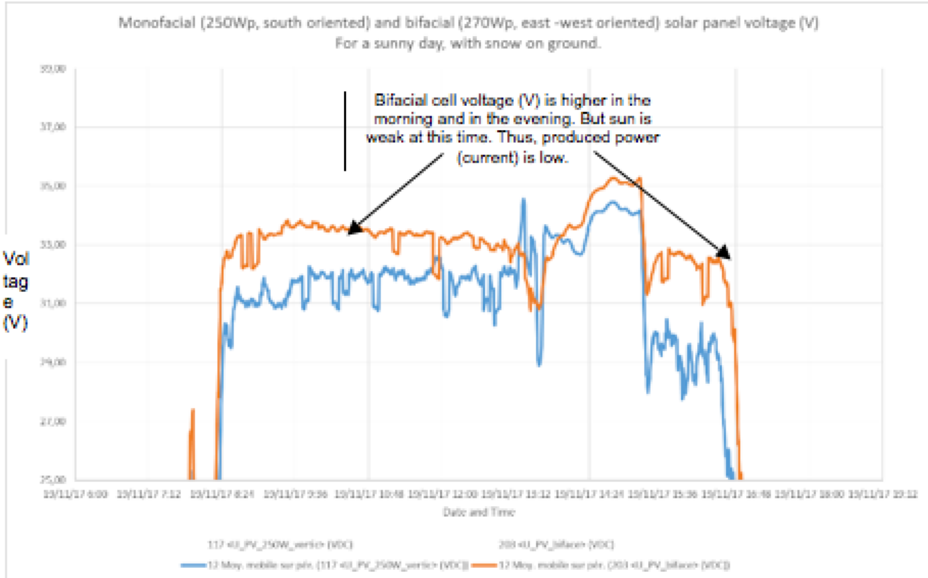


Figure 78 - Monofacial and bifacial solar panel voltage (V) on a sunny day with snow on the ground.

When the sun is weak, being low above the horizon (with much more atmosphere to pass through, thus enhancing light attenuation, like the "red-shift"), only a few Amperes will be produced. Final power production is therefore lower than during the midday hours, when the sun is striking hard, as shown in the next figure, Figure 79. This is further enhanced by a high albedo effect due to the snow cover.

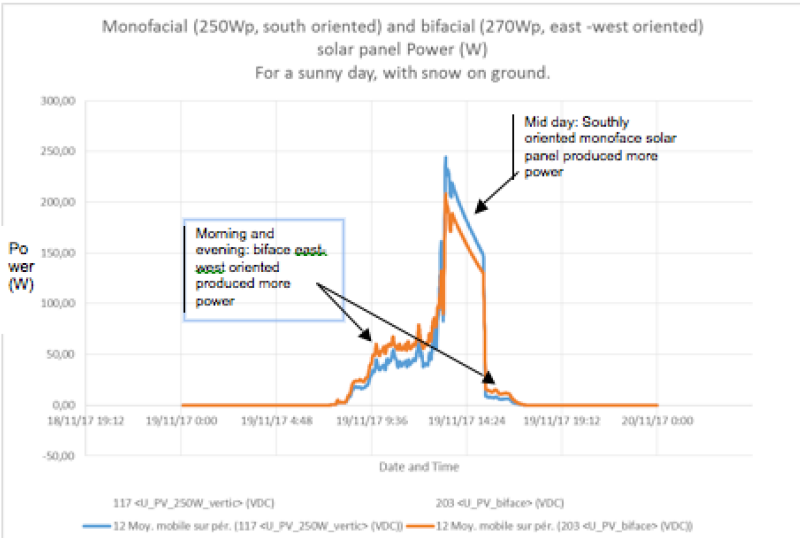


Figure 79 - Monofacial and bifacial solar panel power (W) on a sunny day with snow on the ground.

As shown in Figure 80, on this very sunny day with snow on the ground, the maximum rated power of the bifacial panel is relatively low: 211.38 W ($P_{nominal}$ = 270 Wp), as its cells are never perpendicular to the powerful sun.

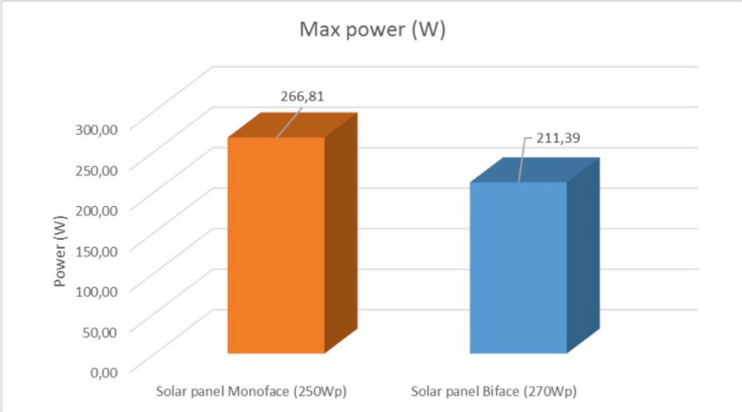


Figure 80 - Monofacial and bifacial solar panel maximum rated power (W) on a sunny day with snow on the ground.

In conclusion:

- East-West bifacial solar panels are not well suited to the conditions of an isolated scientific station in the mountains. An equivalent (in power) monofacial south-oriented panel will produce more power during the midday hours than an east-west bifacial panel during the morning and evening.
- Our evaluation does not confirm the advantages claimed by manufacturers of "≈ 20% more energy" from bifacial solar panels. Voltage $U(V)$) might be 20% higher, but the sun is weak at this time of day and, as current is directly proportional to photons ($I\ (A) = f\ (light)$), then power $P(W) = U(V).I(A)$) is low.
- Bifacial panels could be of interest in polar regions while the sun is "ON", since it turns for the full 24 hours.
- Bifacial solar panels are currently (2017) only available on the global photovoltaic market in large sizes, ≈ 1.60m x 1.10m, which is too large to be transported by people in the field. This critical issue actually makes bifacial solar panels irrelevant to the specific requirements of RIs.

Note: *We did not test a south-oriented, vertical bifacial solar panel. This might be more powerful than an equivalent monofacial panel, due to the albedo effect on the back of the solar panel. However, in this case, finding appropriately sized cells would still be a problem.*

C.III.2 Wind turbines

In most cases, RIs cannot install wind turbines in optimal positions for constant and laminar wind flow. Average power production (in Wh) of a wind turbine is not therefore a relevant parameter for RI use, due to the high variability of winds, and the absence of electricity production for sometimes lengthy periods.

One sample every 30 seconds is not always enough to record all electrical impulses sent from wind turbines to batteries, due to their Pulse Width Modulation charge regulators. The low sampling rate may result in losing the highest production peaks, and consequently artificially lower the estimated average production value. The low sample frequency was a pragmatic compromise dictated by the need to reduce data volume for storage and transfer purposes with a limited bandwidth 3G connection. In spite of this limitation, the relative energy production of the two types of wind turbine should be correct overall as they recorded the same winds, using an identical sampling rate.

Wind turbine evaluations are based on the following characteristics:

- Mechanical resistance: with respect to manufacturer set-up instructions.
- Comparison of the total relative power produced over the same period, for the three tested wind turbines.

C.III.2.1 Overall results

Wind speed in Col du Lautaret

- Average 2015 = 15 km/h
- Average from September to December 2017 = 16.7 km/h

The specifications of the wind turbine are reminded Table 26.

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

	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
			

The Horizontal Axis Wind Turbine (HAWT) and the Vertical Axis Wind Turbine A (VAWT A) have been used at this site for two winters without suffering any damage. Regular, two-monthly verifications and maintenance interventions are carried out: tightening and adjusting vertical and horizontal axes to prevent premature wear.

The strongest winds reached 80 km/h.

VAWT B was evaluated for 2 months before being set up at its final destination: on a rocky glacier at an altitude of more than 2,500m, to power seismometers.

Figure 81 presents some of the recorded power production figures from these three wind turbines.

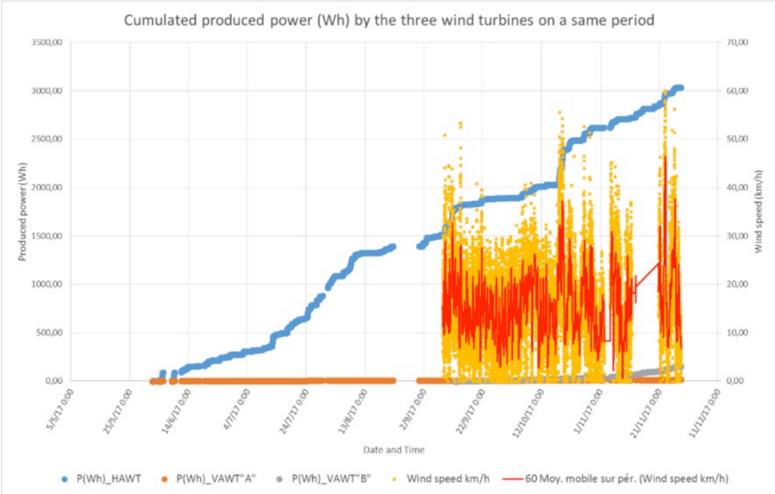


Figure 81 - Cumulated power (Wh) produced by the three wind turbines over the same period.

Relatively speaking (% Wh, base 100 = VAWT B), the three wind turbines produced the following energy in Wh (Figure 82).

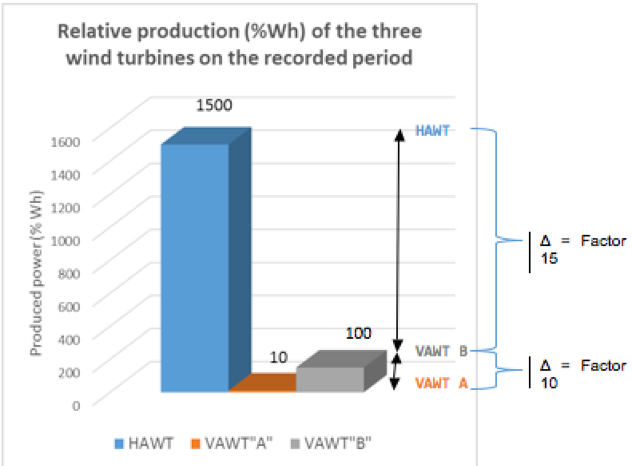


Figure 82 - Relative power produced (Wh) by the three wind turbines during the same recorded period.

All three wind turbines cost approximately €800 (±100) in 2017.

At the date of writing this report, all three wind turbines had been used for 1 or 2 winters, with winds of up to 80km/h.

***Note**: f=30s is not frequent enough as wind gusts can change more quickly and the highest power peak with the strongest gusts could be missed. This is one of the reasons why manufacturers speak more about power production (Wh) than nominal power (Wp) for special wind turbines. However, tests are, of course, carried out in laboratories, using wind tunnels, in conditions nothing like those actually experienced on site.*

At the Lautaret site, average annual wind speed is about 15 km/h, which is also the lower speed threshold for both VAWT A and HAWT (minimum of 12 km/h km/h, but at this speed they are just "starting" to move). Figure 83 shows the power produced for different wind speed ranges.

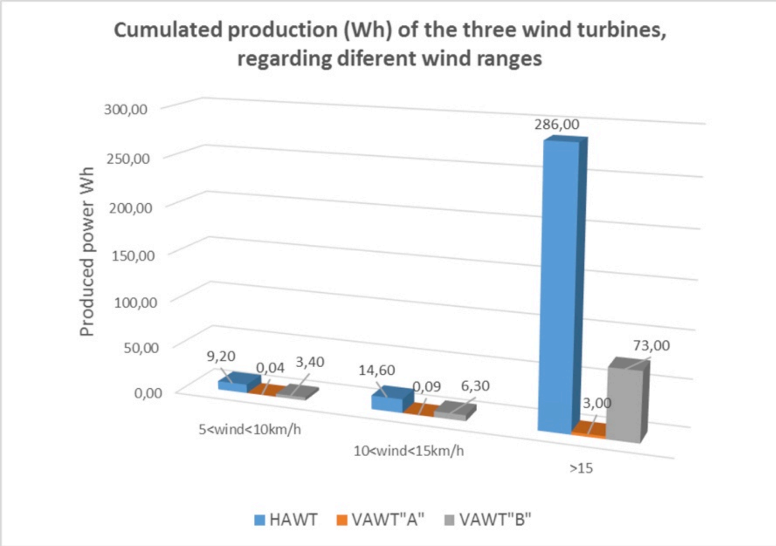


Figure 83 - Cumulated production (Wh) of the three wind turbines, regarding different wind ranges.

VAWT A is not powerful enough for on-site conditions.
HAWT is four times more powerful than VAWT B for wind speeds over 15 km/h.
HAWT is "only" twice as powerful for winds under 15 km/h.
VAWT B could be appropriate for very low wind speed sites. This correlates with the theoretical figures on the manufacturer datasheets, which announce a starting wind speed of 6 km/h.
HAWT and VAWT A production for wind speeds lower than 12 km/h is due to the 30-second acquisition average that can mask certain gusts of wind.

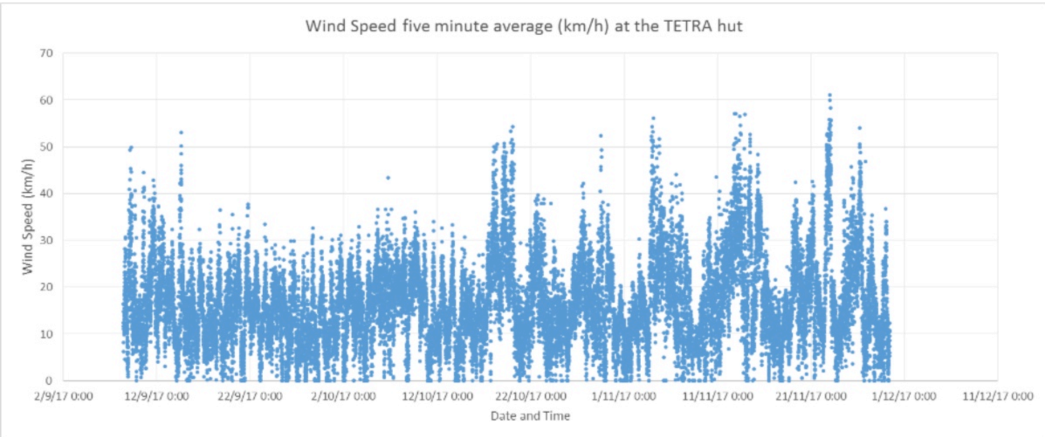


Figure 84 - Wind speed five-minute average (km/h) at the TETRA hut.

Table 27 - Wind speed ranges at the TETRA hut.

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

Following the first evaluation at the ENVRI+ site (TETRA hut), wind turbine B was moved to its final destination, i.e. the rocky glacier in Laurichard Val (Valon du Laurichard), altitude 2,500m, in the Alps mountains.

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

Energy consumption of the entire scientific system is: 1 ≤ P(W) ≤ 3 W. There is no data transmission, only acquisition.

Power equipment to date is: two VAWT B turbines and one 100 Wp solar panel in parallel. These are connected to more than 400 Ah 12 V batteries.

Wire length between the batteries and the data logger causes a 0.8 V voltage drop, due to cable resistance (about 50m in length).

Figure 86 shows the entry voltage (V) of the data logger.

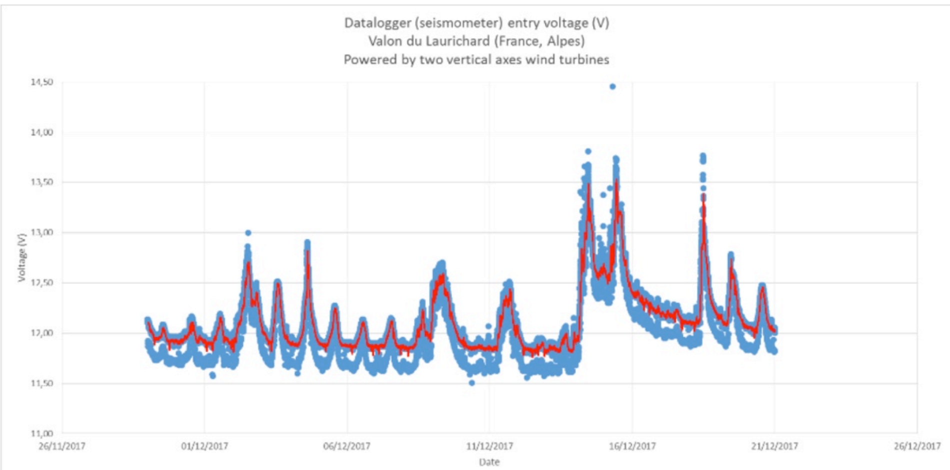


Figure 86 – Entry voltage (V) of a data logger (seismometer), Valon du Laurichard (France, Alps), powered by two vertical axis wind turbines.

All the “little” daily peaks (about +0.2 V) are likely to be due to:

- The solar panel, which, even if it is in the shade during this December period, could still produce a few amps thanks to albedo/reflection effects.
- Light thermic winds (probably not katabatic, as they are not happening in the evening).

Larger peaks appear when the wind is sufficient for the two VAWT B turbines to produce significant energy.
Figure 87 shows additional information on the use of HAWT wind turbines in northern regions, such as Quebec.

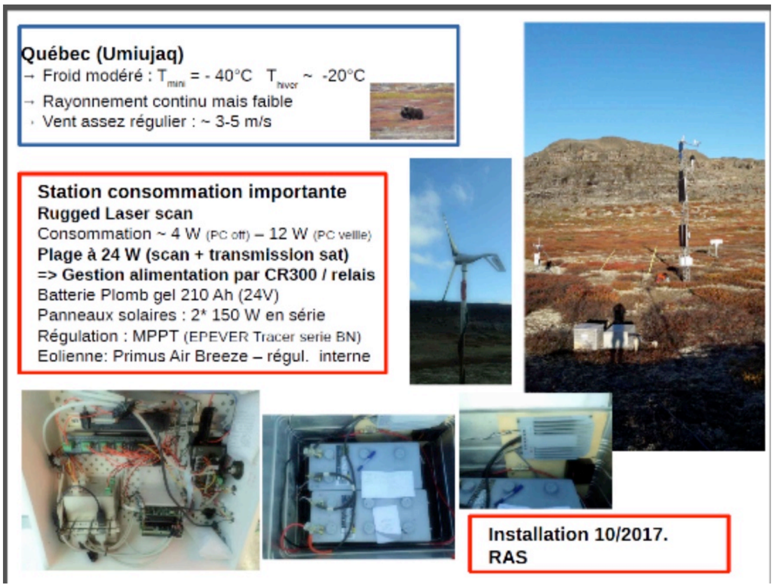


Figure 87 – Further examples of HAWT use in the field (Quebec). Source: IGE

In conclusions, with regard to the wind turbines evaluated for our specific cases of use:
- The HAWT is one of the most appropriate turbines for alpine sites.
- The VAWT B could also be appropriate, if doubled. Strong fixtures are needed.
- Tests are needed in polar regions with very strong winds (sometimes up to 150 km/h) and very low temperatures. In this case, VAWT A could be more appropriate.
- The wind turbine nominal power should be over-sized, as there is a huge gap between the manufacturer's theoretical specifications (based on figures from laboratory wind tunnels) and the reality in the field.

C.III.2.2 Further information on the vertical axis wind turbine B: WAWT "B"

Figure 88 shows VAWT B battery voltage (yellow curve) during wind events (blue curve). VAWT B starts to exceed the 3W consumption level, and therefore to charge the battery, with winds starting at 12 km/h (horizontal threshold red line on Figure 88).

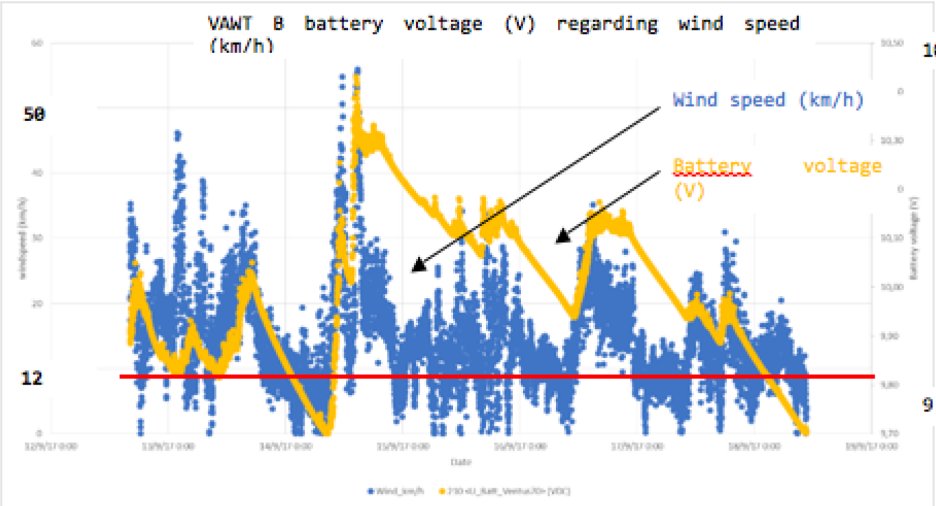


Figure 88 - VAWT B battery voltage (V) as a function of wind speed.

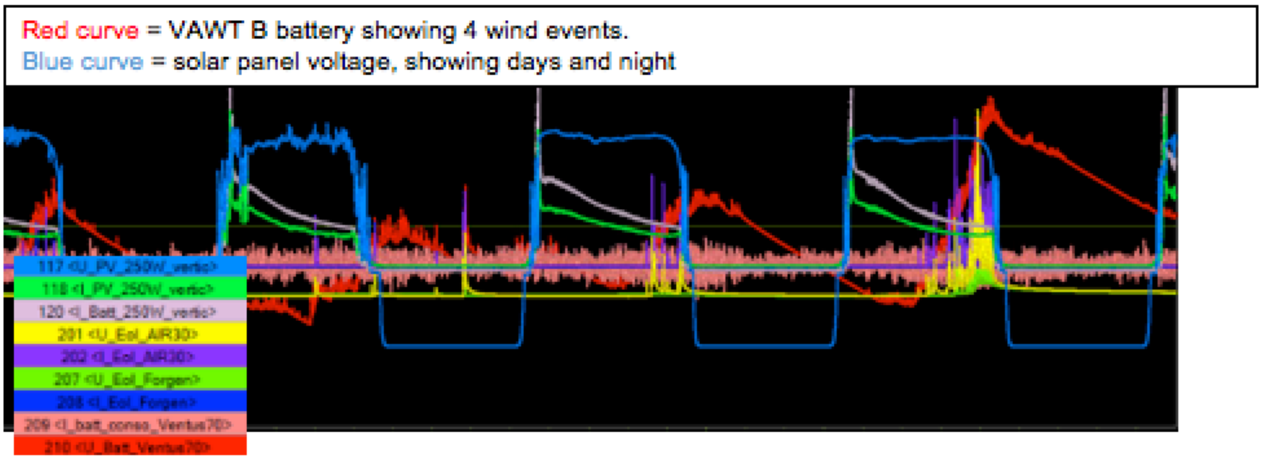


Figure 89 - VAWT B battery voltage during 3 wind events, shown on the acquisition screen.

C.III.2.3 Further information on the horizontal axis wind turbine: HAWT:

Figure 90 shows the evolution of HAWT battery voltage as a function of wind speed.

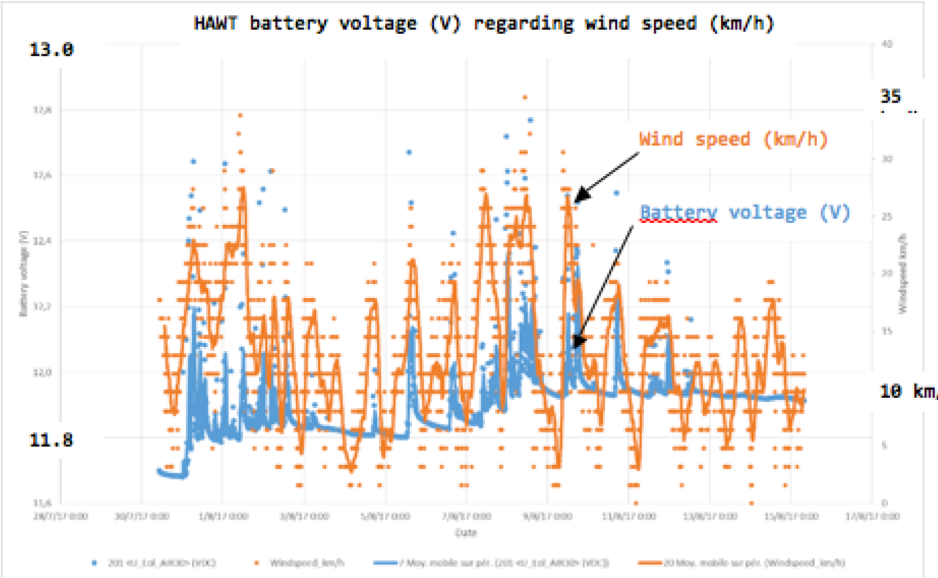


Figure 90 - HAWT battery voltage (V) evolution as a function of wind speed (km/h).

With a continuous consumption of 3 W, the battery was regularly charged and maintained within the correct voltage range, from 11.5 V to nearly 13.0 V. Data from the last recording period (August to December 2017) confirmed that batteries had been regularly and correctly charged.

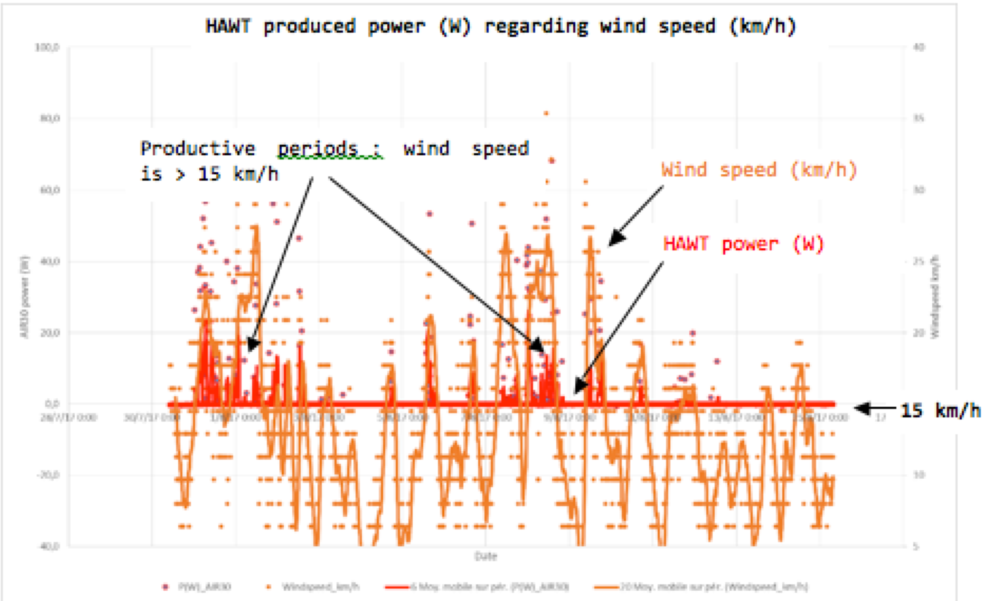


Figure 91 - HAWT power production (W) as a function of wind speed (km/h).

C.III.3 MPPT versus PWM solar charge controllers

During the recording period (3-23/11/2017), the MPPT line (100 Wp solar panel + MPPT charge controller) produced 28% more energy than the PWM line, Figure 92.

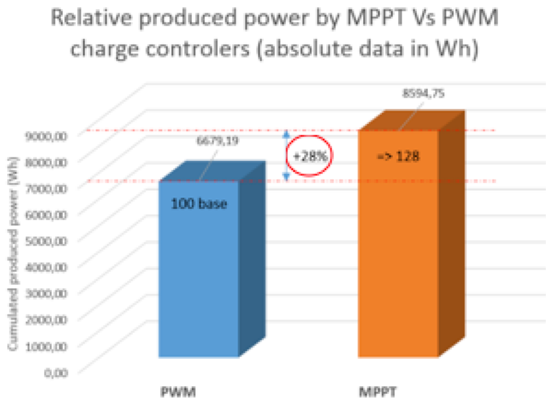


Figure 92 - Relative power produced by the MPPT versus PWM charge controller.

Powered by similar solar panels, the maximum rated power was 118.70 W for the MPPT and 96.42 W for the PWM charge controller, as shown in Figure 93.

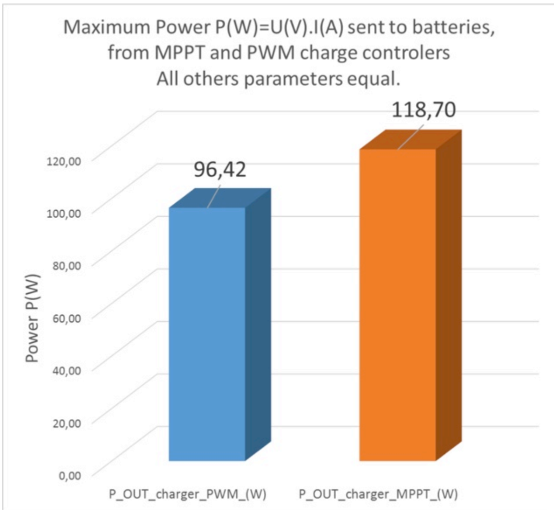


Figure 93 - Maximum power sent to the batteries from the MPPT and PWM charge controllers.

Of course, maximum rated power is not representative as this value is only achieved on very few occasions when all environmental conditions (sun, temperature, wind, etc.) are optimal. However, it still highlights the superior performance of MPPT technology compared with PWM.

Power production even exceeded the nominal value of 100 Wp. As explained in chapter A "general knowledge on energy", solar panel performance increases with colder temperatures, which explains this measurement (altitude 2,100m, winter, with snow albedo effects and some very sunny days).

Effects of the two different types of charger technology on battery charge (voltage level), Figure 94.

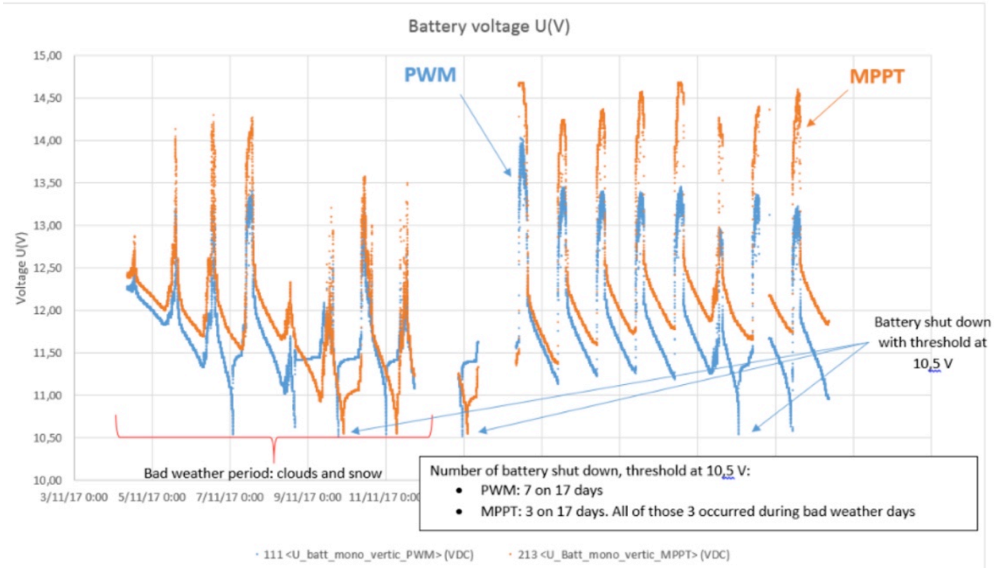


Figure 94 – Comparison of battery voltage U(V) of MPPT versus PWM.

During this period, the PWM line shows seven battery failures in 17 days, due to a battery protector opening the circuit when battery voltage dropped below the 10.5 V threshold to prevent deep battery discharge.

Over the same period, the MPPT line shows only three battery failures.

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

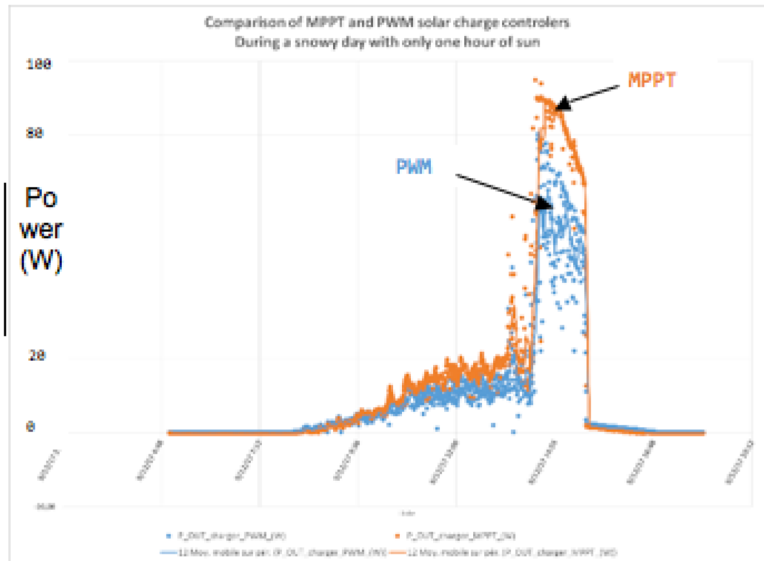


Figure 95 - Power (W) achieved by both MPPT and PWM charge controllers on a snowy day.

During this very short window to recharge the batteries, the PWM and MPPT charge controllers reached the power values given in Table 28.

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

	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%

The effects of the type of charger on battery voltage level are quite evident. In one hour, the MPPT battery charged better than the PWM battery. Furthermore, during the following night, a shutdown occurred for the PWM battery but not for the MPPT battery. Figure 96 shows that the battery charge level was higher at the beginning of this day for the PWM than for the MPPT line.

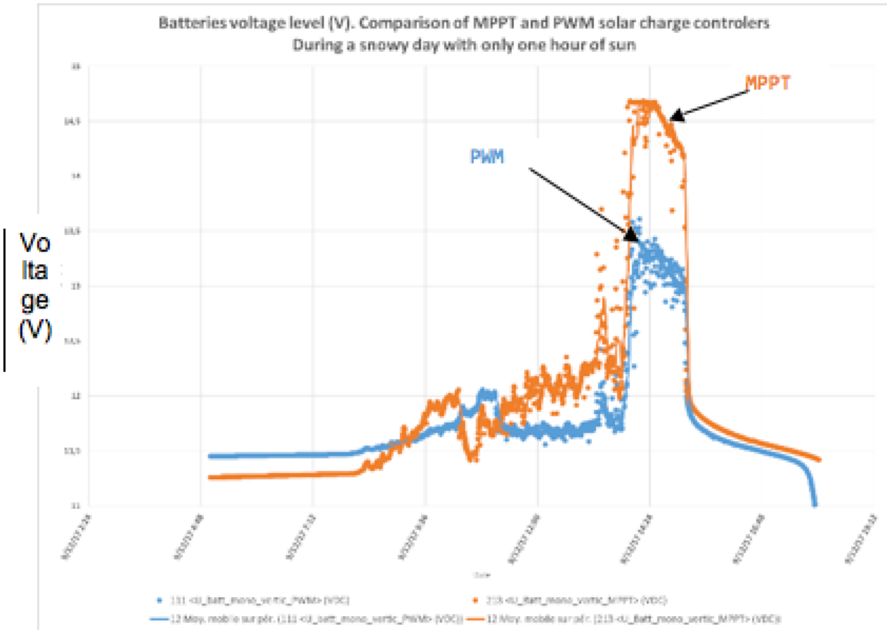


Figure 96 - Battery voltage U(V) achieved on MPPT and PWM lines.

In conclusion, power production differences are high enough (about 30%) to justify a recommendation to use MPPT technology. The price difference is insignificant in the context of the full cost of a scientific station. For a 100 Wp solar array, the MPPT solution costs about €160, compared with the PWM cost of approximately €100[9].

[9] Average prices from different sellers, 2017.

D. Energy storage system evaluations

Many RIs face cold conditions at their measurement stations, particularly within the ENVRI+ Grenoble community (Alps and polar exploration sites). A battery evaluation in cold conditions was set up in the IGE laboratory, using a climate chamber that allows cooling to -70°C.

Based on the results of the ENVRI+ survey of "Who is using what?", the most commonly used batteries, lead-acid, were evaluated.

A student trainee, Mr. Bastien BOURJAILLAT, performed these evaluations from March to June 2017. The following part of the Annex contains the student's report, preceded by an introduction summarising the main technical knowledge.

D.I. Main results

The main technical information on lead-acid batteries obtained by this evaluation includes:

- Typical battery discharge cycles.
- Effect of temperature on battery capacity.
- Differences between gel and AGM.
- Effect of age (cycling) on battery capacity.
- Correlation between impedance (Z) and battery State of Health (SoH).
- Importance of charge quality on battery capacity.
- Validation of a quick test for battery SoH

The five first points are presented below.
The two last (6: "Importance of charge quality for battery capacity" and 7: "Validation of a quick test for battery SoH") have already been discussed in Chapter A "General knowledge".

All this information has been gathered on the "summary technical datasheets".

D.I.1 Typical battery discharge cycle

Figure 97 shows what happens during a battery discharge cycle.

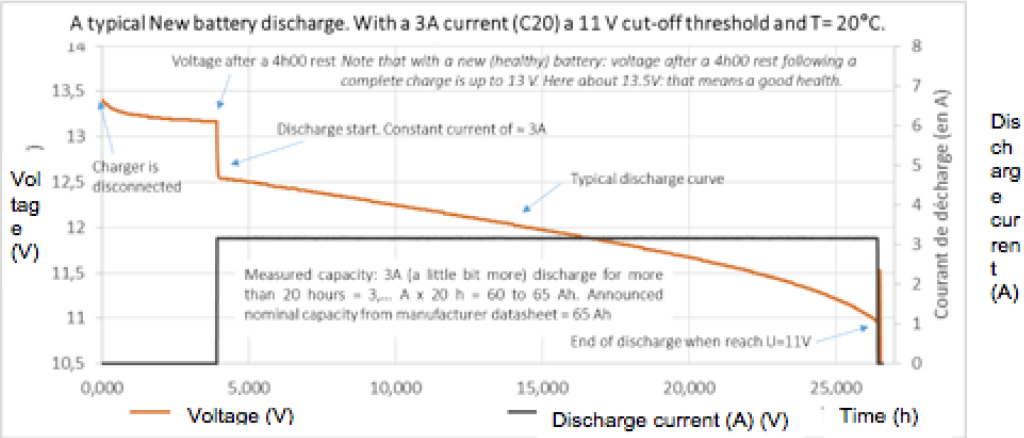


Figure 97 - A typical new battery discharge cycle, with a current of 3A (C20), 11 V cut-off threshold and T= 20°C.

D.I.2 Effect of temperature on battery capacity

In negative temperatures (below 0 degrees), lead-acid batteries are expected to provide only 60-70% of their nominal capacity, as shown in Figures 98 and 99. This important phenomenon must be kept in mind when sizing station batteries.

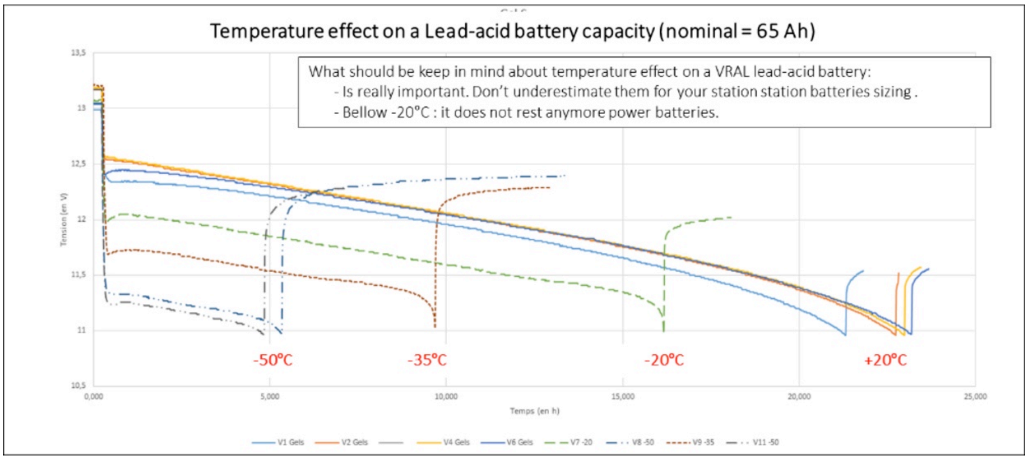


Figure 98 – Effect of temperature on the capacity of a lead-acid battery (nominal = 65 Ah)

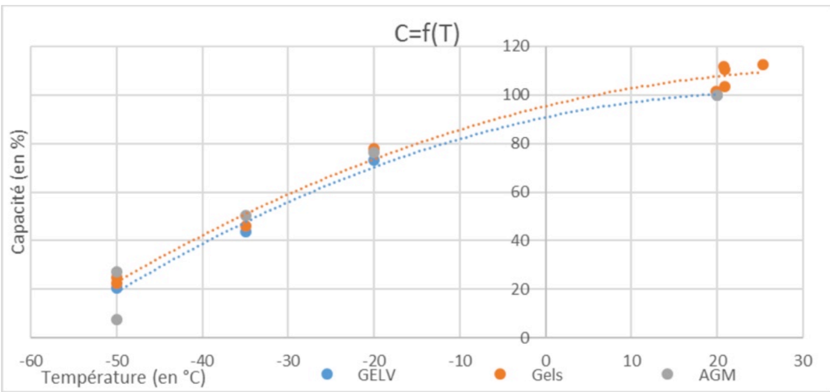


Figure 99 - Battery capacity response as a function of temperature. GELS : Sonnenschein gel battery; GELV : Victron gel battery; AGM : AGM battery

During long term use of a battery, characterised by a large number of charge and discharge cycles, its capacity will, of course, decrease as sulphate crystals appear, and as both the plus and minus plates are deteriorated due to chemical reactions.

D.I.3 Differences between gel and AGM

Gel technology is newer than AGM. Gel initially performed better than AGM, particularly in cold conditions, leading to its reputation for working better under cold conditions. However, it now seems (2017) that AGM technology has made up this difference.

Our evaluations show no major difference between gel and AGM batteries from the same manufacturer in terms of capacity in cold conditions: see Figure 99.

D.I.4 Effect of age (cycling) on battery capacity

Figure 100 shows examples of some old batteries, and their percentage of nominal capacity.

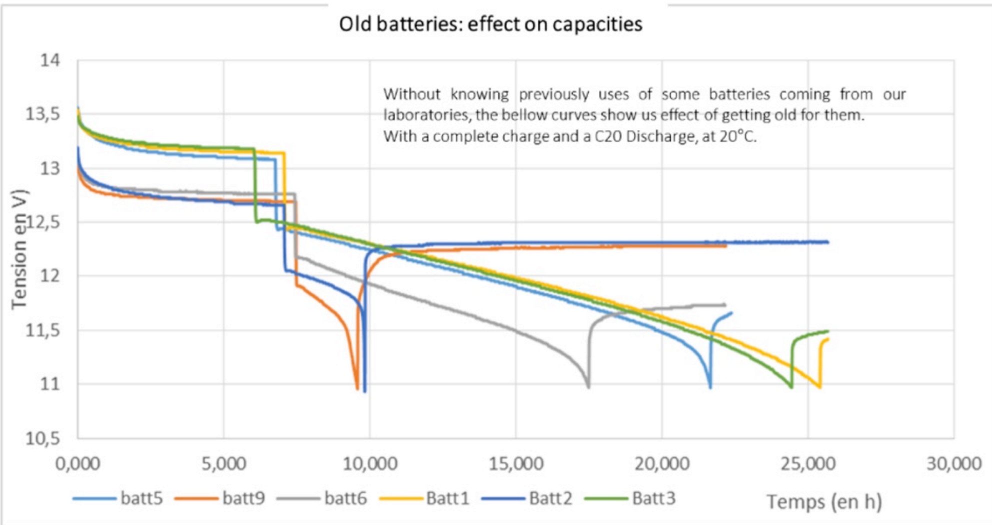


Figure 100 - Old batteries: effect on capacity.

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

Internal impedance (Z in Ω) represents the capacity to make electrons move between the anode and the cathode. In a way, this is its "resistivity" (for physical reasons, as there are 3-dimension resistances, we called this one impedance), or the opposite of conductivity.

Thus, the newer the battery (State of Health - SoH - close to 100%), the lower the impedance. This is confirmed by data recordings shown on Figure 101.

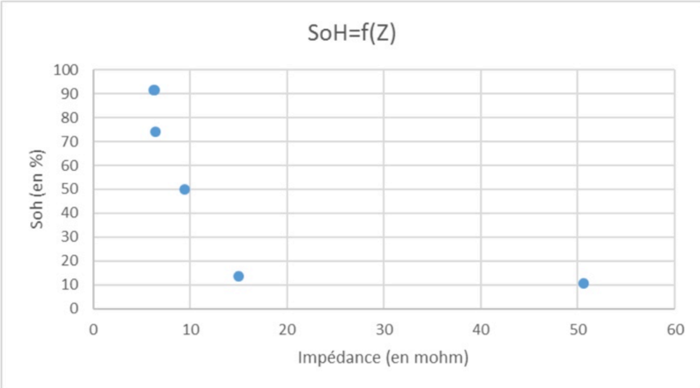


Figure 101 - Graph showing battery state of health according to impedance.

D.II Battery evaluation report

D.II.1 Introduction to batteries

D.II.1.1 Autonomous measurements

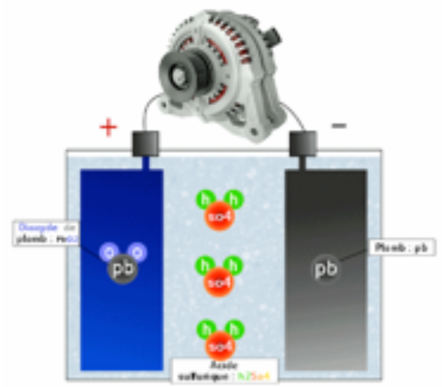
Regardless of the measurements to be made, the sensors used will always require a power supply. This energy must therefore be optimised to enable uninterrupted operation of the observatories and to limit costs. For the ENVRIplus project, Olivier GILBERT gathered information on the battery technologies used by various European laboratories for their measurement stations. It appears that, like IGE, they mostly use lead-acid batteries (VRLA), mainly because of their low cost and resistance to 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 and GEL.

Table 29 - Table comparing different battery technologies.

		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

D.II.1.2 Operation

A battery, or accumulator, is a tank storing 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 to separate and direct the ions between the positive electrode and the negative electrode. In the case of lead, the pair involved is $\{PbO_2/Pb\}$ immersed in sulphuric acid (H_2SO_4). Figures 102 and 103 show the chemical elements present when the battery is charged or discharged.



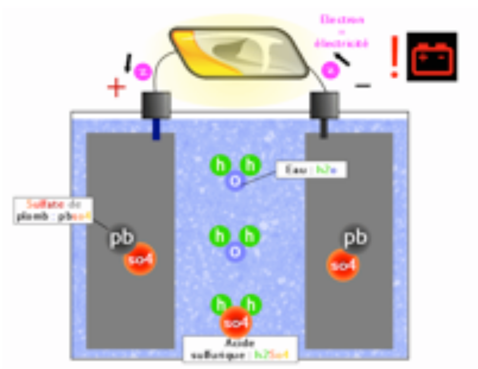


Figure 102 - Charged lead battery

Figure 103 - Discharged lead battery

An electrochemical battery thus operates on the principle of an oxidation-reduction (redox) reaction, as follows:

$$\mathbf{PbO_2 + Pb + 2\ H_2SO_4 \underset{Charge}{\overset{décharge}{\rightleftarrows}} 2\ PbSO_4 + 2\ H_2O}$$

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.

D.II.1.3 Different properties of sealed Pb accumulators

Nominal voltage - 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 placed on the battery terminals, for example. It is directly related to battery charge and can indicate a malfunction of the battery. 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 stabilise after a charge-discharge cycle, as shown in Figure 104. It is therefore important to leave the battery to rest to be able to take repeatable measurements.

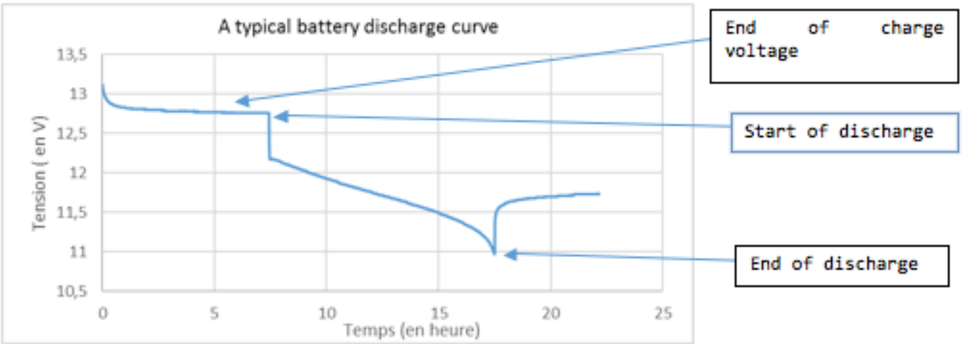


Figure 104 - Typical discharge curve

Capacity - A battery's capacity is the amount of electrical 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 ($Cn = \int_0^t I.dt$) 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.

However, it is much more difficult for a battery to deliver high current than low current. This is known as the Peukert effect. Manufacturers therefore specify 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 station batteries.

Internal impedance - Impedance (Figure 105) corresponds to the sum of the electrical resistances and capacities of the solid materials (electrodes, connections) and the electrolyte solution. Typically, this impedance is on the scale of the milliohm, and varies according to the temperature, state of charge and overall condition (state of health) of the battery. By setting the first two parameters, the possibility of estimating the state of health of the accumulator can be examined.

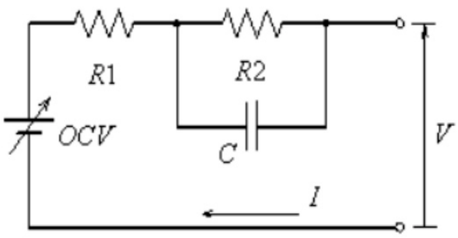


Figure 105 - Battery equivalence scheme.

State of Health (SoH) - Unfortunately, batteries age over time and lose capacity, so their overall condition must also be known[10] to avoid nasty surprises during use. The manufacturer defines a number of cycles[11] that the battery can complete before losing capacity. For a Pb battery, this is approximately 800 cycles. These "cycles" are clearly defined with full charges and non-deep discharges. However, in field conditions, batteries do not follow perfect cycles and may therefore deteriorate more quickly. The easiest way of knowing the overall condition of a battery is to implement a full discharge to find out its capacity (*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 completely, which is why experiments were conducted to determine battery efficiency in cold conditions and to find a simple means of defining SoH.

D.II.1.4 Temperature dependency

Problem - As explained previously, IGE's observatories are located in areas where climate conditions are extreme. In the 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, a repeatable, precise and strict protocol was developed to allow other users to continue the tests after this initial phase. A monitoring form associated with the protocol was prepared to record and date all information and to record any relevant observations throughout the experiment.

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 charging and to measure voltage and impedance with the BT3554. Fill in the monitoring form.
- Leave the battery for at least 4 hours to rest and acclimatise to the temperature if operating in cold conditions, 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.

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

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

[10] State of Health (SoH)
[11] Number of successive discharges-recharges

As shown in Table 30, a single operation at C/20 takes 2 days. It was therefore decided to carry out most tests at C/20 and to see if behaviour was the same at C/100. This operation lasted a further 3 days.

D.II.1.5 Bench test

The characteristics of three new 12V batteries, one AGM, one 90Ah C/20 GEL[12] by Victron energy and one 65Ah C/20 GEL[13] by Sonnenschein were studied. These are both reputed manufacturers. Two CTEK MXS 5.0 chargers were used with the normal program. It is important to use the same charger each time to see if battery efficiency is affected. The tests were carried out in an air-conditioned room, with the temperature set at 20°C, equipped with a SECASI technology ST340 climate chamber, able to operate as low as -70°C. The on-board software was used to program the temperature decrease and stabilisation phases.

A HIOKI Battery Tester 3554 was used to measure battery impedance. 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 kHz, and returns battery impedance. It is important to connect to the same place on the accumulator terminal each time as resistance may vary due to current density.

Two Elektro-automatik EA-EI 3160-60 electronic chargers were used to enable constant current discharges. 3 wires were soldered to retrieve the data of interest on an acquisition station.

The voltage and current values were acquired on a Campbell CR1000 acquisition station using Loggernet software, which was relatively easy to use. A programme was written to select the outputs, acquisition time and means of data retrieval with the required sensitivity or the voltage divider for the PT100 4 files.

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

D.II.1.6 Results

C/20 discharge – Figure 106 is a typical graph for battery discharge at C/20, in this case, the 65Ah GELs. Reminder: at constant current, C/20 = 65/20 = 3,25A. Note that voltage decreases before stabilisation after 4 hours, then the electronic charge begins, which causes a marked voltage drop, before a steady decrease to the 11V threshold. $C = \int_0^t I\,dt$, with current being constant, therefore the capacity obtained is simply the time taken by the battery to reach the threshold multiplied by the discharge current. It is important to remember that for the same current, the longer it takes the battery to discharge, the larger its capacity.

[12] Noted GELv
[13] Noted GELs

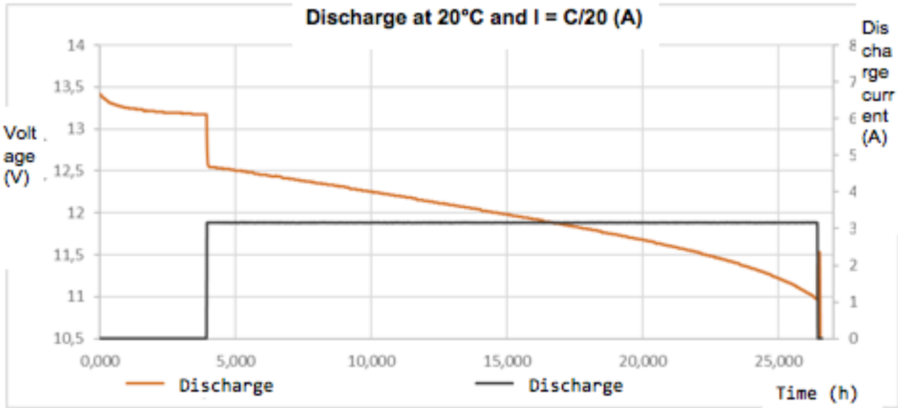


Figure 106 - Typical lead-acid battery discharge graph (3A current).

Three experiments were conducted on each battery at 20°C to ensure the feasibility of the protocol, to make sure that the batteries reacted in the same manner and that the measurements obtained were useable. Note that for the AGM battery, the tests give capacity with a standard deviation of 1.1%. The first graph for GELv and GELs batteries does not correspond exactly to the two others, but this is due to the charger: for the first graph, an old charger, less sophisticated than the MXS, was used. This demonstrates the importance of the charger, which caused a 15% difference in battery capacity in this case. It appears that room temperature was 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 misuse occurring before the batteries were provided for the test. It will be problematic for the battery comparison according to temperature because the batteries were not all subjected to exactly the same conditions in the past.

Since ordering new batteries was not an option (not the objective set), the GELs tests were moved to the climate chamber, using different line styles to represent the different test temperatures. For the tests at -50°C, the battery was left to acclimatise 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 104 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 performed best during the first test at -50°C, collapsed totally during the second test. There was not enough time for another experiment, but this supports the literature, which indicates the superiority of GEL batteries in cold conditions.

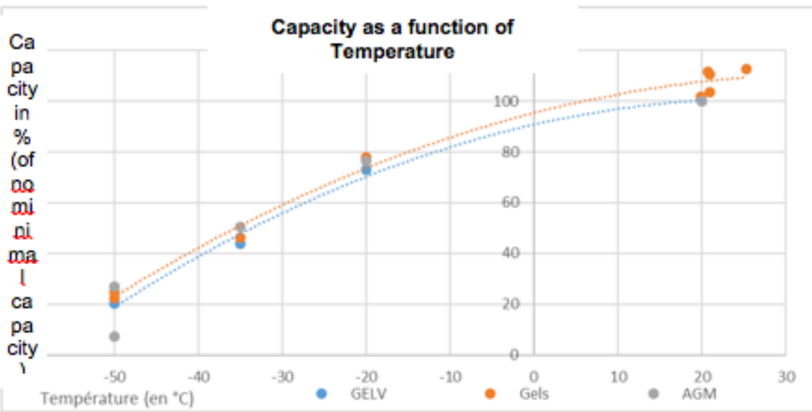


Figure 107 - Graph of the capacity response as a function of temperature.

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. Experiment carried on for Figure 107 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 the accumulator behaved in the same way.

C/100 discharge - 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, the test was carried out 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 hypothesise that at a lower current, the curve moves further upwards, but without altering its shape significantly. It would therefore be possible, following further testing, to estimate 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?

Partial discharges - The curves often appear to have the same shape. It would be useful to find a way, with a shorter discharge, of extrapolating the points to estimate final capacity in just a few hours. First, a linear approach was applied, using the slope of the line in discharge mode over just a few hours. However, even using all the points, error remains greater than 20%.

D.II.1.7 Diagnosing state of battery health

Problem - A good quality electric power supply is essential to ensure reliable operation of a measurement station. To avoid losing data, technicians therefore change the batteries every five to ten years, without knowing the state of health of the battery. 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 a very important question for laboratories.

Protocol - The same discharge protocol at C/20 as that used previously was applied, but focusing more on the impedance, which gives an estimation of the state of battery health. Around ten old identical Sonnenschein 12V 60Ah batteries, which had not been subjected to the same conditions and whose dates had not been monitored were collected.
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 - There was only enough 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.

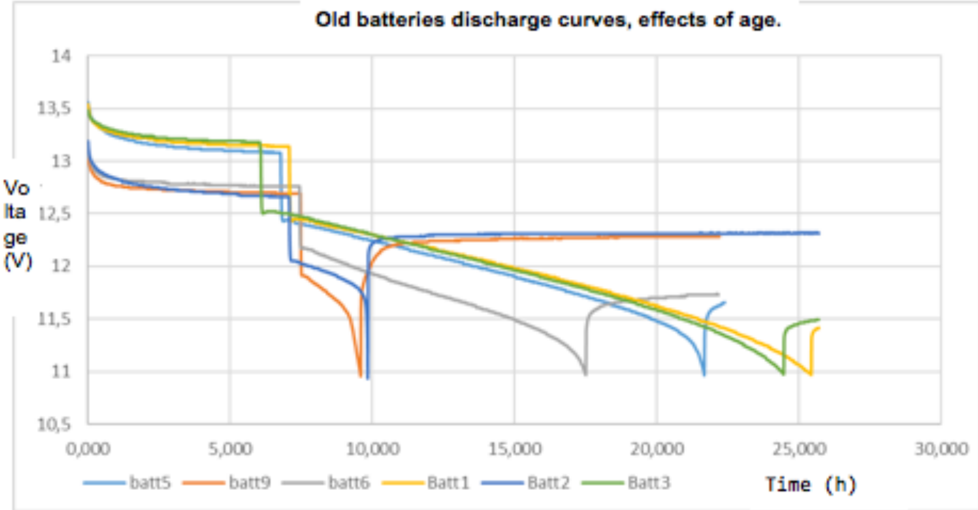


Figure 108 - Old battery discharge curve.

Using a well-completed monitoring form and continuous acquisition, different characteristics were observed according to SoH. Firstly, Figure 109 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, this curve could be examined to determine 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.

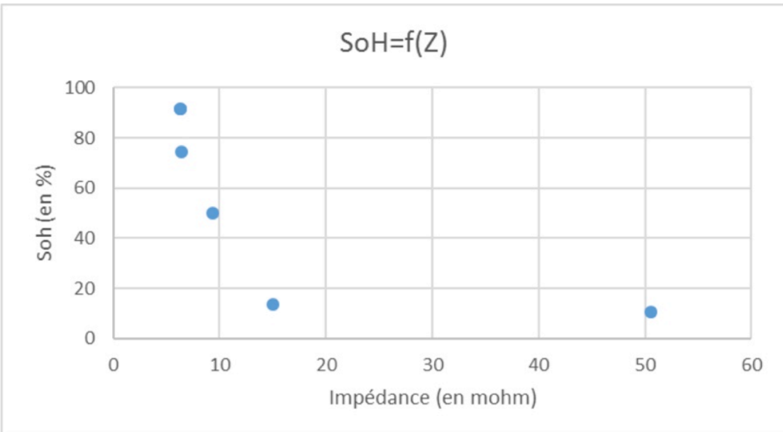


Figure 109 - Graph showing battery state of health according to impedance.

After discussions 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 indication of battery ageing. Again, voltage varies with temperature, and since this operation involves opening the circuit, it would not be easy to use in the field. However, it remains useful to establish rapidly whether battery voltage remains above 13 volts, and if the battery can be reused or not.

This experiment revealed that the final value of the voltage drop[14] during discharge appears to define the discharge time and therefore capacity. Indeed, this is obvious 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.

This final method remains to be explored. Monitoring impedance could provide information on the state of battery health, but a simple full charge followed by a rest period is enough to provide a good estimation. If after a rest period the battery voltage is above 13V, it is in good condition, if not, precautions should 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, researchers would have this information when their batteries are returned from the field.

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

E. Technical summary

***Note -** The following data sheets are designed to be quick and easy to use by potential users. They summarise the main information presented in the previous chapters.*

E.I Photovoltaic solar panels

Solar panels

Summary of technical advice for direct on-site use

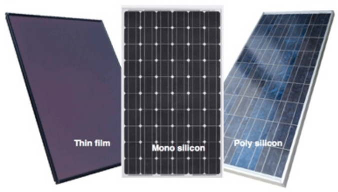
These datasheets have been made to summarise advice on energy issues for Research Infrastructures. They are mainly intended for non-experienced users, allowing them to benefit from the experience of others to save time. For more details, please refer to the complete ENVRI+ energy report. Visit the ENVRI Community website: http://envri.eu/ or contact: olivier.gilbert.fr@gmail.com

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

- Silicon crystals (≈ 90% of worldwide market): mono or polycrystalline. Efficiency typically ranges from 12 to 18%.
- Thin film: silicon or cadmium telluride (Cd-Te), copper indium gallium selenide (CIGS), etc. Efficiency typically ranges from 5 to 12%.
- Multi-junction cells: such as indium gallium arsenide, germanium, etc. Efficiency typically ranges from 25 to 45% (but most are still in the R&D phase).

Most terrestrial and oceanic scientific stations use **silicon crystal technologies**. In this case, it is better to choose **monocrystalline** rather than polycrystalline technology.

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 (45° latitude) sites with regular snow deposition, panels should be placed vertically:
  - To avoid snow deposition, dust, falling rocks, etc.
  - Differences in terms of power production between vertical and "annual optimum" tilt are small as solar arrays are usually oversized. Moreover, the albedo effect (light reflected by snow) is more pronounced in winter when there is less sun.

- Use a pack of two independent batteries:
  - 1 or acquisition (priority)
  - 1 or transmission (secondary)

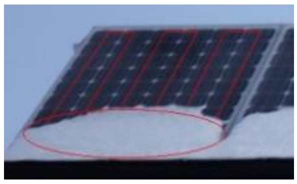
- Prefer an MPPT charge controller instead of a PWM, mainly for > 100 Wp installations.

- Sizing: The table below is a suggestion for "classic" 10 W consumption, 24/7, with the following restrictions:

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)

- Shade/Snow:



PV Cells in series! Be careful to avoid shade (tree, rock, building, etc.) or snow deposition even on a single cell as this will cause a dramatic drop in total production.
As with a water pipe, a single “pinch” will affect the flow rate of the entire system.

- Mechanics:

Pay attention to your fixing systems as solar panels are like sails for the wind and mechanical 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 download from the ENVRI Community website. http://envri.eu/

E.II Wind turbines

Wind turbines (WT)

Summary of technical advice for direct on-site use

These datasheets have been made to summarise advice on energy issues for Research Infrastructures. They are mainly intended for non-experienced users, allowing them to benefit from the experience of others to save time. For more details, please refer to the complete ENVRI+ energy report. Visit the ENVRI Community website: http://envri.eu/ or contact: olivier.gilbert.fr@gmail.com

- Examples of small horizontal or vertical axis wind turbines used in scientific stations (non exhaustive list)

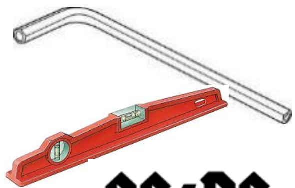
Horizontal axis	Vertical axis	
		
Primus AIR 30	Forgen Antarctica	Forgen Ventus 70

- **Be careful with sizing**: Winds on site can be turbulent as opposed to the laminar flow of laboratory conditions, causing production differences. On-site: oversize wind turbines or you will not have the power you expect. If possible: double with parallel WTs.

For example: For < 10 W consumption and 100 Ah batteries: two Forgen Ventus 70 vertical axis or one Primus AIR 30 horizontal axis.

- **Combine wind turbines with solar panels**: Small wind turbines should be coupled with solar panels to ensure power charging, or any other parallel source, such as fuel cells, etc.

- **Check screws and vibrations**: To prevent premature wear, secure the WT as strongly as possible and make sure it is as stable as possible in both vertical and horizontal axes. Furthermore, a wind turbine inevitably causes vibrations. It is important to check screw tightness regularly (generally every one or two months). Vibration waves may interfere with certain measurements, such as seismology, etc.



- **AC/DC**: To be checked with the manufacturer: the regulator is generally internal to the wind turbine. Wind turbines produce alternating 3-phase electricity that has to be transformed to direct current. AC -> DC. 12/24/48, depending on the batteries and the devices to be powered.

AC/DC

- **Ideally**: Monitor production. Current produced in A or just battery voltage. Try to find a wind speed forecast model for your site to help schedule any necessary interventions during a long period without wind, for example.

E.III Fuel cells

Methanol fuel cells

Summary of technical advice for direct on-site use

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

- Power available: from 25 to 100 W.
- Methanol must be handled carefully: can be toxic if inhaled.
- Release of H_20 and CO_2:
    - Ventilation needed (for CO_2 safety reason)
    - Must be adapted (ventilation and heating) for use at negative temperatures.
- Relatively long autonomy for low electrical consumption (W). Typically 1L Methanol for 1,000 Wh produced = 100 hours for 10W consumption. 28L tanks are available for the model tested.



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

E.IV Lead-acid batteries

Batteries

Mainly lead-acid batteries, with a few recommendations for lithium batteries.

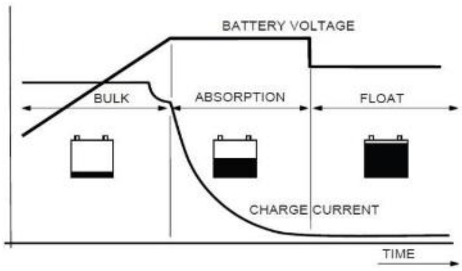
Summary of technical advice for direct on-site use.

These datasheets have been made to summarise advice on energy issues for Research Infrastructures. They are mainly intended for non-experienced users, allowing them to benefit from the experience of others to save time. For more details, please refer to the complete ENVRI+ energy report. Visit the ENVRI Community website: http://envri.eu/ or contact: olivier.gilbert.fr@gmail.com

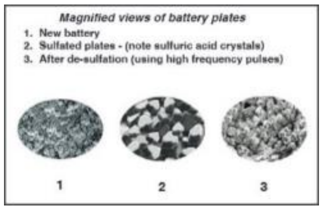
Lead-acid batteries:

- What does C/10, C/20, C/100 mean?
  - For example: C/10 = 50 Ah means that the battery can deliver 50 Ah for 10 hours if fully discharged. C/20 = 90 Ah means it can deliver 90 Ah for 20 hours. C/20 is the common standard for talking about battery capacity.

- Charge:
  - If possible: use a 10% to 25% C/20 current charger. Ideally, use an intelligent 3-step charger (or more steps if possible)
  - For example: for a 80 Ah battery, charge with a current of 8 to 20 A



- Discharge:
  - Do not discharge to more than 50% of C, or below 10.5 V to preserve the state of health (SoH) of your batteries for years. If 40 Ah is required, use 80 Ah in the installation set-up. This will have a strong influence on battery life time: from a hundred available cycles, to a thousand for its full capacity
  - When voltage decreases, acid will be changed to water. Sulphate crystals will form in this water, and block electron movement in the electrolyte causing a loss of capacity. This is the cause of battery damage / overuse.
  - To avoid this sulphation phenomenon, batteries must be recharged at least every 6 months, and whenever voltage falls below 12V.



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

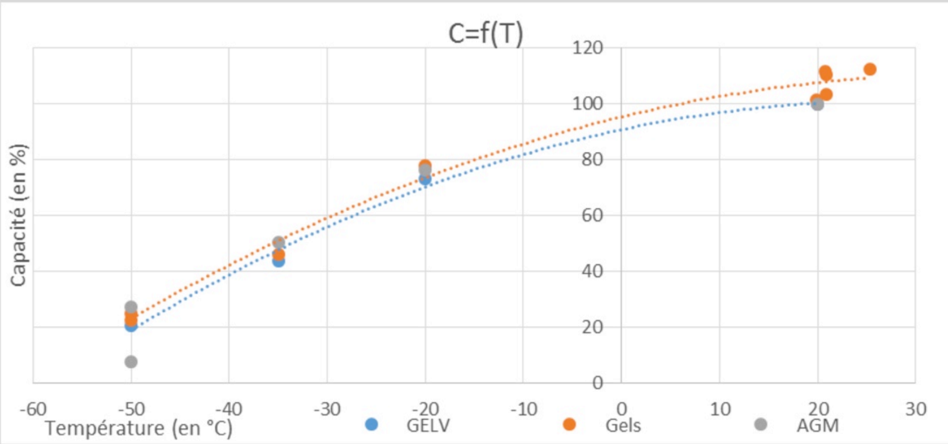
This short, empirical test provides an overview of internal battery SoH (State of Health), i.e. its internal wear due to sulphation. After a complete charge and a 4-hour rest, measure battery voltage. Refer to the table below.

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	

U(V)	Battery State of Health (%)	Comments
>13V	100%	OK for fieldwork use
12.5V	50%	To be use in laboratory
12.0V	0%	End of life

- Storage/maintenance:
  - Store fully charged battery because of internal self-discharge due to a slight but continuous loss of current
  - In a cool, ventilated room. Warm temperatures catalyse the discharge chemical reaction: $H^+ + e^- + SO_4^{2-}$ -> $H_2S0_4 + H_2O$, so store batteries in a cool room. To avoid corrosion on batteries lugs, it is best to avoid humidity too. Charge produces a small quantity of water + sulphuric acid vapours, so the room should also be ventilated.

- Effects of temperature:



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

Lithium batteries:
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 widely used technologies. It is also one of the most secure in terms of fire hazard.
Pay attention:
- A special Li-ion battery charger is required (voltage and current are different from those of lead-acid batteries)
- Difficult to charge below 0°C. Discharge continues down to -20°C (approximation for common Li-$FePO_4$ batteries available on the market)

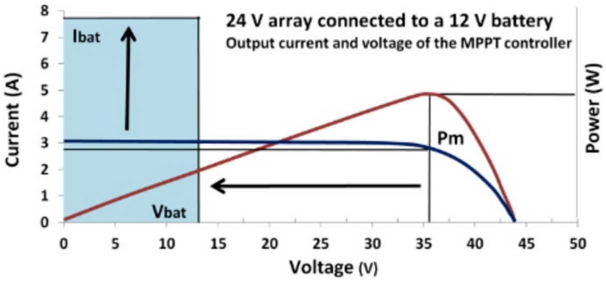
E.V. Power regulation and control

Power regulation: from production to storage

Summary of technical advice for direct on-site use.

These datasheets have been made to summarise advice on energy issues for Research Infrastructures. They are mainly intended for non-experienced users, allowing them to benefit from the experience of others to save time. For more details, please refer to the complete ENVRI+ energy report. Visit the ENVRI Community website: http://envri.eu/ or contact: olivier.gilbert.fr@gmail.com

- Solar regulator/controller:
  - For > 100 Wp solar arrays, use an MPPT charge controller (except in polar regions, where Zener diodes could be better to prevent electronic failures and minimise internal consumption at night)
  - The overall gain is about 30% compared with 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 permitted current from the charge controller
  - When connecting the charge controller, connect the batteries first, then the production to avoid an electric arc if batteries are connected during production. The solar panels can also be covered to interrupt production.
  - If possible (usually for PWM), use “duo” charge controllers that can manage a rack of two batteries (one for acquisition, one for telecommunications) or a battery separator.

- Wires:
  - Try to minimise wire length to avoid power losses (Joule effect).
  - Maximum wire cross-section with respect to 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	1.6
22	0.025	0.6452	16.140	52.9392	7	0.92
24	0.020	0.5106	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
–	–	–	–	–	–	–

  - Batteries in series or parallel: Try to use wires of the same length and cross section to homogenise current transportation

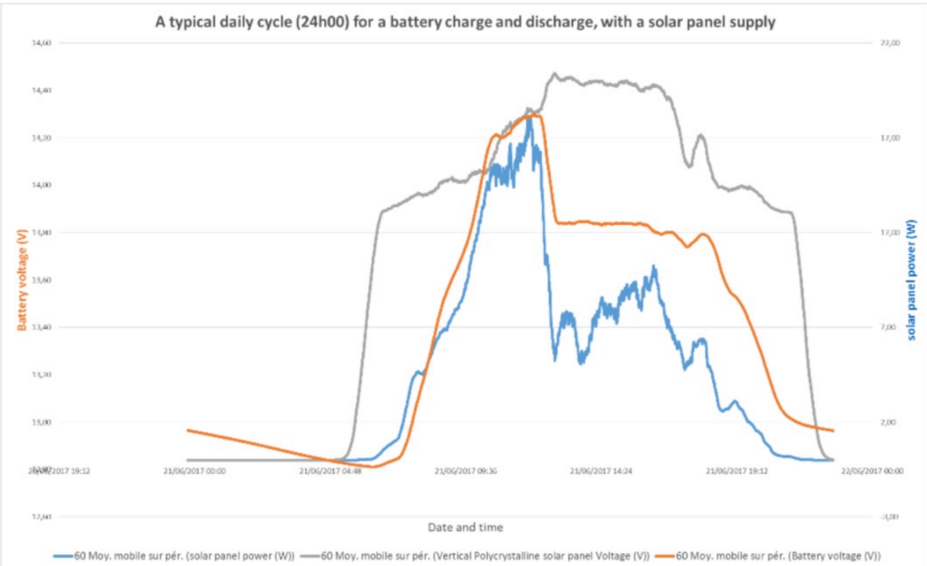
E.VI A typical daily battery cycle for an isolated station powered by solar panels

Typical battery + solar panel daily cycle

Summary of technical advice for direct on-site use.

These datasheets have been made to summarise advice on energy issues for Research Infrastructures. They are mainly intended for non-experienced users, allowing them to benefit from the experience of others to save time. For more details, please refer to the complete ENVRI+ energy report. Visit the ENVRI Community website: http://envri.eu/ or contact: olivier.gilbert.fr@gmail.com

For a better understanding of the physical phenomena occurring occurred in isolated scientific sites powered by solar panels and batteries, the following diagrams show the typical stages of a 24-hour battery charge and discharge cycle.



Step	What happens?
1	Night: battery voltage decreases as it is the only power source for consumption.
2	Daylight arrives (as the solar panel voltage shows on the grey curve), solar panel voltage quickly rises to an operational level.
3	When solar panel voltage is high enough (around 14.00 V for this 100 W panel), with sun striking hard enough, electrical current is produced. Until the battery is fully charged, the solar charge controller allows the solar panel to transmit current. This is called the “bulk mode”.
4	Battery charging. Voltage and current are regulated to suit the battery level.
5	The battery is fully charged. The solar charge controller switches to the “floating mode”.
6	The solar charge controller remains in the floating mode to maintain optimal battery voltage (around 13.8V in this case), without causing damage. Any additional current produced will power the electrical devices, such as scientific sensors, data-logger, transmission modem, etc.
7	The sun starts to decline and the solar panels will soon be unable to provide enough energy for both the electrical load and to maintain battery levels. The batteries take over from the solar panels, causing battery voltage to start to decrease.
8	Until the sun comes up again…

F. Glossary

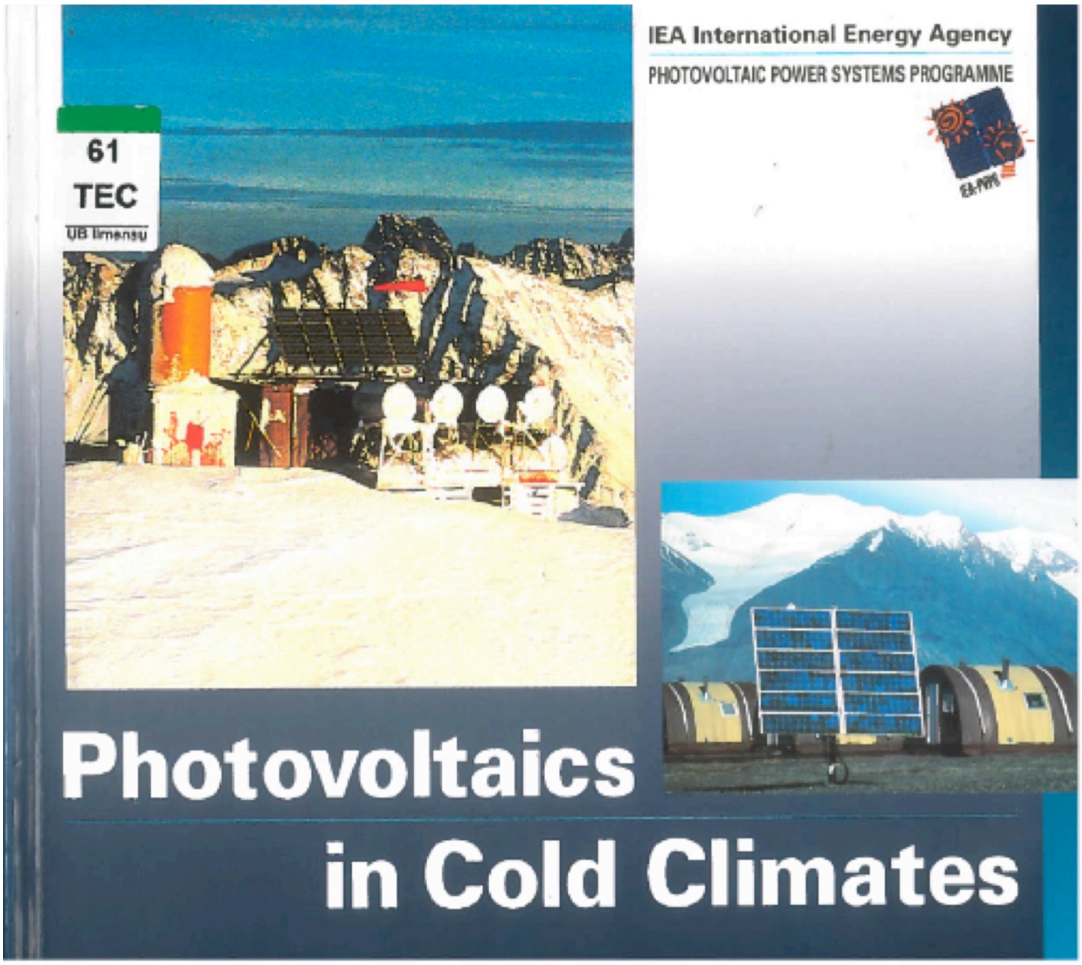
A (unit)	Amperes
CNRS	National Scientific Research Centre (France)
Energy	Energy = electrical energy (misnomer)
FluxAlp	Measurement station for carbon flux exchanges in the Alps (soil, air, rain).
I	Intensity, Current in Amperes
IFSTTAR	French Institute of Science and Technology for Transport, Development and Networks
IGE	Institute of External Geosciences
ISTerre	Institute of Earth Sciences
OSUG	Observatory of Sciences of the Universe, Grenoble ,France
PAR	Photosynthetically active radiation: refers to the spectral range (wave band) of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use for the photosynthesis process (https://en.wikipedia.org/wiki/Photosynthetically_active_radiation
PV	Photovoltaic solar panel
SAJF	Joseph Fourier alpine station: The evaluation site for energy production systems. Located at “Col du Lautaret” between Grenoble and Briançon, altitude 2,100m, French Alps. Part 1: General knowledge on energy for isolated sites
SoH	State of Health
U (unit)	Voltage
V	Volts
W (unit)	Watt
Wh	Watt.hour
Wp	Watt Peak: optimum power production of a solar panel in laboratory conditions: 25°C, 1000 $W.m^{-1}$, and determined air density (which varies with pressure/altitude, and therefore with the available quantity of solar radiation on the solar panel).

G. List of figures

H. List of Tables

I. Annexes

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



Might be of interest, being one of the few documents available about energy in cold climates

Annex B: Technical guide for solar panel + battery 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 (PSC(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

Annex C: Management of battery testing and storage

Management of battery testing and storage (return from the field)

1: Put to charge.

Ideally with a current 10% to 25% of the C20 battery capacity (capacity for 20 hours' use, usually indicated on the battery by the manufacturer).
For example, for a 70 Ah battery => current of 7 A.
If the charger can only deliver a 1 A current, it will take 70 hours to charge (if totally empty) and the battery will not be optimally charged.

2: Test:

Protocol: (ideally, each step should be performed at 20°C)

1. Fully charge the battery.
2. Wait 4 hours after disconnecting the charger.
3. Measure voltage U(V) in reference to the table below.
   Option: if possible, check impedance (Z in Ω)
4. Note U(V) (and Z as an option) on a label to be placed 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 concerning impedance Z(Ω)
Typical new lead-acid battery impedance = from 5 to 10 mΩ.
When Z(Ω) is doubled: the battery is seriously damaged, and has been used enough.
If Z(Ω) > 30 mΩ: battery end of life. Send for recycling or de-sulphation (consult a professional for advice on this topic).
Ideally: write the Z value on the battery immediately upon delivery (new battery).

3: Store in a cool, dry and ventilated place.

4: Before next use:

- Batteries should be stored fully charged because of internal self-discharge.
- They should be refuelled every 6 months at least, or if voltage < 12V
- Battery self-discharge increases in warm temperatures.

- Battery charge can release water + sulphuric acid: ventilation is necessary.

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

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, overall average for estimation. Contact distributors for an up-to-date quotation)

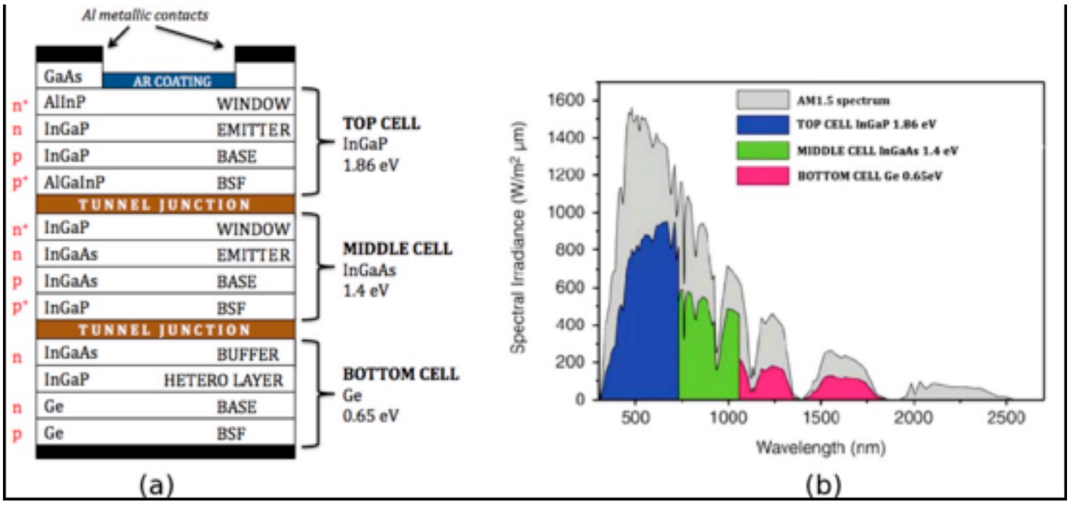
Annex G: Wind speed conversion units: m/s <=> km/h <=> mph

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

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

Annex H: Other evaluations of photovoltaic technologies.

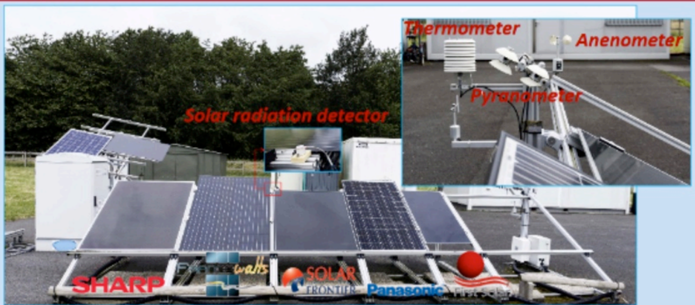
Other technologies could be useful on-site, particularly to maximise production if the sun is only present for a few hours. The most widely available technology at present is silicon crystal cells. Efficiency varies from approximately 15 to 20% (in 2017).
Other technologies use more efficient compounds, such as multi-junction cells (as shown in the figure below). Prices are proportional to production, and at this time (2017), multi-junction solar panels are still difficult to find on the market.



For more information on efficiency evaluations of multi-junction cells, see (for example) the SIRTA evaluations (Site Instrumental de Recherche par Teledetection Atmospherique), as shown in the figure below.

- A study of the energy performance of different photovoltaic (PV) module technologies under real outdoor conditions at Ecole Polytechnique.
- Crystalline silicon (c-Si), Heterojuntion with Intrinsic Thin layer (HIT) and micromophous silicon (a-Si/mc-Si) are 3 PV module technologies which were investigated in this study.
- The data was collected from PV platform at SIRTA with 6 months data for HIT and more than 1 year for c-Si and a-Si/mc-Si.

PV platform at SIRTA



a-Si/mc-Si	C-Si	CIS	HIT	CdTe
P_M^{STC}= 128 W	P_M^{STC} = 250 W	P_M^{STC} = 150 W	P_M^{STC} = 240 W	P_M^{STC} = 82.5 W
η* = 9.5%	η = 15%	η = 12.2%	η = 19%	η = 11.4%

η*: Efficiency

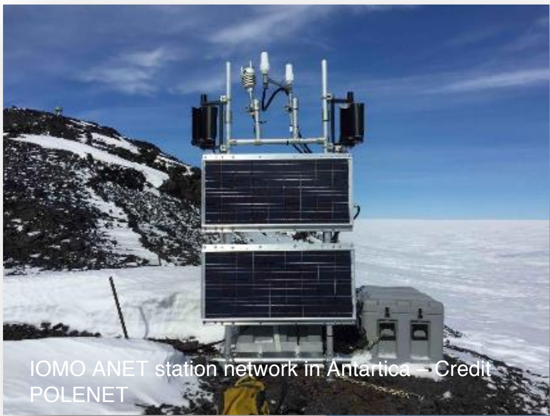
Daily data calculated from the measurements

- Daily energy: $E_{daily}(Wh) = \int_{sunrise}^{sunset} P_M(t).dt$
- Daily irradiation: $H_{daily}(Wh/m^2) = \int_{sunrise}^{sunset} G(t).dt$
- Daily yield: $Y_{daily}(Wh/Wp) = \frac{E_{daily}}{P_M^{STC}}$
- Daily reference yield: $Y_{daily}^R(Wh/W) = \frac{H_{daily}}{G_{STC}}$
- Performance ratio: $PR(\%) = \left(\frac{Y_{daily}}{Y_{daily}^R}\right).100$
- Daily efficiency: $\eta_{daily} = \frac{E_{daily}}{H_{daily}.Area}.100$

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

Annex I
Energy for isolated scientific stations

A contribution to a shared knowledge


IOMO ANET station network in Antartica – Credit POLENET


Kerguelen *Monts de l'Atmosphère* Credit: IPGP


AGO Seismic station – Credit OPGC

Annex II : On-board energy of autonomous marine stations

Distribution:

Chantal Compère	REM/RDT/D
Jean-François Rolin	REM/RDT/D
Jérôme Blandin	REM/RDT/SI2M
Xavier Bompais	REM/RDT/SI2M
Jean-Yves Coail	REM/RDT/SI2M
Loïc Dussud	REM/RDT/SI2M
Laurent Gautier	REM/RDT/SI2M
Julien Legrand	REM/RDT/SI2M
Patrick Rousseaux	REM/RDT/SI2M
Michel Répécaud	REM/RDT/LDCM
Laurent Delauney	REM/RDT/LDCM

☐ Confidential

☐ Restricted

☒ Open

Date : 30/11/17 Doc reference : RDT/SI2M/17-R020 Project reference : Analytics : P204-0024	Number of pages : 35 Number of figures : 9 Number of appendices : 3 Filename :

Subject/Title:

On-board energy of autonomous marine stations

Summary:

This document provides a review of production and/or electricity storage systems for non-cabled marine observatories or autonomous marine stations

Keywords: energy, observatories, stations

Modifications

Index	Purpose	Date	Written by
_	Creation of document	31/03/17	L. Dussud
a	Addition of “tidal energy” and “waves energy” chapters.	31/01/18	L. Dussud
b	Addition of “Conclusion” chapter and Final correction for ENVRI+ delivery	08/10/18	L. Delauney

Contents

1. Context

Non-cabled observatories are instrumentation systems dedicated to data production (biogeochemical, photos, videos, sound, etc.) acquired from sensors associated with dedicated electronic equipment. For a set of sensors to achieve the desired operation in a given environment, additional functions should be performed by peripheral systems:

- ✓ Data processing and archiving,
- ✓ Voltage adaptation,
- ✓ Communication of information,
- ✓ Actuator motorization,
- ✓ Sensor protection,
- ✓ Etc.

This set of functions consumes a certain amount of energy, which all observatories need to provide for the duration of the monitoring, taking into account the extreme environmental conditions as well as possible additional consumption due to potential malfunctions.

This document provides a review of production and/or electricity storage systems for non-cabled marine observatories or autonomous marine stations.

2. Purpose of the document

The purpose of this document is to provide the essential elements needed to choose the type and size of energy sources capable of supplying electrical energy to a set of equipment designed for the autonomous observation and monitoring of biogeochemical parameters installed on marine and/or submarine stations.

3. Definitions - Glossary

3.1. Units of energy

The unit of measure of energy legally in effect in Europe and in almost all countries of the world is the joule (J). This is part of a global system called the International System of units (SI). The joule is defined as the work done by a force of one Newton whose point of application moves one meter in the direction of the force. It represents an amount of energy perceived as small in the context of normal human activity, which hampers its use in certain circumstances. Therefore, multiples of thousands of joules are sometimes used: kilojoule (kJ), megajoule (MJ), or gigajoule (GJ). The joule is defined with respect to other units of mass, length, and time in the International System. It is a so-called derived unit ($kg.m^2.s^{-2}$).
In practice, energy is frequently measured using other units than the joule. These are generally in use in a field of activity and/or have a long history of use, such as: electronvolt (eV), erg (erg), calorie (cal), large Calorie (kcal), British Thermal Unit (BTU), kilowatt hour (kWh), ton of oil equivalent (toe), etc.

- electronvolt (eV): kinetic energy gained by an electron accelerated by a potential difference of one volt, used mainly in the physical sciences because it corresponds to the order of magnitude of the energy of an electron in an atom....1 eV = 1.602×10^{-19} J
- erg (erg): unit of energy in a different system to the International System, called CGS (centimeter, gram and second basic units) .... 1 erg = 10^{-7} J
- calorie (cal): historical unit of measure of energy initially defined by Nicolas Clément in 1824 as the quantity of heat necessary to raise the temperature of a liter of water by one degree Celsius. This inaccurate definition was subsequently made more specific and deflated by a factor of 1000, by indicating that it was the amount of heat required to raise one gram of degassed water from 14.5°C to 15.5°C under one bar of atmospheric pressure ....1 cal = 4.1855 J
- frigorie (fg): in the refrigeration field, a "negative" unit is sometimes used ...1 fg = -1 cal
- the large calorie (Cal or kcal) is mainly used in dietetics .... 1 Cal = 1 kcal = 4185.5 J
- the thermie (th) is an old energy unit.................................. 1 th = 1 Mcal = 4185.5×10^{3} J
- British Thermal Unit (Btu or BTU): Anglo-Saxon unit of energy defined as the amount of heat required to raise a mass of water of one pound by one degree Fahrenheit under an atmosphere of one bar. ....1 Btu = 1055.6 J
- Quadrillion (quad): primary or final energies are often measured in terms of millions or billions of tons of oil equivalent, or even in countries using the British system, in quadrillion Btu .... 1 quad = 10^{15} Btu
- watt hour (W.h or Wh): energy consumed by a 1 watt appliance in a period of one hour. This unit is particularly used in the electrical industries. Multiples of Wh are widely used (kWh, MWh, GWh) ....1 kWh = 3.6×10^{6} J
- ton of TNT: energy released during the explosion of one ton of an explosive called TNT. Its value is likely to vary depending on the conditions of the explosion. However, it has been standardized. In practice, the use of the ton of TNT is essentially limited to the military world.. 1 ton of TNT = 4.184×10^{9} J
- ton of oil equivalent (toe): calorific energy of one ton of "crude" oil. This unit is particularly used by energy economists who make frequent reference to some of its multiples of thousands (ktoe, Mtoe) .... 1 toe = 4.186×10^{10} J
- In the same spirit as the ton of oil equivalent, the unit of energy equivalent to a barrel of oil (boe) is sometimes used. The value is set conventionally .... 1 toe = 7.33 boe
- Before the reference to oil, to define an energy unit from an economic and industrial point of view, the ton of coal equivalent (tce) was used. In addition, depending on the industrial circumstances, tons of other energy products are also used: gasoline, heavy fuel oil, gas, lignite , etc. ....1 tce = 2.930×10^{10} J

Conversions between these units are possible, but they are necessarily partly arbitrary, meaning that the values can differ according to the authors and/or times.

3.2. Units of electricity

The electrical units used to characterize an electrical circuit are listed below.

3.2.1. *Intensity of electrical current*

ampere	A	Intensity of a constant electric current which, maintained in two rectilinear parallel conductors, of infinite length, of negligible circular section, and placed at a distance of 1m from each other in vacuum, would produce between these conductors a force of $2x10^{-7}$ N per meter of length (IX^{e} CGPM resolution 7 – 1948).
biot	Bi	Old CGS unit, corresponds to 10 A.
edison		Old CGS unit, corresponds to 100 A.
➢ 1 ampere corresponds to a flow of about $6.24x10^{18}$ electrons per second		

3.2.2. *Potential difference or voltage*

volt	V	Potential difference between two points of a conducting wire traversed by a constant current of 1A, when the power dissipated between these points is equal to 1W (1V = 1 W/A).
In practice, for a generator the following voltages are generally differentiated: ➢ Nominal voltage: average voltage of a generator observed over most of its discharge curve ➢ No load voltage: voltage measured at the terminals of a generator not connected to a load ➢ Load voltage: voltage measured at the terminals of a generator connected to a load		

3.2.3. *Electrical resistance*

ohm	Ω	Electrical resistance existing between two points of a conducting wire when a potential difference of 1V, applied between these two points, produces in this conductor a current of 1A, the conductor being the seat of no electromotive force. (1 Ω = 1 V/A).
➢ The inverse of electrical resistance is electrical conductance and is expressed in siemens ($1S = 1\ \Omega^{-1}$).		

3.2.4. *Electric power*

watt	W	Corresponds to a quantity of energy of 1 joule, produced or used in 1 second (1W = 1 J/s).

➢ To measure an active electric power (denoted P) in a circuit with an alternating current, the volt-ampere can be used (1 VA = 1W). ➢ To measure a reactive electric power (denoted Q) in a circuit with an alternating current, the volt-ampere-reactive can be used (1 VAR = 1W). ➢ To measure an apparent electric power (denoted S) in a circuit with an alternating current, the volt-ampere can be used (1 VA = 1W and $S^2=P^2+Q^2$).

3.2.5. *Quantity of electricity or electric charge or energy capacity*

coulomb	C	Electrical intensity produced or consumed during a given time (1C = 1 A.s).
ampere-hour	Ah	Electrical intensity produced or consumed in 1 hour (1Ah = 3600C).
franklin	Fr	Old CGS unit, corresponds to 3.33564×10^{-10} C
faraday	F	Old CGS unit, corresponds to 9.6487×10^{-4} C
➢ An accumulator of 10 Ah can theoretically provide 10A for 1 hour, 5A for 2 hours or 100A for 6 minutes. ➢ In everyday language, the energy capacity and electrical capacity are very often confused. Thus, the energy capacity of accumulators (in Ah) is incorrectly called 'electrical capacity'. The International System unit for electrical capacity is the farad (1F = 1 C/V). ➢ The charge or discharge current is very often expressed as a function of the energy capacity (denoted C) of an accumulator. Charging an accumulator of 600 mAh at C/5 or C_5, means charging it with a current of 120 mA.		

3.3. Derived units and measures

3.3.1. *Electric current density*

ampere per square meter	A/m^2	Used to characterize the amount of current flowing across a surface. This concept is used to size the section of cables.

3.3.2. *Gravimetric energy density*

Energy / mass	Wh/kg	Used to characterize the amount of available energy per kg of material

3.3.3. *Volumetric energy density*

Energy / volume	Wh/dm^3	Used to characterize the amount of energy available per liter of material (reminder: 1 dm^3= 1 liter)

3.3.4. *Solar panel maximum power*

Watt peak	Wp	Maximum power that a solar panel can deliver in optimum STC (Standard Test Conditions) lighting conditions.
These conditions are 1000W of light / m^2, i.e. a solar spectrum AM 1.5 and 25°C ambient temperature (sunlight at noon in temperate zones). It is considered that it takes 8 m^2 to produce 1 kWp, or 1000 kWh per year.		

3.3.5. *Surface power of solar radiation*

Irradiance	W/m^2	Power per unit area of the received solar radiation. This power depends on numerous criteria (geographical position, weather conditions, atmospheric diffusion, etc.).
The solar constant is the radiation power received by a $1m^2$ surface at a mean distance of $150x10^6$ km from the sun and outside the atmosphere. This constant is 1367 W/m^2.		

3.4. Abbreviations - acronyms

AIS: **A**utomatic **I**dentification **S**ystem
AUV: **A**utonomous **U**nmanned **V**ehicle
MPA: **M**arine **P**rotected **A**rea
AOT: Authorization to temporarily occupy publicly owned land (***A**utorisation d'**O**ccupation **T**emporaire*)
BMS: **B**attery **M**anagement **S**ystem
CCA: **C**old **C**ranking **A**mps (characterizes the cold start energy for a battery)
RME: **M**arine **R**enewable **E**nergies
GPRS: **G**eneral **P**acket **R**adio **S**ervice
GPS: **G**lobal **P**ositioning **S**ystem
MOC: **M**aintenance in **O**perational **C**ondition
MPPT: **M**aximum **P**oint **P**ower **T**racking
NMEA: **N**ominal **O**perating **C**ell **T**emperature
NOCT: **N**ational **M**arine **E**lectronics **A**ssociation
PV: **P**hoto**V**oltaics
PWM: **P**ulse **W**ith **M**odulation
STC: **S**tandard **T**est **C**onditions
UTC: **U**niversal **T**ime **C**oordinated

4. Available energy sources

The energy sources available to supply electric power to installations with electrical consumers are very diverse. The following concepts (technical functions) should be differentiated, although they are complementary:

- ✓ Storage of energy and release in electrical form to meet the requirements
- ✓ Supply of energy to consumers according to demand
- ✓ Supply of energy to storage devices for this energy, which are then considered as consumers

The user should look for the system that provides optimal gravimetric and volumetric energy densities in a given environment and conditions at a cost compatible with the available budget.

In this document, the following energy sources are described:

- ✓ Electrochemical cells and accumulators
- ✓ Solar energy
- ✓ Wind energy
- ✓ Tidal energy
- ✓ Fuel cells
- ✓ Wave energy
- ✓ Exploratory energies
- ✓ Storage of energy and release in electrical form to meet the requirements

At the end of the document, the combination of some of these different energy sources is presented.

5. Electrochemical cells and accumulators

5.1. Principle

The invention of the electric battery is attributed to the Italian physicist Alessandro Volta (1745-1827) who described the principle in March 1800. A pile of pairs of copper and zinc discs separated by paper or cloth soaked in saltwater [1].

A battery consists of two electrodes of different materials. When they are connected to an external electric circuit, a chemical oxidation reaction, releasing electrons, occurs on one of them (the anode) while a reduction reaction, absorbing electrons, occurs on the other (the cathode). For there to be exchange of electrons, the two electrodes are dipped in a conducting solution or gel. The battery provides this flow of electrons until the potentials of its electrodes are equalized.

5.2. Characteristics

Depending on its composition, a battery is rechargeable or not. In the first case, it is called an "accumulator" or "secondary", in the second case, the term "primary" is used. There is a wide range of batteries, depending on the electrode pairs and the electrolyte used. Some of the most common are:

- For primary systems (non-rechargeable):
  - Alkaline batteries ($Zn-MnO_2$);
  - Lithium batteries, with several types of electrolyte: thionyl chloride (Li-SOCl2), manganese dioxide (Li-MnO2) or sulphur dioxide (Li-SO2).
- For secondary systems (rechargeable):
  Lead-acid, Nickel-Metal hydride (Ni-MH), Lithium-ion (Li-ion), Lithium-polymer (Li-Po). Lithium-ion covers different technologies: Lithium-cobalt (Li-CoO2), Lithium-iron-phosphate (LiFePO4 or LFP), Lithium-manganese (Li-MnO2), etc. For Li-Po elements, the electrolyte is included in a polymer gel, which allows more flexibility in the form of the container to be used. Recently, Li-ion and Li-Po batteries doped with graphene have been developed.

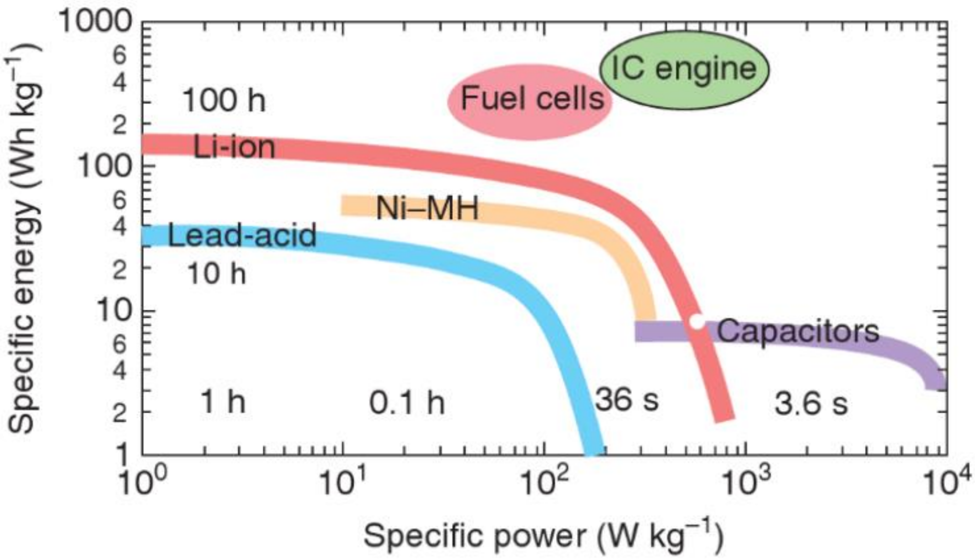
The output voltage of an element depends on the potential of the materials constituting its electrodes (see table below).

Table 1: Output voltage according to the materials used for the electrodes (for one element, at 25°C).

Materials	$Zn-MnO_2$	Pb-acid	Ni-Cd	Ni-MH	Li-ion	Li-Po
Voltage (V)	1.5	2.1	1.2	1.2	3.7	3.4

5.3. Sizing

A battery is characterized by the maximum voltage (in V) and current (in A) that it can deliver (these two parameters are often multiplied to give the maximum power, in W) as well as by its energy capacity (in Wh). When different technologies are compared, these values are often related to the mass of the element to produce a diagram called a *Ragone* plot (example below).



Ragone plot for different energy storage technologies. [3].

To obtain the correct voltage for a given application, the batteries can be connected in series. For example, for lithium-ion batteries, 4 elements in series deliver a voltage of 14.8V. To obtain the necessary intensity and energy, the precedent sets are connected in parallel.

In general, manufacturers provide three diagrams (established for different operating temperatures) allowing to target the product adapted to the application:

- The voltage as a function of time, for different values of the operating current;
- The capacity (Ah) as a function of the operating current;
- The self-discharge current as a function of time.

The following considerations may also help to choose the type of technology to be used:

- Alkaline batteries are the most economical, but are only suitable for applications that are not very demanding in terms of current, energy and temperature.
- Battery models exist with low self-discharge, which makes them more suitable for long-term usage.
- At equal mass, lithium elements have the highest energy capacity and lead elements have the lowest (see diagram). For the price, the order is the opposite.

Example of sizing

Consider a station, operating continuously, requiring a power supply of 12-15V and consuming 50 mA. We wish to use lithium-ion batteries with a unit capacity of 13 Ah. How many batteries would be needed for one year of autonomous operation?

To obtain the desired voltage, it is necessary to use packs of 4 Li-ion batteries connected in series (4 x 3.7 = 14.8V). The number of packs needed for a one year operation is determined by the electric load that will be consumed. This load is given by the following calculation: 0.05 A x 24 h x 365 d = 438 Ah, or 34 packs of 13 Ah, connected in parallel. The station must therefore be equipped with 136 batteries (34 x 4).

5.4. Rules of use

- An accumulator is recharged using a direct current, at a higher voltage than the one it delivers.
- Li-ion or Li-Po batteries require a precise charging voltage (4.2V). If a lithium accumulator is overcharged, it produces hydrogen, which usually results in overpressure, which can lead to an explosion. The same phenomenon occurs if it is short-circuited. Be careful of the consequences of a water intake in an underwater enclosure containing lithium batteries!
- Rechargeable lithium batteries must incorporate an electronic board, at least to control the charging and discharging of each of its constituent elements.
- It is useful to include a device for measuring the quantity of electricity delivered (coulomb-meter) to estimate the load balance of a system.
- Lead accumulators do not support deep discharges. The usable capacity of a lead battery is considered to be between 30% and 50% of its real capacity.
- Care should be taken when charging lead batteries as they release hydrogen.
- For a usage at large depths, lead batteries are able to operate in equipressure containers filled with oil.
- Above a certain amount, batteries or accumulators containing lithium are considered as "dangerous goods" and classified in class 9 (*Class 9 - Miscellaneous dangerous goods*). Consequently, they are subject to specific regulations concerning their packaging and transport, notably by air [5]. For example, lithium cells or batteries not contained in equipment are not allowed in the hold on passenger aircraft.
- For air transport, lithium cells or batteries must have successfully passed a series of tests using a procedure described in the document [5] (Part III, section 38.3) and at the end of which a certificate is issued.

5.5. References

[1] PIRE Bernard, “Pile de Volta”, *Encyclopædia Universalis* [online], consulted 8 June 2016. URL: http://www.universalis.fr/encyclopedie/pile-de-volta/

[2] B.B. OWENS, P. REALE, B. SCROSATI, “Primary Batteries: overview” in *Encyclopedia of Electrochemical Power Sources*, vol. 4, p. 22-27, ISBN: 978-0-444-52745-5, Elsevier B.V., Amsterdam, 2009.

[3] P. KURZWEIL, K. BRANDT, “Secondary Batteries – Lithium Rechargeable Systems: Overview” in *Encyclopedia of Electrochemical Power Sources*, vol. 5, p. 1-26, ISBN: 978-0-444-52745-5, Elsevier B.V., Amsterdam, 2009.

[4] FREDON ERIC*, Initiation au monde des accumulateurs rechargeables*, 3ème édition, 86 p., ISBN 978-2-9521383-4-5, Copy-Media, 2007.

[5] IATA, *Transport of Lithium Metal and Lithium Ion Batteries – Guidance Document, Revised for the 2016 Regulations*. https://www.icra2016.org/wp-content/uploads/sites/18/2016/04/lithium-battery-guidance-document-2016-en.pdf

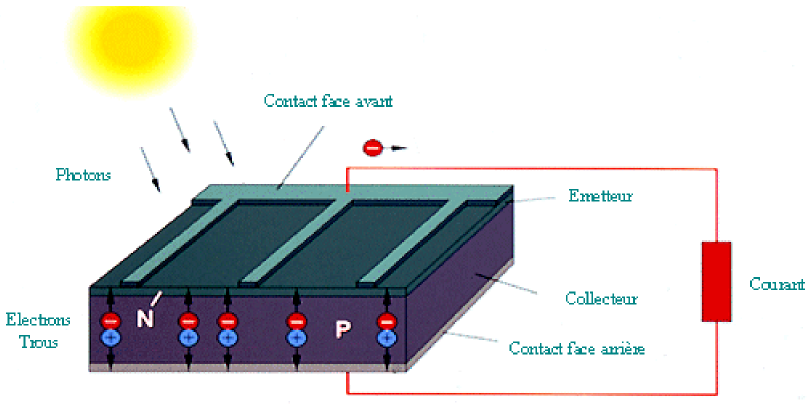
[6] UNECE, *Transport of Dangerous Goods - UN Manual of Tests and Criteria, rev. 5*. Ref. ST/SG/AC.10/11/rev. 5, United Nations, New York and Genova, 2009. http://www.unece.org/trans/danger/publi/manual/rev5/manrev5-files_e.html

[7] GROUPE RETEX, *Recommandations concernant le choix, l’intégration et l’usage de batteries Li-ion pour des applications sous-marines - v1,* Ifremer - DGA - ECA Group, 20/10/2016.

6. Photovoltaic energy

6.1. Principle

Photovoltaic solar energy is based on the conversion of sunlight into electricity or photovoltaic conversion, transforming the energy of photons into electrical energy through the process of absorption of light by a material. In this process, when a photon is absorbed by the material, it ejects an electron of a lower energy level towards a higher energy level, thus creating an electron-hole pair, and electrical energy. The doping of semiconductor materials creates a potential barrier that prevents the electron-hole pair thus formed by photon absorption from recombining, which would produce heat. Instead, the electric charge created can only flow through an external circuit, the receiver of the energy produced.



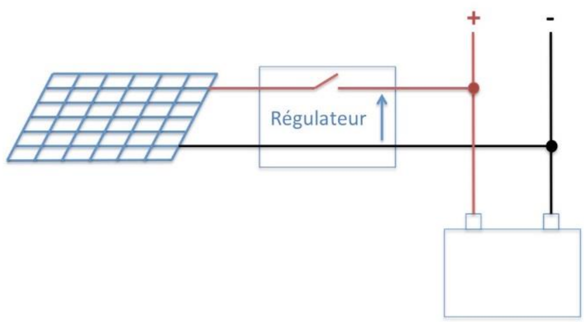
Working principle of a photovoltaic cell

6.2. Characteristics

Since photovoltaic production requires exposure to sunlight:
- Its use is limited to surface or very shallow applications: buoys, surface drones,
- Its intermittence requires an appropriate means of storage and restitution when a permanent energy availability is necessary.

A photovoltaic installation most often includes:
- one or more solar panels suitably combined (see rules of use),
- a voltage regulator,
- one or more storage batteries,

The following schema shows the simplified case of production of direct current:



<u>Cost of installation</u>:

The following is an indicative cost of the equipment:

100 € per solar panel of 0.18 m² (20W peak),

160 € for a lead battery of 12V and 40 Ah with electrolytic gel,

The price of the regulator is negligible.

The lifetime of such an installation is limited by the number of battery cycles.

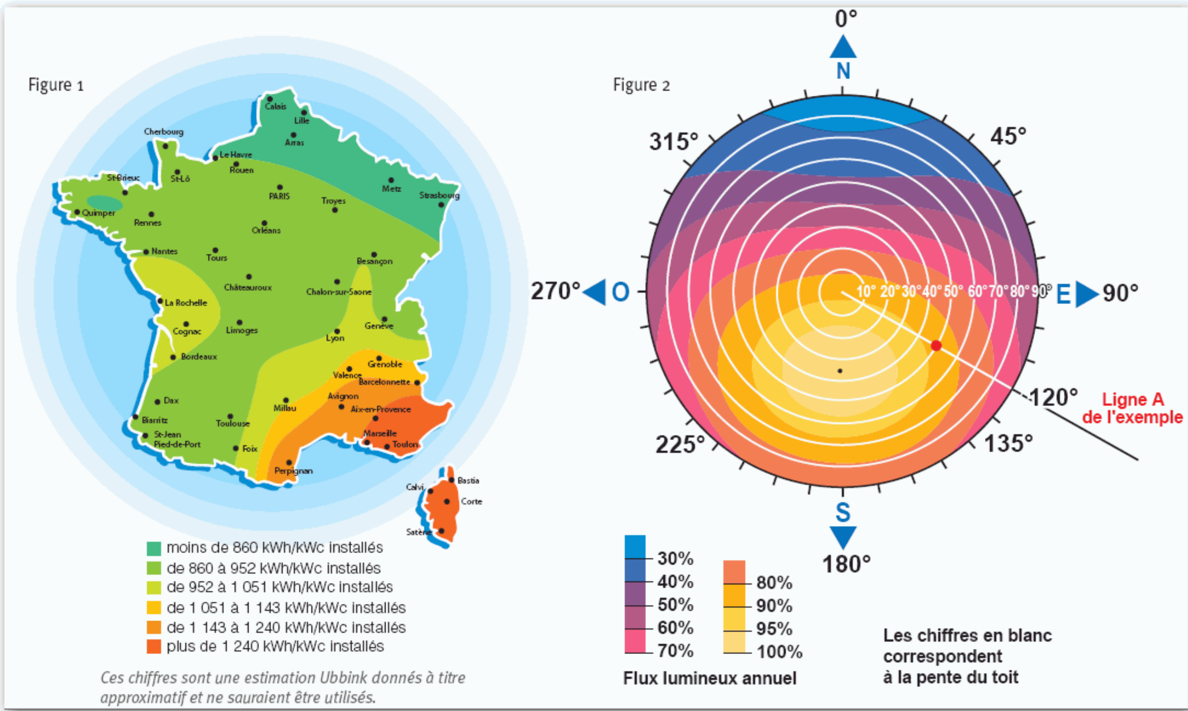
Cost of production:

Zero once the installation is done.

6.3. Sizing

To size a photovoltaic installation, the essential data are:

- the power of the equipment in use in kW
- the number of operating hours in hours/year
  - ⇒ the product of these values gives the energy consumed in kWh/year
- latitude and longitude of the installation
- orientation and inclination of the installation
  - ⇒ these data can be used to calculate the cumulative annual sunlight in kWh/m²
- on the basis of a kWh/m² produced for a Wp/m² of photovoltaic panel
- taking into account the different losses (inverter, cables, temperature, etc.)
  - ⇒ the number of kWp required for the installation is obtained and thus the surface



A simplified calculation method involves the determination of the electrical energy produced annually based on the performance of the solar panel and the sunlight.

$$E_{(kWh/an)} = S_{(m^2)} \,.\, rp_{(\%)} \,.\, H_{(kWh/m^2.an)} \,.\, re_{(\%)}$$

$E_{(kWh/an)}$: *énergie produite annuellement*

$S_{(m^2)}$: *surface des panneaux photovoltaiques*

$rp_{(\%)}$: *rendement des panneaux photovoltaiques* (5 à 20%)

$H_{(kWh/m^2.an)}$: *ensoleillement surfacique annuel*

$re_{(\%)}$: *rendement électrique de l'installation* (60 à 80%)

In the case of a freely rotating buoy, the sizing of the photovoltaic surface should take into account the *a priori* unknown azimuth of each panel. To maximize the chance of sunlight at a given time, diametrically opposed panels should be combined in parallel pairs, given that at best only one of the two will produce at any given time.

For example, the surface buoy of the EMSO-Azores observatory, located at 37°N - 32°W, is sized to remain autonomous in winter (short days and winter weather conditions reducing the average duration of sunlight). Under these conditions and taking into account the rotation of the buoy, we estimated the ratio of average power to peak power delivered by a panel at 1/20. To ensure an average production of more than 8W, the buoy is equipped with 8 solar panels of 0.18 m^2 and 20W peak each.

6.4. Rules of use

Inclination: the inclination should take into account the latitude. However, in marine applications, even at low latitudes one does not deviate too much from the vertical plane (about twenty degrees at most), in order to minimize the risk of soiling, and taking advantage of the radiation reflected by the seawater (backscatter radiation or albedo).

Disposition and combination of solar panels:
Depending on the desired voltage, combine in series the panels arranged on the same plane (same exposure, so same current produced at a given moment). In case of breakage of a panel, all the panels of the same electrical branch will stop producing. It may be useful to include spare branches.
Combine in parallel (with return prevention diode) the panels installed on different planes to maximize the chance of exposure of at least one branch.

Protection to be included:
From bird droppings: the installation of wires preventing birds from landing on the top of the panels provides effective protection.
From wave shocks: installation outside of the wave breaking zone. Include a wave-resistant support plane behind each solar panel, while maintaining an air gap of a few mm for ventilation.
From ship collisions: prevented by effective visual signaling (yellow color) and electronic identification (AIS).

PROS (extremely dependent on requirement)	CONS (extremely dependent on requirement)
• Absence of noise • Absence of pollution during use • Low maintenance • Zero production cost • Lifetime	• Intermittent production • Potentially significant exposure surface • Fragility of the exposed surfaces • Usage limited to surface applications

7. Wind energy

7.1. Principle

Wind energy is the **kinetic energy** of moving air masses around the globe. It is an indirect form of **solar energy**: the sun's rays absorbed in the atmosphere cause differences in temperature and pressure. As a result, the air masses move and accumulate kinetic energy. This can be transformed and used for several purposes:

- Transformation into **mechanical energy**: the wind is used to move a vehicle (yacht or sand yacht), to pump water (wind pumps for irrigation or watering cattle) or to rotate the grinding wheel of a mill.
- Production of **electrical energy**: the wind turbine is coupled to an electric generator to produce direct or alternating current. The generator is connected to an electrical network or operates within an "autonomous" system with a backup generator (for example an electric generator), a battery park or another energy storage device. A wind turbine is sometimes described as an aerogenerator when it produces electricity.
- **Onshore** wind turbines are installed on land.
- **Offshore** wind turbines are installed at sea, with floating or fixed solutions depending on site constraints.
- Two main types of wind turbine also exist: horizontal axis and vertical axis wind turbines. The latter are much less developed because of their lower performance.

7.2. Characteristics

The largest aerogenerators installed at sea can today achieve a power of the order of 8 MW, while the largest onshore aerogenerators provide about 2 MW.

Small aerogenerators for individual use inshore provide from a few kW up to several tens of kW. Small individual offshore wind turbines (yachts, buoys, etc.) provide several kW.

As an example, the horizontal axis wind turbines tested on our MOLIT coastal buoy provided a maximum of 300W for a rotor diameter of 1.2 meters. The gross cost of an aerogenerator of this category is about 2500€ (excluding taxes) and excluding the installation budget.

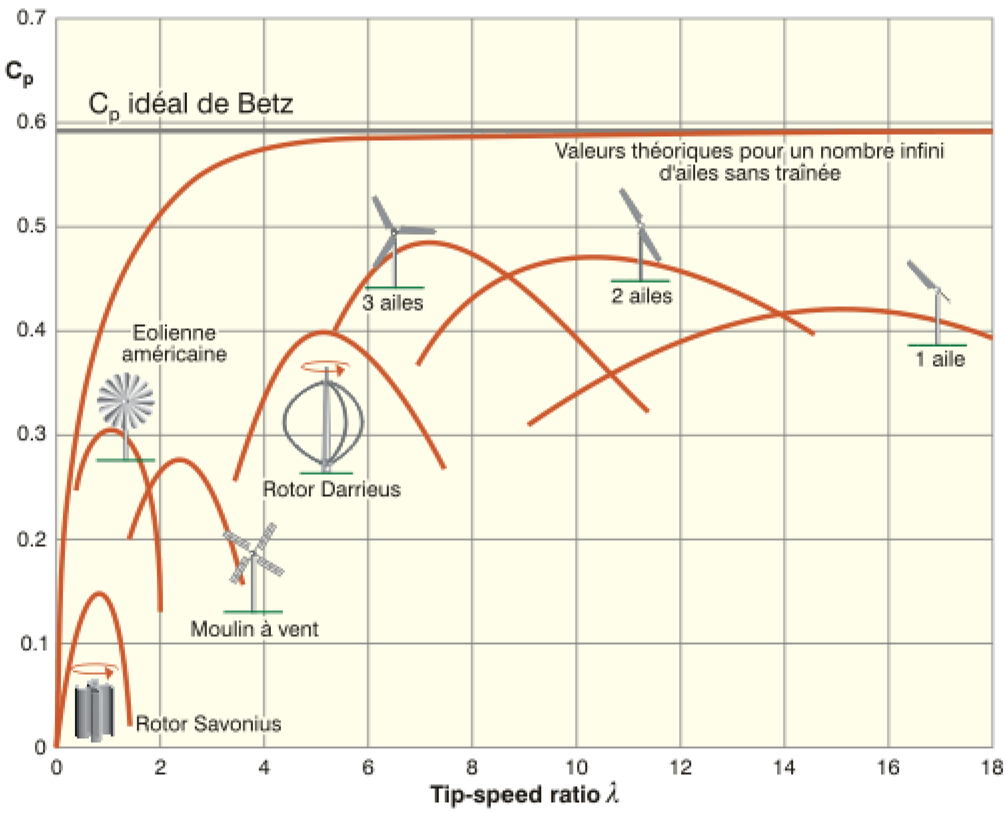
7.3. Sizing

The recoverable energy corresponds to the kinetic energy that can be extracted. It is proportional to the surface swept by the rotor and to the cube of the wind speed.

The recoverable maximum power (P) is given by the law of Betz:

$$P = 0.37 \times S \times V^3$$

where 0.37 is the constancy of air at standard atmospheric pressure (1013 hPa), S is the surface swept and V is the wind speed.



Aerodynamic performance as a function of tip-speed ratio and the wind turbine model

7.4. Rules of use

We will focus here on low power onboard wind turbines; marine applications

<u>Positioning:</u> The machine should be installed in such a way that the wind is not disturbed by the structure.

Precaution: A system should be planned for maintaining and stopping the rotor when working on the platform or on the machine itself. Particular attention should be paid to the immediate environment of the rotor in operation because of the danger represented by a blade hitting an individual.

Protection: Horizontal axis wind turbines do not support overspeeding, Therefore, it is necessary to equip the machine with a rotation overspeed limitation system for high wind speeds. Note that some wind turbines have blades that automatically retract in case of overspeed. Most of these aerogenerators have an upper speed limit of about 25m/sec.

Support buoy or platform: The feedback from the MOLIT buoy in the Bay of Vilaine (coastal area) has shown that the important mechanical constraints generated by the float's accelerations made the stability of a "standard" wind turbine very limited in time. This is why the energy production with a horizontal axis wind turbine was abandoned. It should be noted in this regard that the "*Phares et Balises*" (Lighthouses and Beacons: organism responsible for all coastal buoys with French signaling) only install aerogenerators on fixed turrets. Only some very large size buoys with mostly heaving motions can be successfully equipped with horizontal axis wind turbines.

PROS (small offshore wind turbine)	**CONS** (small offshore wind turbine)
• Product available commercially at a medium cost • Energy completely carbon-free • Reliability of common usages (yachts) • Low noise in normal operation • Zero production cost	• Intermittent production: depends on the strength and regularity of the wind • Relatively low performance • Potentially high maintenance • Startup with wind speed of 3m/sec • Operation stops if wind speed exceeds 25m/sec • Potential damage from collisions with birds

8. Tidal energy

8.1. Principle

Launching of the second Naval Energies/OpenHydro tidal turbine in May 2016

Tidal turbines or hydrogenerators are used to transform the kinetic energy of marine currents into electricity. The movements of the sea are an inexhaustible source of energy. There are three main ways to capture this energy:

- ✓ transformation of the kinetic energy of marine currents, particularly of the tidal currents found near the coast, in the case of the water turbines discussed here;
- ✓ use of the potential energy linked to the tidal range (difference of level between high and low tide) by tidal power stations like the one on the Rance river;
- ✓ exploitation of the energy of waves resulting from the wind on the surface of the seas (known as wave power).

Tidal turbines are a sort of underwater wind turbine. A tidal turbine exploits the flow of water to generate electricity. The generated mechanical energy is converted into electricity by a dynamo or an alternator.

8.2. Characteristics

A tidal turbine is a submerged wheel with blades, or a propeller, that is rotated by the relative velocity between a mass of water and the propeller. The propeller drives an alternator that generates a current. The propeller shaft and its alternator are inserted in a fairing to improve the hydrodynamics and protect the system from aggressions of the marine environment (waterproofing, shocks, etc.). On some models, the system has the capacity to adjust the rate of the blades depending on the battery charge and the velocity of the water flow.

8.3. Sizing – Energy efficiency

The kinetic power of a fluid passing through a disc is proportional to its surface area, and thus to the square of its diameter, to the volumetric mass density of the fluid and to the cube of its velocity.

In practice, the fluid stream widens in the vicinity of the blades of the turbine, which reduces its velocity. The power harvested is thus limited to 60% of the theoretical power. The machine losses linked to friction and to the conversion of mechanical energy into electrical energy must also be deducted, which leads to an overall efficiency of 40 to 50%.

For a tidal turbine placed in a current of 2.5 m/s, if we wish to obtain a power of 1 MW, an interception surface of the order of 300 m^2 is needed, corresponding to a diameter of 20 meters. The demonstrators currently being developed are equipped with turbines whose diameter is between 10 and 20 meters, the latter size corresponding to an upper limit given the technical production constraints (mass of the rotating system and interfering torques due to the turbulences in the flow).

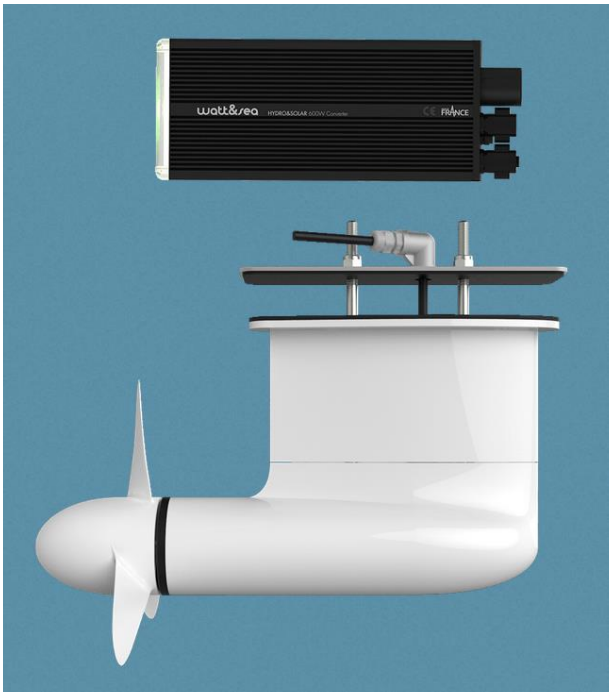
8.4. Issues relative to energy

Unlike winds, marine currents are predictable in the long term since the tidal current turns regularly following a sinusoidal curve, with known amplitudes that vary with the moon. When the current turns, the turbines no longer produce energy until the strength of the current reaches about 2.5 knots again. They attain full power above 4 knots.

The annual global performance expressed in hours of operation at full power is of the order of 4000 to 5000 hours, or 11 to 14 hours per day. The load factor of the turbines therefore reaches 46 to 57%, compared with the average 30 to 35% for offshore wind turbines.

Tidal turbines are much smaller than wind turbines (by a factor of 3 to 4) for the same power because the density of water is about 800 times higher than that of air, even though the velocity of the current is 3 to 4 times lower than that of the wind on the selected sites. Also in comparison with wind turbines, the impact on the environment of tidal turbines is low because they have a small visual signature. In contrast, the investment and operating costs associated with the marine environment are higher (of the order of twice those of wind turbines, for the same installed power). The assessment of the economic interest of tidal turbines can only be established based on feedback over a sufficient period of time.

The dimensions and masses of these tidal turbines are incompatible with the capacity of autonomous stations. Low power (<1kW) systems called hydrogenerators are available on the market that operate on the same principle as tidal turbines. On the monohulls of the Vendée Globe race, one or two of these devices are mounted on the transom near the rudders: the water flow is accelerated in the vicinity of this part of the boat. These devices have the major drawbacks of slowing the boat due to the system’s drag and of being sensitive to any objects found near the surface (algae, waste, wrecks or different types, etc.). On the boats, retractable arm systems exist but the risk of breakage remains high.



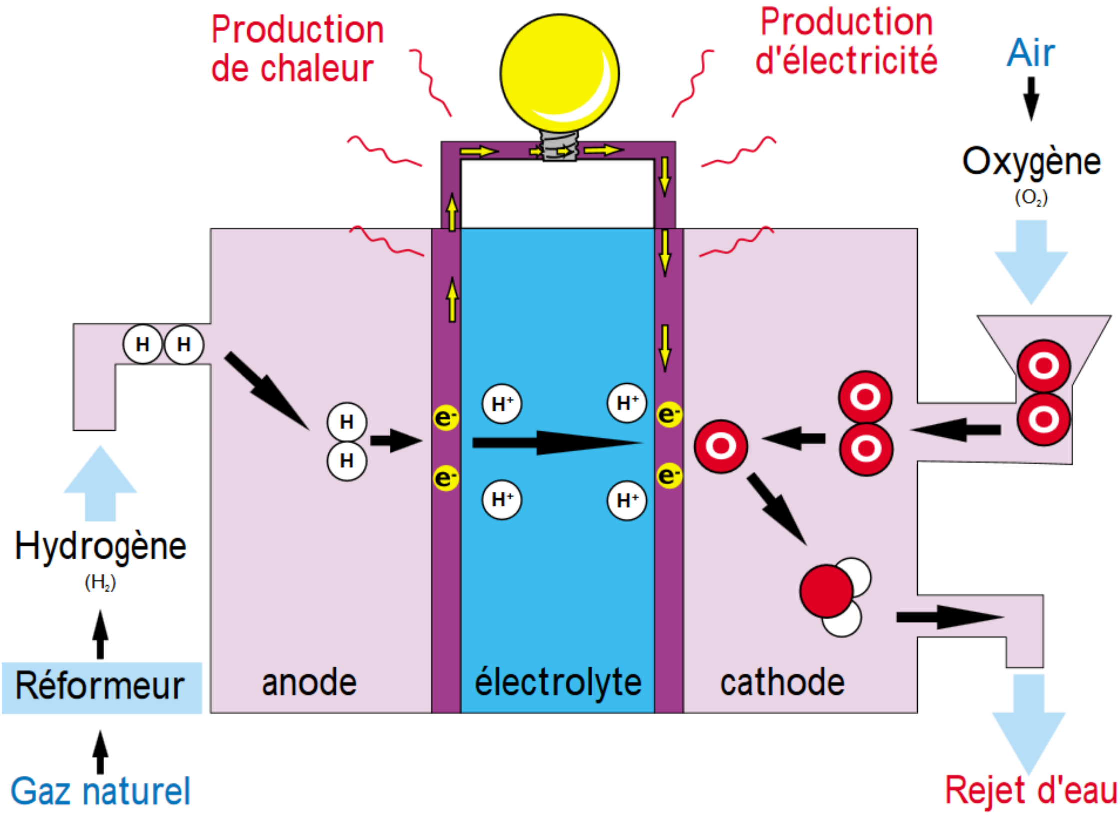
The Watt&Sea company, based in La Rochelle, is a pioneer in the development of these hydrogenerators. The power of their "Racing" model increases with the cube of the velocity. This type of device can generate about 100 Watts at 5 knots of current and, according to the manufacturer, the power output can reach 500 W at 10 knots of current.

PROS	CONS
• Technical principle well understood • High energy potential • Vertical axis propeller systems are effective regardless of the orientation of the current • High power systems under development	• Alternating nature of sea currents reduces efficiency • Few products on the low power market • High risks of collision with unidentified floating objects • Main rotating part remains fragile • Mechanism for alignment of the rotor in the direction of the current is additional • Efficiency is reduced in the presence of fouling

9. Fuel cells

9.1. Principle

The fuel cell is a process discovered in 1839 by the Englishman Sir William Groove. The technique is relatively simple: electricity is produced through oxidation of a **reduction fuel** (pure or compound hydrogen) on an electrode coupled to the reduction of an **oxidant**, such as the oxygen in the air, on the other electrode. The hydrogen oxidation reaction is accelerated by a platinum catalyst.



Operating principle of a fuel cell

On the anode, the combustion reaction of the hydrogenated compound (H_2, CH_3OH, C_nH_m, etc.) produces H^+ ions and electrons. On the cathode, the oxidation reaction of H^+ ions produces pure water. A cell using pure hydrogen releases very little water. In contrast, a fuel cell using methanol releases water and carbon dioxide.

If the oxygen in the air is, in a non-submerged situation, by definition ubiquitous, the reduction fuel is more problematic to use because pure hydrogen does not exist in a natural form. It must be produced and stored, which are costly and sometimes dangerous operations. The hydrogen compounds (methanol, methane, etc.) are more easily manipulated.

9.2. Characteristics

The known technologies can theoretically be used to produce a wide range of requirements;

- ✓ Mobile batteries; portable systems for backup electricity generation (a few W),
- ✓ Onboard batteries; for land, marine vehicles, etc. (a few kW),

- ✓ Stationary batteries; combined production of heat and electricity, to replace emergency electric generators (a few MW).

Despite the low performance, methanol technology is the most widely used because the fuel is easy to use and not very dangerous. The devices already commercialized successfully meet the needs of a series of surface applications, either fixed or mobile, although the economic and ecological cost remains high.

- ✓ Cost of watt produced ≈100€ for low power
- ✓ Cost of methanol 50€ for a 10 liter can
- ✓ Consumption of 0.9 to 1.2 liters/kWh
- ✓ Average production of 1 to 2 kWh / 24 hours

Methanol fuel cells can be used to charge batteries fully automatically. The startup can be done on a low battery voltage information and vice versa, the high battery voltage information stops the charge. It is also possible to connect devices directly via regulators or inverters.

9.3. Sizing

The sizing of a fuel cell is performed as for any source of electrical energy. The basic data is the required amount of electrical energy (in Ah) for operation of the installation. This data is generally presented as the average daily requirement (Wh/day). As in most cases, a fuel cell is inserted into a circuit as a backup electrical generator, the electrical energy consumption overloads are handled by the battery park.

The commonly provided characteristics of fuel cells, correspond to an operation at maximum power. As for an electric generator, the amount of electrical energy produced annually should be adjusted depending on the number of hours of use and the charge rate. In operation, it is normal to use a fuel cell at $80^{\pm 5}$% of its maximum capacity.

9.4. Rules of use

The modern and quiet technology of the fuel cell is attractive but still expensive. It has the disadvantage of poor performance and uses a liquid fuel whose storage has to be secured. This technology is tempting on a buoy as a source of backup energy in addition to more traditional energy sources (solar, wind, etc.).

The installation of a methanol fuel cell implies respect of the following rules:

- ✓ protected and dry location, having a reasonable list
- ✓ the methanol container should be installed less than 30 cm away
- ✓ good air intake and air without sea spray
- ✓ good air evacuation, since the process generates heat
- ✓ the amount of water produced as waste is low, but requires a drainage
- ✓ greater distance from batteries implies respecting the cable sections

In the submerged version, tests were conducted on autonomous AUV type vessels. The installation of pressurized cylinders (type B200) containing hydrogen and oxygen results in a prohibitive mass density for an autonomous vessel. Some technical functions, such as effluent discharge (condensates) pose problems of vessel equilibrium.

PROS	CONS
• Compact system • Absence of noise • Absence of pollution in use • Low maintenance as few moving parts • Fully automatic • Startup assured with low voltage batteries • Production possible in addition to wind and solar power	• Use of a specific fuel • Currently not widespread outside Europe • Electricity production relatively low • Incomplete recharge (idem alternator) • Produces essentially 12V • Positive temperature for startup • Commercial versions limited to 3 kWh

10. Wave energy

10.1. Principle

Wave energy refers to the production of electrical energy from the swell or from a successive wave field arising from the effect of the wind on the surface of the sea and sometimes propagated over very long distances. Various devices exist to harness this energy. Many systems are currently being studied and concern powers of several hundred kilowatts. Some are already commercialized, although none have reached the stage of industrial maturity.

10.2. Characteristics

There is a large inventory of wave energy solutions, some of which are submerged, while others are installed on the surface, either on the shore or offshore. Energy capture systems vary from one prototype to another: capture of mechanical energy on the surface (ripples) or under water (translations or orbital movements), capture of pressure variations from the passage of waves (variations of water height) or even physical capture of a body of water (via a retention).

Existing or studied processes for autonomous surface or submerged stations can be classified into six main systems.

10.3. Examples of use (www.connaissancedesenergies.org)

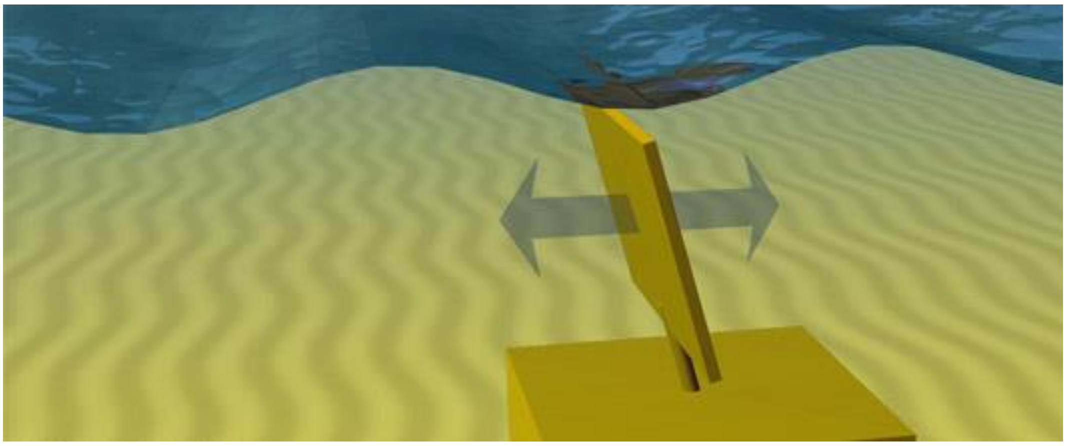
10.3.1. Articulated floating chain

System consisting of a series of long floats that align in the direction of the wind perpendicular to the waves and whose head is anchored to the sea bed by a cable. The waves create an oscillation of the chain. This oscillation is exploited at the articulations to compress a hydraulic fluid, which in turn drives a turbine. This is the most well-known method for harnessing wave energy.

The articulated floating chain system generally has more than two parts - Pelamis structure with a power of 750 kW. It is composed of five articulated floats, weighs 1350 tons and has an overall length of 180 meters for a diameter of 4 meters.

10.3.2. Submerged oscillating wall

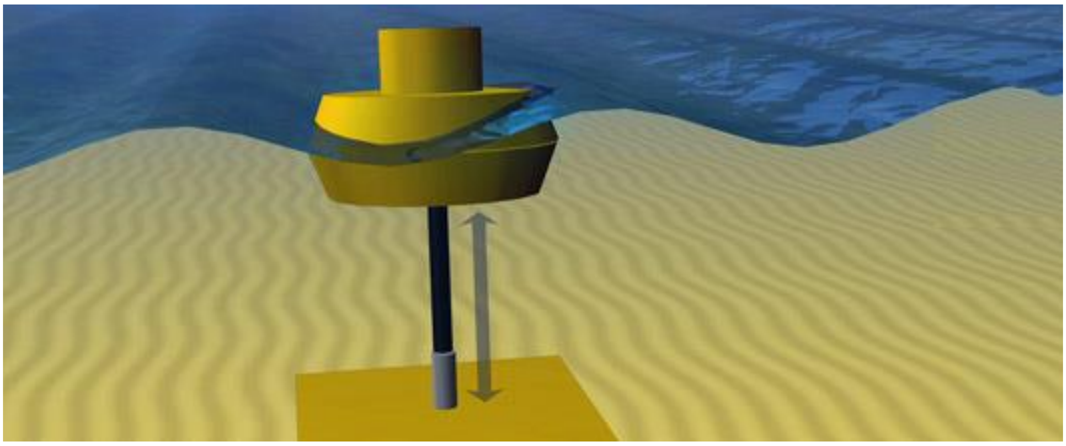
Pivoting system driven by the orbital motion of water during the passage of the waves. These oscillations activate pumps that compress and turbine a hydraulic fluid.



Submerged oscillating wall - Oyster prototypes, developed by Aquamarine Power and tested in Scotland.

10.3.3. Vertical oscillation column

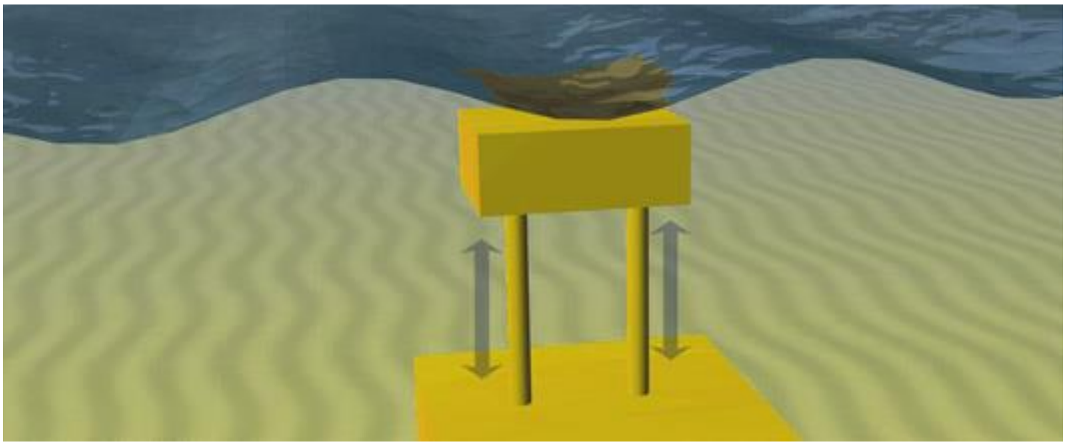
Floating structure installed on the surface of the sea, transforming all horizontal or vertical movements into displacements of weights (elements using centrifugal force to create work). The energy associated with the moving weights is used to drive a pump and put a hydraulic fluid under pressure, which then makes it possible to rotate a turbine that in turn drives an alternator. A possible variant directly uses the displacement to drive the alternator.



Vertical oscillation column - Wavebob, under development since 1999 and tested in Ireland since 2006.

10.3.4. Submerged pressure devices

System anchored to the sea bed that uses the orbital motion of waves to compress a hydraulic fluid. The simplest device to use is a balloon. It is possible to build a network of devices and collect the compressed fluid onshore where it is turbined to produce electricity.

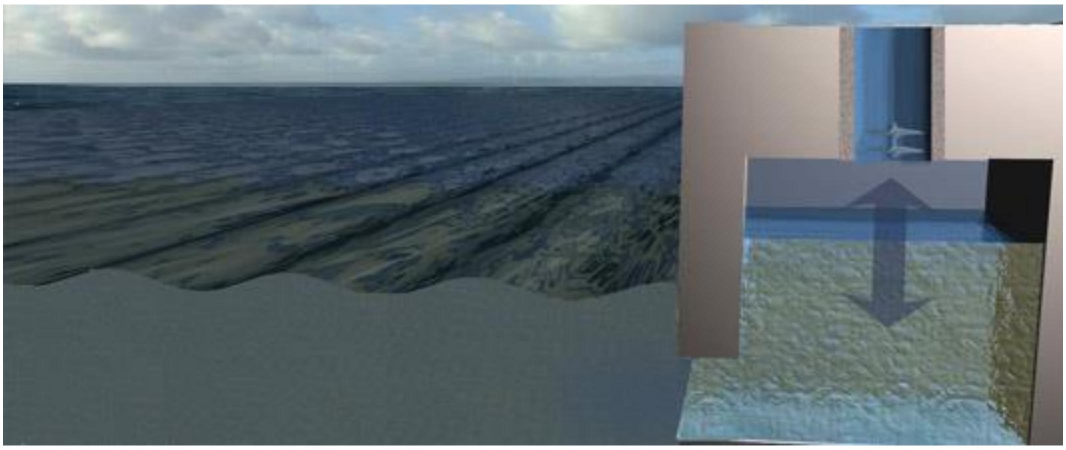


Submerged pressure device - CETO prototypes, developed by Carnergie in Australia.

The following systems contain fewer moving mechanical parts, which can contribute to improved reliability.

10.3.5. Water column

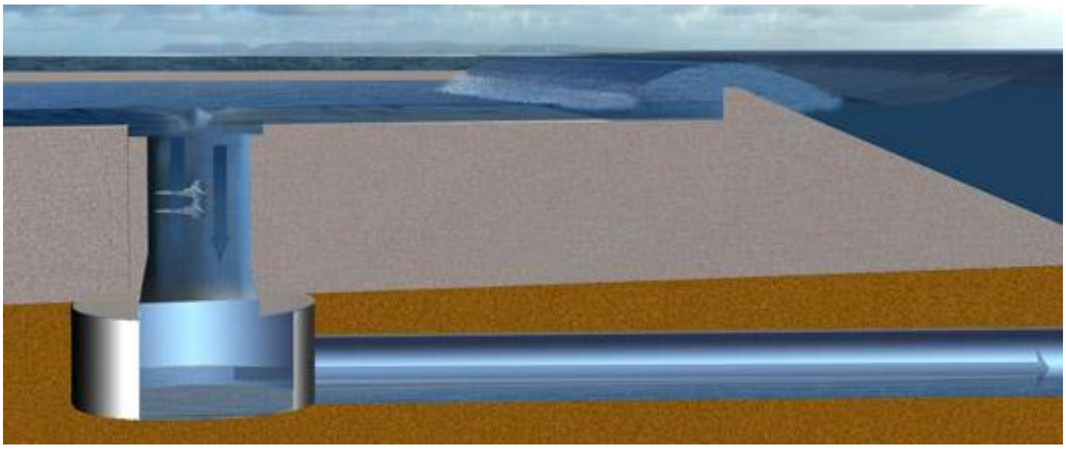
Floating structure of steel or concrete, open at the base and closed on the top. The waves raise and lower the water level in the column. This has the effect of alternately compressing and decompressing the air trapped in the upper part of the column. The air then drives a bidirectional turbine to produce electricity. The system can be installed offshore or on the shore.



Water column - Oceanlinx prototype developed in Australia, with a power of 450 kW

10.3.6. Surge trap

Overtopping system that retains water from the crests of waves, creating overpressurization in the tank. The trapped water volume is turbined.



Surge trap - SCG (Slot-Cone Generator) by Wave Energy, tested in Norway.

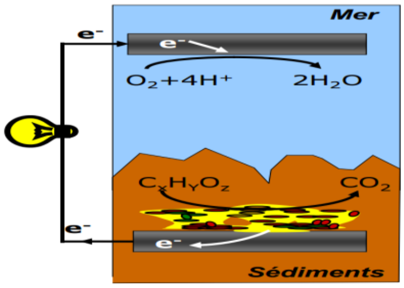
This system underwent improvement/adaptations by a French company in order to permit its integration on a surface buoy. The oscillations of the float allow small amounts of water to gain in potential energy while moving away from the axis of revolution of the buoy. Once the highest level is reached, the water is directed to the central point, where a turbine is located. We have no quantitative results concerning the energy recovered by this system.

PROS	CONS
• High energy potential	• Development not fully mature • Resistance to harsh marine environment • Requires a strong anchor point • Moving mechanical parts • Mostly coastal applications

11. Exploratory energies – benthic microbial cell

11.1. Principle

The benthic microbial cell has the advantage of being of simple and robust design. Indeed, this battery uses metabolic mechanisms that exist naturally in the benthic zone of a sedimentary environment. The bio-anode uses the electro-catalytic properties of the living microorganisms in sediments, while the bio-cathode exploits those of aerobic microorganisms present in the surrounding water.



Operating principle of a microbial cell

A potential difference is established naturally between the two bio-electrodes thanks to the electro-catalytic activity of micro-organisms and the redox reactions of the two media formed by the sediments and the surrounding water.
This potential difference allows the generation of an electric current in the battery.

11.2. Characteristics

Benthic microbial cells have a relatively low production cost because the principle elements, the electrodes, are made of cheap industrial materials such as graphite or stainless steel.

The maximum power that can be recovered from this type of cell is between **10 and 30 mW/m²**, depending on the electrode surfaces implemented.

The main limitations of the sedimentary microbial cell are the low power and voltage generated, respectively of the order of a few mW at 100 mV. The cells presented in the literature cannot therefore provide a high enough voltage or current to power an electronic function directly, even of low power consumption, without electronics for management of the intermediary energy. **In this context, an ANR project (RECIF) was submitted in 2015 by the LGC, the CEA and Ifremer.**

11.3. Sizing

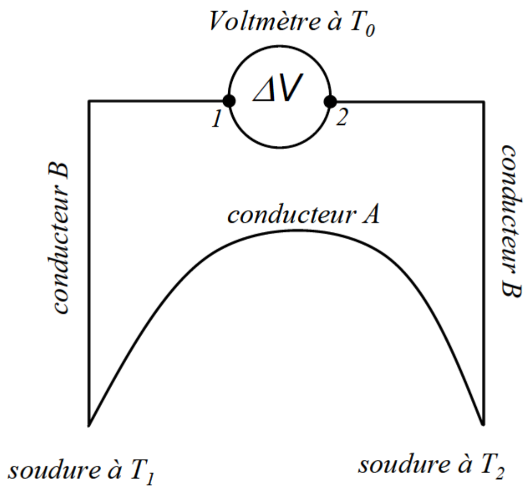
The key point limiting the power output from a benthic battery is the concentration of bio-available organic matter in the sediments.

PROS	CONS
• System supplying energy from a sediment • Numerous potential operating locations • No mechanical parts	• Very low energy production (≈100mW/m²) • No feedback on sustainability of the technology (depletion of the sediment) • Unpredictable production

12. Exploratory energies – thermoelectricity

12.1. Principle

Two conducting materials of different kinds A and B are linked by two junctions located at the points T_1 and T_2. In the case of the **Seebeck effect**, a temperature difference dT is applied between T_1 and T_2, which causes the occurrence of a potential difference dV between 1 and 2.



Basic mounting of thermoelectricity

12.2. Characteristics

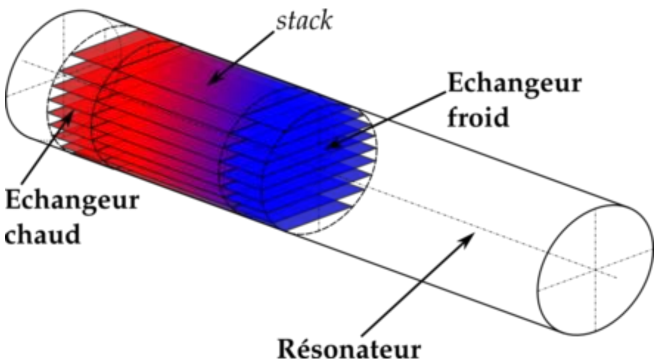
The characteristics of thermoelectric systems are extremely varied, depending on the selected pairs of material and the environmental constraints sought. Each material has in fact its own Seebeck coefficient.
The difficulty is to find a pair of materials that support the working temperature, while being highly electrically conductive and poorly thermally conductive.
Each pair of materials provides a potential difference (µV to a few mV) depending on the temperature difference to which it is exposed.
Thermopiles are used in spacecraft (Voyager probe) where it is possible to exploit high temperature differentials (several hundred degrees).
The performance of a thermoelectric generation system is of the order of 2 to 3% before electrical conversion.

PROS	CONS
• Production potentially useful for seafloor observatories • No moving parts	• Needs to be close to hot water sources • Radiators need to resist corrosion caused by hydrothermal sources

13. Exploratory energies– thermo-acoustics

13.1. Principle

The simplest thermo-acoustic machines incorporate an acoustic resonator, inside of which is disposed either a porous structure or a stack, with heat exchangers at their ends. The temperature difference at the ends of the stack, maintained by the two heat exchangers, gives rise to the acoustic wave in the resonator.



Typical thermo- acoustic generator (®wikimedia)

A sound wave source/receiver is most often used to provide an electromechanical conversion of the acoustic power maintained by the resonator (source wikipedia).

13.2. Characteristics

PROS	CONS
• System providing energy from a temperature gradient	• The gradient must be important, such as on hydrothermal sources • Generation of noise on principle

14. Combination of these energy sources

14.1. Some common configurations

14.1.1. Charge controller

The charge controller can be used to associate all the energy generating elements, the storage elements of this energy and the consumers. It is therefore a casing with electronic components used to stabilize and control the charging and discharging of the battery, by ensuring that it is maintained in a nominal operating range. More technologically advanced products also allow management of the global energy capacity by starting or stopping backup production sources. It is possible to take into account degraded situations (polarity inversions, short circuits, deep discharges, etc.) depending on the technology chosen and the complexity of the charge controllers. It is strongly recommended to record the temporal monitoring of this management of the electrical production and consumption.
Several battery charge controller models exist. The technologies allowing an optimal yield of the produced energy, at the same time ensuring the safety and longevity of the batteries are:

- the controller of type PWM *(Pulse With Modulation)*
- the controller of type MPPT *(Maximum Point Power Tracking)*

14.1.2. PWM type controller

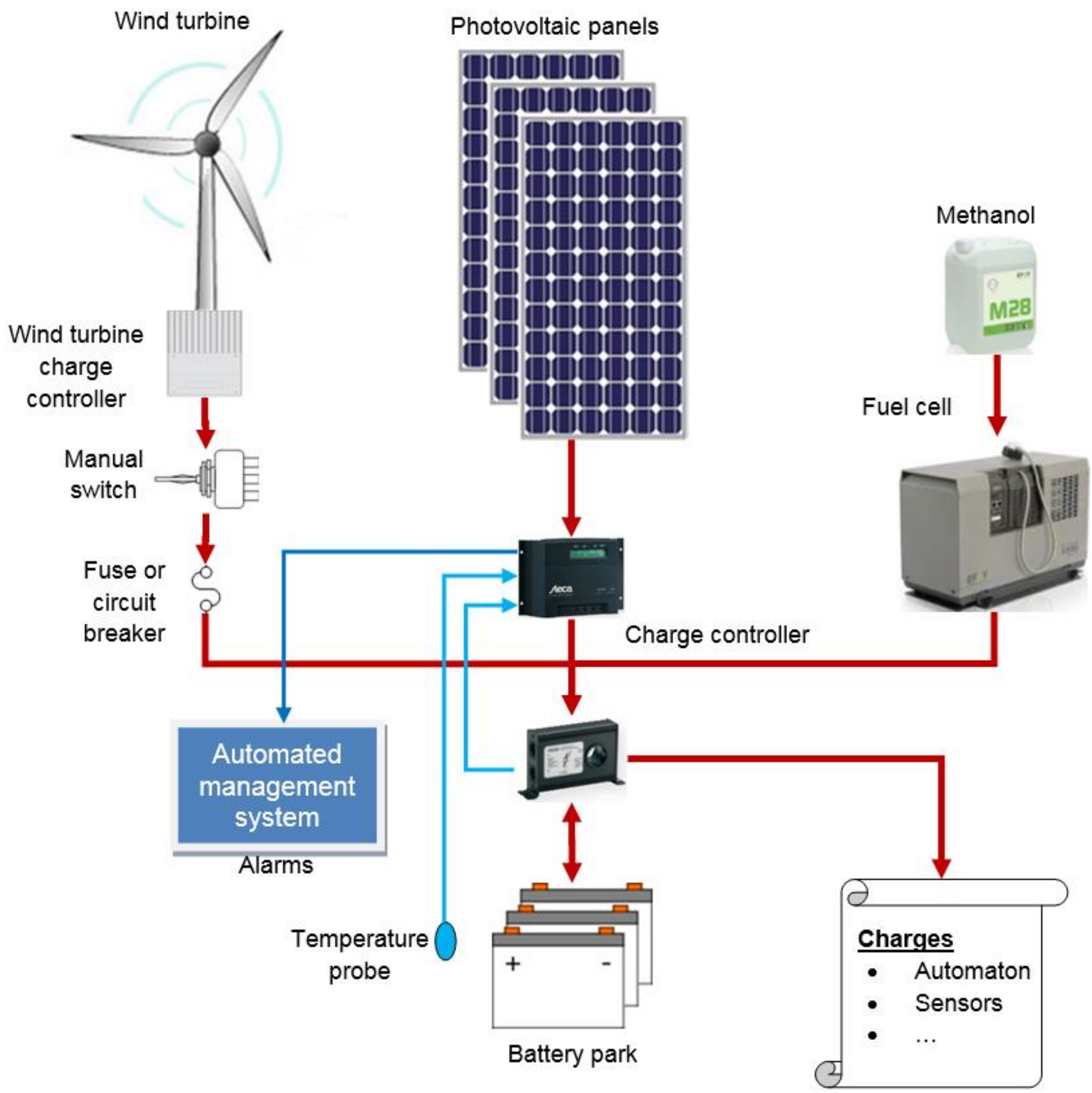
PWM technology, or in French "*Modulation de Largeur d'Impulsion*", is a very effective method to modulate the frequency and duration of the current pulses sent. The PWM controller thus allows the 100% total recharge of a solar battery, while the older systems called "shunt" only partially restored the battery by opening the circuit at the end of the charge in order to divert the energy which could not be stored.
The PWM controller is piloted via a high-performance integrated microprocessor. It continuously checks the battery charge state to adjust the duration and frequency of the current pulses to be delivered (long and frequent current pulses for maximum and rapid recharging, then short and less frequent pulses). This PWM technology thus reduces the sulphation of the conductive plates, since the charging current of the battery is pulsed at high frequencies.

14.1.3. MPPT type controller

MPPT technology, or in French "*Recherche du Point de Puissance Maximum*", is currently the most effective method and outperforms PWM technology. This type of controller is certainly more expensive to purchase and should only be used in the search for the absolute optimization of an installation.
A conventional controller, such as the PWM controller, merely supplies the battery at a voltage equal to that of the battery according to its charge state, i.e. 13.2 volts at its maximum charge and close to 11.7 volts when the battery is discharged. The MPPT controller offers the advantage of taking into account the voltage delivered by the energy producer (> 13.2 volts) regardless of the state of the battery, thereby increasing the charging speed by optimizing the current characteristics. Integrated software controls the variability of the characteristics in order to optimize the charging of the battery.

14.1.1. Typical configuration

Schema provided as an example



Combination of energy sources –SIMEO project by NKE

14.2. Coastal buoys

The combination of different energy sources is a typical configuration for coastal buoys. Accumulators (secondary systems) are used systematically. The production of offshore energy is achieved mainly by photovoltaic panels. This combination covers most environmental conditions in our latitudes and even more so in lower latitudes. At high latitudes, backup sources of energy production may be necessary in some conditions (recurring bad weather, low daytime duration).

The use of wind turbines on buoys is complicated. The platform motions seem to be incompatible with the lifetime of the rotating elements. Configurations based on fuel cells have been used with good feedback to compensate for a recurrent lack of sunshine. Similarly, the mounting of an electric generator can be considered as an occasional and emergency source of energy. Tidal and wave power systems do not yet have a sufficiently high TRL for use on this type of buoy.

14.3. Oceanic buoys

The observation made for coastal buoys is also true for ocean buoys except for the use of the electric generator that is not pertinent. Since the intervention capacity for curative or preventive maintenance is much lower due to the distance from the coast, the guarantee of having sufficient and sustainable electrical energy is an essential performance criterion.
A detailed and comprehensive analysis and in situ simulations of energy production covering the normal, probable and exceptional conditions, remain to be done. Designers should base their approach on validated and recorded data over long periods (sunlight spectra, wind spectra, wave spectra, etc.). The conditions under which the system will have to operate in degraded situations should be defined.

14.4. Non-cabled observatories

Non-cabled observatories are essentially electrically powered by batteries (primary systems), the latter having a greater mass capacity than rechargeable accumulators. Some providers have offered seafloor stations connected to wind turbines. No publication exists to date on the subject.

14.5. Autonomous stations

The observation made for non-cabled observatories is true for autonomous stations.

15. Establishment of a consumption report

15.1. Prerequisites for the energy provider

The voltage(s) available at the level of energy distribution should be specified.

15.2. Prerequisites for the consumer

15.2.1. *Configuration*

The consumption report can provide for the installation of numerous sensors without necessarily realizing the installation in a sustainable way. The configuration of a sensor has two possible exclusive states:

$$\left.\begin{array}{l}\text{Consumer in service} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)\\ \text{Consumer out off service} \ldots\ldots\ldots\ldots\ldots\ (0)\end{array}\right\}\ \text{Flag}$$

15.2.2. *Operating mode*

The consumption report should specify the operating mode of the sensor, the latter generating very different consumptions. The operating mode of a sensor has 4 possible exclusive states:

Standby consumption .... C_3
Warmup consumption .... C_2
Operating consumption .... C_1
Off consumption .... C_0

Consumption in mA

In addition to these operating modes, the daily activity time in each of these modes should be specified as well as the number of cycles per day.

Standby duration .... t_3
Warmup duration .... t_2
Operating duration .... t_1
Off duration.. t_0

Duration in seconds /

The number of cycles performed by the sensor corresponds to the daily recurrence periods t_0+ … +t_3.

Number of cycles .... (Nc)

Number per day

15.2.3. *Electrical consumption of the sensor*

The following product provides the electrical energy consumed by the sensor in one day.

$$E_{capteur_{(mW.s/jour)}} = Flag \times U_{capteur} \times \sum_{i=0}^{i=3} C_i \, . \, t_i \times Nc$$

To obtain the electrical energy consumed by the sensor during the mission, the daily consumption should be multiplied by the total number of days of the mission.

$$E_{capteur_{(W.h)}} = N_{jours} \times E_{capteur_{(W.s/jour)}} \times (3{,}6 \, . \, 10^6)^{-1}$$

15.3. Supply voltage

The supply voltage of a sensor may be different from the voltage available at the level of the energy distribution system. A voltage converter is therefore required. This converter is regarded as a consumer in the global electrical report. The normal electrical performances of these converters are of the order of 50% in standby mode and 80% in normal operation. To be more comprehensive, the reader should contact the supplier of these converters in order to obtain the exact operating curves (current vs. performance).

15.4. Global consumption report

This method should be repeated for each consumer. The sum of the consumed energies gives the global consumption of the installation except for internal losses (Joule effect, Foucault current, etc.). An example of a consumption report is given in appendix 3 below with the following differences:

- Only 2 states have been considered: active and standby state for each consumer
- Operating durations and periods have been given in minutes

The method is the same.

15.5. Uncertainties

In practice, it is customary to assign to a total amount of energy consumed, a multiplying coefficient that provides a "safety margin" covering all the uncertainties, errors and/or omissions.

Another solution is to ensure that the uncertainties are assessed case by case for each consumer. In the consumption report, the calculation of electrical energy consumption for each element can be weighted with its own uncertainty. These weights per element combine the following uncertainties:

15.5.1. Uncertainties about the consumptions

The uncertainties about the consumptions can be defined for each operating mode in a standardized way (example ±5%). If these consumptions were verified by measurement, this information should be preferred and the uncertainty can then be reduced or removed. The uncertainties about the consumptions may be due to specific environmental conditions (pressure, temperature, etc.) or in the case of actuators to efforts that are difficult to assess.

15.5.2. Uncertainties about the durations

The sequencing of different consumers can induce modifications in the operating time of a particular consumer. These uncertainties are usually minimal.

15.5.3. Uncertainties about the transients

The transient phenomena that accompany the change of state (for example, off mode to operating mode) of a consumer are quite difficult to assess. These uncertainties correspond to the overconsumptions observed during the powering of a circuit, which are generally low for a sensor but are not negligible in the case of a capacitive actuator.

The sum of the uncertainties by consumer then determines the global uncertainty of the consumption report.

16. Conclusion

On-board energy for stand-alone environmental marine stations can use different energy sources, but the choice depends primarily on the location of the station. In fact, near or far from the shore, on the surface or under water, in a hostile environment or in a protected bay, these various situations require careful selection of the type of energy sources. The situation of the station will therefore generate various levels of accessibility of the station, and consequently various maintenance difficulties. So the TRL[1] and the reliability of the solution must be very well chosen to avoid inoperable systems to be deployed.

For marine environmental applications, the energy demand can be very different from one application to another.

Consequently, the matrix of solutions parameterized by the constraints inherent to marine applications is complex. "Energy demand" vs "distance from shore" vs "depth" vs "size" vs "weight" vs "reliability" vs "TRL" are one of the inputs needed to make the good choice.
The two parameters, Reliability and TRL, are for the moment two very discriminating parameters. Indeed, many of the energy sources described in this document have a low TRL (TRL_5 at most) because many energy sources are under study and can not be used in an operational context requiring a TRL_9.

For many energy sources described in this document PROS & CONS has been presented and should help to choose the right source or the right combination of sources as explained in chapter 14.

[1] TRL : Technological Readiness Level

Appendix 1 –Characteristics of the main secondary systems (accumulators)

	Lead - Acid	Nickel - Cadmium	Nickel – Metal hydride	Lithium-Ion	Lithium-Polymer	Lithium-Sulphur	
End of discharge	1.80 Vpc	1.10 Vpc	1.10 Vpc	2.50 Vpc		1.70 Vpc	
Normal tension	2.10 Vpc	1.20 Vpc	1.20 Vpc	3.00 Vpc		2.50 Vpc	
Full charge	2.15 Vpc	1.25 Vpc	1.25 Vpc	3.60 Vpc		3.00 Vpc	
Float setting	2.20 Vpc	1.35 Vpc	1.35 Vpc				
Starts to gas	2.30 Vpc	1.40 Vpc	1.40 Vpc	4.10 Vpc			
Equalize at	2.35 Vpc						
Energy / weight	20-40 Wh/kg	40 à 60 Wh/kg	30 à 80 Wh/kg	120-185 Wh/kg	150-170 Wh/kg	400-50 Wh/kg	
Energy / volume	40-100 Wh/L	50-150 Wh/L	140-300 Wh/L	400 Wh/L		700 Wh/L	
Energy / price	150 €/kWh			500 €/kWh			
Self-discharge	1% /month	1% /day, 5 à 10% /month	3 à 4% /jour, 20 à 40% /month	2 à 3%/month at 20°C	1% /month		
Lifetime	4-5 years	8 years	8 years	2-3 years (10 years in good conditions)	2-3 years		
Number of cycles	500 if usage ≈50% 1000 if usage >70%	500 to 1000	500 to 1000	500 to 1500	50 to 100	350 to 1C	
Advantages	Proven, Inexpensive technology, High currents, Low self-discharge	Low internal resistance, Supports strong currents, Inexpensive, Endothermic recharging, Flat discharge curve,	Low internal resistance, Supports strong currents, Energy density 50% > Ni-Cd, Flat discharge curve,	Very high energy density, Very low self-discharge, Relatively low internal resistance, Prismatic or cylindrical shape,	Very high energy density, Very low self-discharge, Very low internal resistance,		
Disadvantages	Low energy density, Oxidation and sulfation of plates possible	Moderate self-discharge, Medium energy density, Heavy and polluting cadmium metal, Memory effect,	Strong self-discharge, Exothermic recharging, Never discharge below 0.8 Vpc	Special charger required, Risk of explosion if elements short-circuited,	Special charger required, Voltage min and max of elements should imperatively be respected, Ignition if heated,		
Charge	Phase Constant Current at C/10 for U≤2.35Vpc Phase Constant Voltage for U>2.35Vpc Maintenance charge at C/1000	Standard charger function at C/10 for 14h Quick charge at C/5 … C/2 for 30mn Fast charge at 1C … 2C but risky!	Standard charger function at C/10 for 14h Quick charge at C/5 … C/2 for 30mn Fast charge at 1C … 2C Never go above 45°C	Special charger at 4.10Vpc (±0.05V) and current between C/2 and 1C Inexpensive charger	Special charger at 4.20Vpc (±0.05V) et and current between C/2 and 1C		

Discharge	Under low currents U>11,7 V Under high currents (5C … 7C) U>10.0 V	Never go below 1.0Vpc	Never go below 0.8Vpc	Never go below 3.0Vpc	Never go below 3.0Vpc		
Storage	In charged state, apply 1 cycle/month	In discharged state (1.1Vpc) apply 1 cycle/month	In charged state, apply 1 cycle/6 months	In charged state, Apply at least 1 cycle/year	In charged state, Apply at least 1 cycle/year		
Options	Lead / Calcium (Starting batteries), Lead / Antimony (Deep cycle batteries) Gel electrolyte	Nickel-Iron: 3000 cycles Nickel-Zinc: 65 to 80 Wh/kg		Suppliers have ‘High cycle rate’, ‘High Temperature’ or ‘Intense cold’ versions			

Appendix 2 –Characteristics of photovoltaic panels

Technology	Performance	Price (€/m²)	Advantages	Disadvantages
Monocrystalline	13-15%	130 - 140	Classic product, high power	Sharp drop in output with temperature (-0.5%/°C) Strong dependence on good quality silicon
Standard polycrystalline	11-13%	100	Classic product, high power	Sharp drop in output with temperature (-0.5%/°C) Strong dependence on good quality silicon
Hybrid	15-18%	120 - 140	Operates at high temperatures (-0.3%/°C) High power and use of diffuse sunlight Also available in transparent version	Provision ifficult
Rigid amorphous	5-6%	180	Operates at high temperatures (-0.2%/°C) Uses direct and diffuse radiation	Low power
Flexible amorphous	4-5%	100	Operates at high temperatures (-0.2%/°C) Uses direct and diffuse radiation Very light	Low power
Thin layer (cadmium telluride)	7-9%	New technology	Not dependent on silicon Operates at high temperatures (-0.2%/°C) Uses direct and diffuse radiation	Relatively low power, dangerous
CIS thin layer	8-11%	75 - 120	Not dependent on silicon Operates at high temperatures (-0.2%/°C) Uses direct and diffuse radiation Black color	Low power
Engraved polycrystalline	13-14%	New technology	"Classical" product slightly modified High power	Dependent on silicon Strong reduction of power at temperature (-0.47%/°C)

Appendix 3 – Example of a consumption report

Multiparameter observation station - Estimation of electricity consumption																
		Components	No	Voltage supply	Current supply		Power		Activity			Durations		Energy		Remarks
					Active	Stand by	Active	Stand by	Description	Duration	Frequency	Activity	Standby	Per day	Mission total	
				V	mA	mA	mW	mW		min	min	min / day	min / day	Wh	Wh	
COSTOF2	1	Monitoring board	1	24			78	0	15 min / day	15	1440	15	1425	0,02	**1**	
	2	I/O card for optode	1	24			78	0	1 min / 10 min	1	10	144	1296	0,19	**11**	
	3	I/O card for CTD, turbidimeter	1	24			78	0	1 min / 5 min	1	5	288	1152	0,37	**22**	
	4	NAS (storage on hard disk)	1	5			3250	0	4x10 min / day	10	360	40	1400	2,17	**130**	
		COSTOF2 Sub-total												2,7	**165**	
GENERIC SENSORS	5	Optode	1	14	24,2	0,2	338	2,8	1 min / 10 min	1	10	144	1296	0,9	**52**	
	6	CTD	1	14	35	0,03	490	0,4	60 s / 10 min	1	10	144	1296	1,2	**71**	
	7	Turbidimeter	1	14	50	0	700	0	10 s / 5 min	0,17	5	48	1392	0,6	**34**	
	8	Camera	1	36	520	0	18720	0	4x2 min / day	10	1440	10	1430	3,1	**187**	
	9	Lamps	2	24	1700	0	40800	0	as for camera	8	1440	8	1432	10,9	**653**	
SENSOR 1 SPECIFIC	10	MicroProfiler	1	12	415	2	4980	24	autonomous	90	10080	13	1427	1,6	**98**	
	11	Positioning actuator	1	24	5000	0	120000	0	2x / week	20	10080	3	1437	5,7	**343**	
SENSOR 2 SPECIFIC	12	Benthic chamber	1	12	140	0	1680	0	2x24 h / week	2880	10080	411	1029	11,5	**691**	
	13	Mini camera	1	5	300	0	1500	0	2x5 min / week	10	10080	1	1439	0,0	**2**	
	14	Optode	1	14	24,2	0	338	0	2x288 min / week	576	10080	82	1358	0,5	**28**	
	15	Positioning actuator	2	24	5000	0	120000	0	2x / week	5	10080	1	1439	2,9	**171**	
		Sensor sub-total												38,8	**2331**	
Options	16	Chlorinators (antifouling)	4	2,6	10	0	26	0	continuous	1440	1440	1440	0	2,4	**147**	
	17	24V/36V converter	1	24	175	1	4200	24	4x2 min / day	10	1440	10	1430	1,3	**76**	
	18															
	19															
		Option sub-total												3,7	**223**	
		TOTAL												**45**	**2719**	

Corresponds to total estimated electrical energy requirement for the duration of the mission i.e. 60 days.
If this estimation is weighted with an uncertainty of ±5%; to meet the requirements with an accepted margin of uncertainty, the energy capacity to be supplied is 2855 W.h (2719 W.h x 1.05).