Integrating Activities for Advanced Communities

D3.11- INTERACT Report on Reducing Environmental Impacts at Arctic and Northern Alpine Research Stations

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

Contents

Publishable Executive Summary

This deliverable report on reducing environmental impacts at Arctic and northern Alpine research stations was led by the International Polar Foundation that operates the Antarctic Research Station, Princess Elisabeth, which is the first research station in Antarctica to be able to operate in Zero Emissions mode. The aim of this report is to aid station managers to reduce their environmental impact and help their path towards a Zero emission Station. The input to this report has been based on best practices at the Princess Elisabeth Station, outcome from a workshop where specialists and industry providers explained how mitigation of different aspects of operations could contribute to achieve the Zero Emission goals and the currently best practices and the challenges experienced by the INTERACT research stations.

The Report examines the process of environmental impact mitigation by looking at the pathways to reduction of impact through easily accessible methods. The importance of Energy Efficiency as a broad approach is highlighted. Waste management strategies are addressed. With regard to the most significant environmental impacts, such as from the use of fuel, and in particular diesel fuel, and the discharge of waste water to the environment, these were considered as the areas where an immediate impact reduction could be achieved using off the shelf technologies, dimensioned to meet the different needs of Stations. In order to deploy these "low-hanging fruit" technologies the current situation would need to be audited to see where improvements could be made. Some Stations will be able to carry out their own audits, but others might need to call in specialist help.

For the deployment of solar and wind energy, the potential of the site needs to be carefully studied. Particularly in the case of wind energy, there are several regions where the available wind speed is too low for the wind turbines currently on the market. New types of low wind turbines are being studied, and will eventually be made available. When this happens, the situation will evolve for the Stations concerned by this "wind poverty". In addition, the solar regime is such that at high latitudes several months of the year will see low or no production of energy, and the Stations located in these areas will have to find alternative methods to obtain renewable energy. In some regions there is a clear preference for cleaner diesel engines, which are more reliable where extreme cold will make the deployment of wind energy prone to multiple failures. Certain regions, particularly Iceland, benefit from an endless supply of geothermal energy, and so will not need to use other renewables. Similarly, Stations in Canada will benefit from the availability of hydroelectric energy, and will have low incentive to install solar or wind unless they are very remote and off-grid.

Each Station will need to examine the areas where impact mitigation can be improved. The Report also provides examples of on-line websites for procurement of technology and services, or for a rough estimation of energy potential of different sites using tools such as the Wind Atlas, and the Solar Atlas.

The Conclusion of the Report is that in the present context of high level of awareness, coupled with good internal mechanisms for collecting data and availability of certain technical competences, that the way forward for the Consortium in the next phase would be to build a platform for sharing information on the existing INTERACT website. In this way Station Managers can showcase solutions that have been rolled out, or methodologies for carrying out the Environmental Impact Assessments, the Energy Audits, the Wind Potential Studies, the names of recommended experts, and technology providers. By using locally available engineering and product procurement, Stations would also be encouraging the development of these competences in their local areas, and contributing to the Communities in which they find themselves.

1. INTERACT Report on Reducing Environmental Impacts at Arctic and Northern Alpine Research Stations – Summary of Contents

1.1. General Objectives of INTERACT

Summary of the objectives of the INTERACT project Consortium from Phase I to Phase II. The Work Package 3 aims and organisation. The Princess Elisabeth Station – strategies for achieving Zero Emissions.

1.2.INTERACT – The Stations

Comparison of the Stations using the data available in the INTERACT Station Catalogue, produced in the first Phase. Comparison of geographical location by country, latitude (which will affect solar potential of a site), size and capacity of Stations, proximity to urban areas and settlements, energy use by type of energy, and age of infrastructure.

1.3.Comparing the Arctic and Antarctic

A brief introduction is given to the instruments of the Antarctic Treaty System, including the Annexes to the Madrid Protocol, (as the basic documents governing the approach to environmental protection in the Antarctic). The Arctic Council and its Working Groups and some of the relevant reports are outlined. Environmental Impact Reduction at Antarctic Stations are discussed, as well as the key drivers, such as the cost of fuel, and the long-term impacts of waste-water discharge on Antarctic sites occupied over several decades.

1.4.Challenges

The challenges examined are those due to the demands of differing regulatory frameworks, access to funding for renewable energy or impact mitigation projects, finding technical competences for installation and operation, mind-sets affecting the adoption of renewable energy, logistic challenges, water management challenges and waste management challenges.

1.5.The Impact Reduction Road Map

The Road Map has several stages, and some can be omitted, if required. Environmental Impact Assessment prior to activity allows the base-line impact to be established. This is followed by an energy audit, a site survey, strategy elaboration, energy efficiency options, renewable energy evaluation of potential, definition of solid waste management strategy, water treatment options, green procurement strategy, identifying funding, and technical competences required for installation and operation.

1.6.Environmental Impact Assessment

Various approaches are compared from the European Union, to the Arctic Council, to the Antarctic approach derived from Annex I to the Madrid Protocol. Many Stations have their own methodology and some will use standardised methodologies, especially where these are imposed by regulatory bodies.

1.7.EIA – Audits

Energy, GHGs, and water use and waste water production, and solid waste audits have to be carried out to assess where impact reductions can be most effective.

1.8.EIA Site Survey

Site surveys will be critical where infrastructure needs to be installed on a site. Optimal energy delivery will be affected by the choice of site. GIS tools developed by other WP3 partners could be used for mapping and evaluation of different locations on a site.

1.9.Energy Efficiency

Energy Efficiency strategies include building techniques, space heating from renewables, smart technologies for energy management, low energy appliances, reduction in waste of energy during transformation. The energy performance of buildings as a concept is briefly touched upon, in particular how it concerns the Princess Elisabeth Station, where traditional building materials were used to deliver high performance.

1.10.Renewable Energy Technologies

Incentives for the adoption of renewable energies are examined, in particular as some Stations are connected to the public grid, and installing solar PV for example will be less attractive as a means of impact reduction. Calculating the potential for energy production (solar and wind) will also decide whether a project is financially viable or attractive. Energy storage is key for optimising renewable energy installations, and for managing intermittent production, which characterises RE. Battery technologies are compared. Costs and life cycle assessment are broached as criteria in the selection of technology. PV panels are compared to explain what to look out for when buying a panel. The balance of systems (BOS) is explained as an unforeseen cost element. How to put together a RE set up using different components. Dimensioning and selection of components.

1.11.Water Treatment

Increasingly effective methods of treatment using filtration, and biological agents to breakdown waste to harmless by-products. Membrane bio reactors, automation, water treatment on-line resources.

1.12.Conclusion

Each Station will have to develop a customised strategy based on current impacts, available solar and wind potential to improve renewable energy production, and available funds. If the exercise is carried out properly it is quite likely that cost savings can be achieved, but this will vary on a case-by-case basis. The Report recommends setting up an on-line platform to share Best Practice in mitigation of environmental impacts. This would be the best way to capitalise on the vast experience available within the Consortium, to the benefit of all Members.

Appendix I: INTERACT Report on Reducing Environmental Impacts at Arctic and Northern Alpine Research Stations

Introduction

INTERACT is a network of terrestrial field bases in arctic and alpine areas of the Northern Hemisphere. The network is funded for by EU's Horizon 2020 Framework Programme as an 'Integrating Activity' under the theme 'Research Infrastructures for Polar Research'.

The network has been endorsed by the International Arctic Science Committee (IASC), the Arctic Monitoring and Assessment Programme (AMAP), the Circumpolar Biodiversity Monitoring Program (CBMP), the Sustaining Arctic Observing Network (SAON), the International Study of Arctic Change (ISAC) and the World Wildlife Foundation (WWF).

General Objectives of INTERACT

"The overall objective of the second phase of INTERACT is to provide a geographically comprehensive and excellent infrastructure of terrestrial research stations throughout the Arctic and adjoining forest and alpine regions[1]."

From a small network of nine north-Atlantic research stations in 2001, INTERACT has become an advanced community of 86 research stations by 2019.

INTERACT used the advanced status to consolidate its vast geographical and diverse environmental coverage, to provide pan-arctic access to the world's scientists and to equip station leaders around the Arctic to enhance their science support.

Externally, INTERACT is now seen as the major terrestrial research infrastructure of the North and is constantly engaged in supporting national, regional and global organisations as well as informing governments. INTERACT reaches out to provide new services, for example in detecting and responding to potential environmental hazards and uses its extensive international networking activities (over 80 networks) and impressive in-house knowledge gained from annually hosting around 5000 scientists to inform the public and provide educational resources on the rapidly changing Arctic environment.

In addition to integrating, harmonizing and improving research and monitoring at research stations around the North, one of INTERACTs greatest impacts, based on international research agendas, is transforming words to action!

INTERACT Work Package 3: Station Managers' Forum

The specific objective of this work package is to provide first class science support and excellent fieldwork efficiency and safety by optimising practices using consortium meetings and a Station Managers' Forum (WP 3). The Station Managers' Forum is an essential element established in the first phase of INTERACT and has now more than doubled in size. This forum ensures improved data gathering and reduced environmental impacts of operations. Also, station managers are brought together with leaders of relevant

[1] 2018 Interim Report

international, single discipline organisations to increase uptake of standardised monitoring and innovative research activities.

Task 3.5 Reducing environmental impacts of station management and science activities

"The environmental impact of arctic and alpine research stations' activities may be small in relation to the often vast and remote areas in which they operate. However, they often affect the local environment and as such influence the scientific studies they host - in remote areas anthropogenic impact of research might in fact be the most important effect on the local area. Environmental impacts should therefore be minimised – with the establishment of Zero Emission Stations being the ultimate goal.

Task 3.5 will deploy a series of lectures by station managers, specialists and industry, to discuss and develop various ways in which stations can reduce emissions and environmental impacts"[2].

The International Polar Foundation (IPF) was invited by INTERACT to join the Consortium in order to provide insight gained from the construction of the Princess Elisabeth Antarctica, the first Zero Emissions Research Station in the Antarctic.

The Princess Elisabeth Station uses a combination of energy efficiency methods and renewable energy (produced by wind and solar energy managed by a smart grid and a automation system designed specifically for the Station in order to manage loads on the system against production) to provide all life support services in terms of heating, lighting, electricity, water production (snow-melting) and heating. The aim was to achieve 100% reduction in the use of fossil fuels in the running of the Station. Setting this objective was an important part of the design process. Every aspect was studied with the intention of reducing energy consumption as far as possible through building techniques, and low energy devices, and efficient electronics. The skeleton of the PE Station is made of engineered wood, which uses a traditional material with excellent qualities in a new way to deliver strength and resilience. In this way, the Station was able to combine tradition and modernity in a way that uses the best of both.

The building shape (Figure 1) was chosen to reduce the amount of surface area, while materials used aimed at providing as close to zero heat loss through the structure as was possible to obtain, which meant very high performance insulation, combined with triple glazing and membranes to prevent humidity build up in the walls.

Energy consumption was further to be driven down through the management of loads, including with the control of energy delivery being removed from the human side of the Man Machine Interface, to reside with the machine. Decisions on energy availability are now made by the PLC, (the Programmeable Logic Controller), or the super brain of the Station.

[2] Elmer Topp Jorgensen – Management Planning for Arctic and northern alpine Research Stations

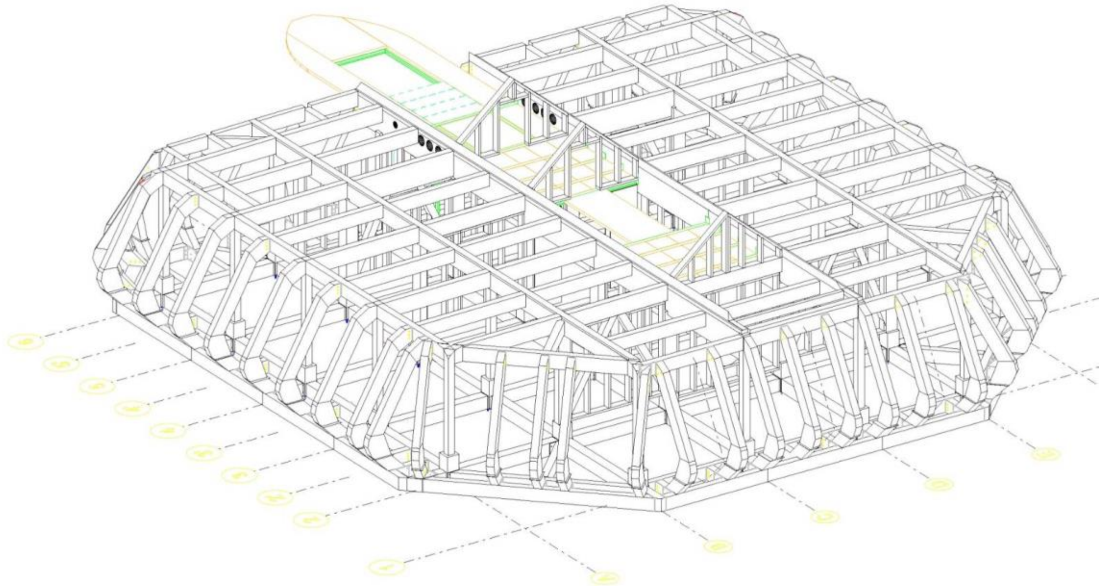

Figure 1. The building shape of the Princess Elisabeth Antarctica was chosen to reduce the amount of surface area, while materials used aimed at providing as close to zero heat loss through the structure.

The next step was to address the production side, by studying the potential of the site to produce energy in the form of wind energy and solar energy (Figure 2). The solar energy was divided into solar photovoltaic for electricity and solar thermal for space and water heating.

Figure 2. Installing Building Integrated Solar Panels at Princess Elisabeth in 2009

The energy produced could be converted and stored in a large array of batteries, which were connected to a micro smart grid for off-grid operation. The production and demand were balanced out and handing the task of load management to the computer allowed the grid to deliver energy to many more users, depending on availability and priorities set into the system. The energy efficiency targets were also met, and continued to evolve with better and more high-performance technologies coming on stream, which allowed for an overall reduction in the total electrical loads being continuously reduced over the years. This was particularly the case with the electronics used in servers and communications devices which have continued to become smaller and more efficient. Solid-state technologies have also been important in reducing the failure rate of devices.

Every system at Princess Elisabeth Station is integrated into a centralised management system, from the heating, lighting, ventilation, cooking, water production (from snow) to water treatment. Every light-bulb, every pump, every valve has its own importance in the equation, and is connected to the PLC via an intricate network of signalling cables. The data on the system is collected via pressure and temperature sensors, flow meters, etc., and this information is fed into a management and automation interface called a SCADA or supervisory control and data acquisition software, which allows the operator to intervene on the system (Figure 3).

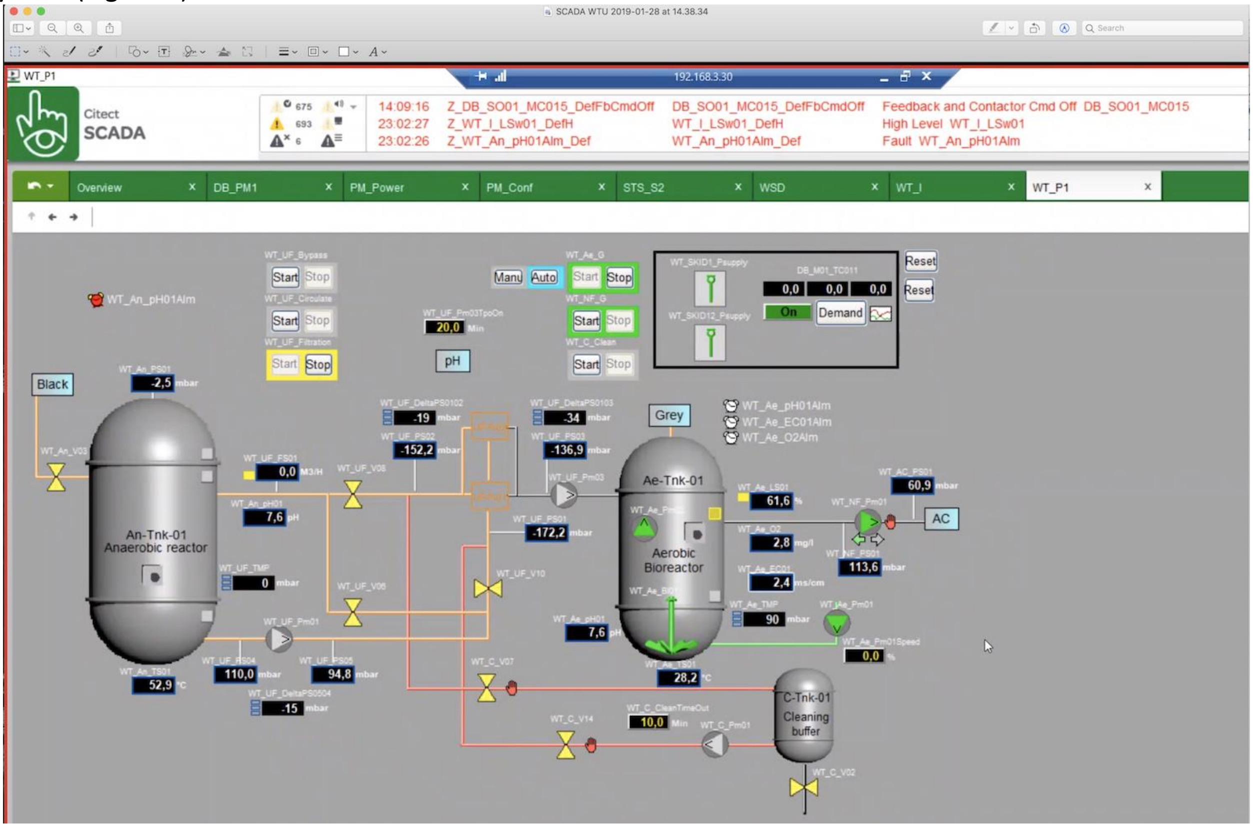

Figure 3. SCADA (a management and automation interface) screen for water treatment system

Once the Station is running, it is not necessary to intervene on automated functions, which are managed according to the amount of energy available. As a safety feature, if energy levels fall below a certain threshold the back-up generators can be brought on to the grid by the SCADA, but in practice this has become increasingly rare. The input from the technical partners was considerable, and these partners have continued to support the on-going project, through assistance with planning modifications, to providing parts, and update strategy and training of the Station Crew. The competences required are very specialised and it is difficult to find engineers who have the all the competences required to manage the diverse systems installed at Princess Elisabeth Antarctica. The management strategy includes providing training in the systems and programming competences required to update the automation of the Station when a new element is added. The full range of competences has to be collected over the whole team, and multi-disciplinary profiles are common among the crew.

The Zero Emissions target has regularly been met over the winter period, when the Station continues to operate in autonomous mode and also to during the summer period when the Station is occupied, despite the fact that the occupancy rate was finally much higher than initially foreseen, but continuous adjustments to production and management of the production of energy from various sources (including solar thermal) has allowed the Station to achieve the 100% emissions reduction for long periods of operation[3]. The next target for the Station is to look at vehicles that can be run on renewables, including hydrogen fuel cells.

INTERACT: The Stations

The IPF participated in the Station Managers' Forum, and held a one-day Workshop for Station Managers in Vahrn, Italy in March 2018, to explore the different aspects of the objective to use Best Practices to reduce the environmental impact of Arctic Research Stations. A cursory examination of the available statistics reveals that there is no common profile for the Arctic Stations that are the subject of this exercise. Closer examination of the statistics unearths a complex network of national and regional variables affecting the running of Arctic Research Stations spread over several countries, and geographical and climatic zones. **Each Station has thus a unique composite of possibilities and constraints linked to the exercise of reduction of environmental impact.**

The INTERACT Station Catalogue provided the statistics necessary to obtain a preliminary understanding of the Stations concerned. The Catalogue provides a wealth of detailed information about each station: geographical location, activities, climate (including wind speeds and temperature), logistics means, proximity to towns, capacity, age, and types of energy use.

Geographical Location of INTERACT Stations

Of the 17 countries participating in INTERACT II, several were operating Stations in a country outside the home country of the Institute (Table 1). This was the most prevalent in Svalbard, where several countries have established research stations in Ny Alesund. Among these are the Czech Republic, Italy, the Netherlands, Poland and the United Kingdom. The Danish Stations are all established in Greenland.

Table 1. Overview of number of INTERACT stations represented in each country (based on data from INTERACT I) and what country that operates them.

COUNTRY	LOCATED IN	OPERATED BY
AUSTRIA	2	2
CANADA	16	16
CZECH REPUBLIC	1	2
DENMARK	0	5
FAROE ISLANDS	1	1
FINLAND	8	8
GREENLAND	7	1
ICELAND	4	4

[3] Maintenance of the systems and extraordinary loads during construction will sometimes lead to the back-up generators being started.

ITALY	0	1
NETHERLANDS	0	1
NORWAY	8	2
POLAND	2	3
RUSSIA	23	23
SWEDEN	3	3
SWITZERLAND	1	1
UK	1	2
USA	3	4

More than half the Stations included in the INTERACT I statistics are located outside the EU. This implies that they are subject to another regulatory framework, and will be subject to other administrative procedures and will benefit from access to funding from sources other than the EU financing instruments, including banks and national research foundations.

Certain of the countries in the sample have access to a mature marketplace for renewable technologies, and access to a range of manufacturers, suppliers and technical support providers. The uptake in some countries is already so high (Norway, Finland, Sweden, Denmark), that the ease of take up, *where this does not already exist*, will be much simpler than for those situated in countries where there is a low rate of adoption of renewables and little support or financial incentive provided by the national authorities. Some countries are also largely dependent on geothermal power (Iceland) and the incentives to move to other renewables are consequently less prevalent. This is equally true for hydroelectric power, which is widely available (e.g. in Canada) but despite this, due to the vast size of that country, and the distances to the electric grid, off grid technologies are popular and well served by a large and flourishing renewables industry and government support schemes.

Despite the pre-conceptions with regard to the image of the USA being a nation addicted to petrol, the US renewables industry is among the most mature and the range of possibilities available to those wishing to take up renewable energy, or to go off-grid, is wide and varied.

The geographic location also affects other considerations, such as the potential to be able to benefit from solar energy, wind energy potential, temperature constraints on choices of energy, and logistical constraints with regard to delivery of material to the Station. Almost one third of the Stations are situated further North than 70°N (Table 2). By comparison, the Princess Elisabeth Station is situated at 71°57’ S. The majority of the Stations will thus be in a zone, which is more favourable than that at PEA Station for solar energy. It should be reassuring for these Stations to know that it is feasible to produce a large part of the electrical energy used through solar PV. Equally, hot water production using solar thermal is low maintenance and very effective. Solar thermal is an important element in the energy equation at the Princess Elisabeth Station.

The solar potential, a measure of the amount of energy arriving at the surface of the Earth at a given location, decreases North of 60°N latitude, and is significantly lower than for areas further to the South. This implies that more panels would have to be installed to provide the same amount of energy as South of 60°N. The months of the year when there is sufficient sunlight available will vary greatly depending on the latitude. Combined with the access to the electrical grid, low solar insolation may be a disincentive to the adoption of solar PV. This factor might affect the economic incentives to use solar, but should not really affect the decision, as this is a low cost adaptation, which is accessible to all Stations.

Table 2. The geographical location affects the potential to benefit from solar and wind energy. Here number of INTERACT Stations at each latitude (based on station data from INTERACT I).

LATITUDE	NO.	%
80-90°N	3	3,9%
70-79° N	16	21,1%
60-69° N	39	51,3%
50-59° N	13	17,1%
40-49° N	5	6,6%

Air temperature, permafrost, presence of wetlands and the months of the year that are snow free, will affect the combination of choices. Low air temperatures will affect the adoption of solar thermal panels, while technically these have been shown to work with great efficiency in the Antarctic and are prevented from freezing through the use of glycol based anti-freeze. From the INTERACT I data it is possible to conclude that the majority of the Arctic Stations are not exposed to the extremes of temperature experienced in the Antarctic, at the site of the Princess Elisabeth Station, where winter temperatures can drop to -40°C, and there is no sunlight from mid-May until the end of August. For higher latitudes, the combination of solar PV and wind turbines can allow for energy generation during the whole year, if sufficient energy storage is included in the design.

Capacity

The Stations are of differing sizes and types of organization. The larger the Station, the greater the energy consumption for items such as space heating. In addition, the greater the cost to introducing energy efficient building materials and techniques. The size of Stations varies greatly. More than half are over 200 sq. metres in size, with almost one third being over 1000 sq. m. (Table 3a). Around a third are small to medium sized. Some large Stations also operate remote cabins, while others have one large central infrastructure.

Table 3. a) The size of the station determines the energy consumption and the cost to introduce new energy efficient materials and techniques. 3b) The energy and water need at a station is determined by the number of visitors.

a)

AREA UNDER COVER	NO.	%
NO DATA	11	14,5%
<30 SQ M	2	2,6%
31-100 SQ M	13	17,1%
101-200 SQ M	11	14,5%
201-1000 SQ M	21	27,6%
> 1000 SQ M	22	28,9%

b)

CAPACITY	NO	%
NO DATA	9	11,3%
1-10	16	20,0%
11-20	10	12,5%
21-50	29	36,3%
>50	16	20,0%

A good number of Stations have the capacity to house over a hundred people (Table 3b). The majority of Stations studied will accommodate less than 50 people including staff. At least one third of the Stations in the consortium have accommodation for less than 20 people. The services provided and the energy and water needs of these Stations will vary immensely from one to the next. The cost of reducing environmental impact will be proportional to size and capacity, whereas the reduction of impact will also be proportional to these variables.

Proximity to urban settlements

Almost 45% of the Stations are situated at less than 10 km from the nearest town or urban centre, and could therefore have access to municipal utilities (water, electricity, sewage, refuse collection; Table 4). Almost one third are situated at less than 100 km from an urban centre and access for logistic purposes would logically be less onerous. Only one fifth (approx. 20%) of the Stations are at more than 100 km from an urban centre, and only 6 Stations are situated at more than 500 km from the nearest settlement. The case for the Antarctic is very different, with all Stations being thousands of kilometres from a port, or airport. The distance from an urban centre will greatly influence the logistic costs, and fuel costs and availability of access to municipal utilities. The economic incentive to install renewable energies and water treatment will diminish with closer proximity to services, while fuel costs will be a driver of change.

Table 4. The distance to nearest settlement determines the logistic costs, fuel costs and availability of access to municipal utilities.

DISTANCE TO NEAREST SETTLEMENT	KM	%
<1 KM	18	24,0%
1-10 KM	16	21,3%
10 -100 KM	25	33,3%
101 -500 KM	10	13,3%
>500 KM	6	8,0%

Energy Use

A large number of respondents to the Station Catalogue questionnaire are on the electric grid, and will not have the same incentive to install renewables as the more remote Stations. Similarly, the 5% who are using hydroelectric power or geothermal energy will have little incentive to use solar or wind power in areas where this use is complicated by low potential (Table 5). Among the INTERACT Stations, 32 confirm that they use diesel generators, although some will be using these as back-up power or parallel power to renewables. Several stations have begun to use solar power, but the amounts of energy being produced by installations are not available. The use of wood or coal stoves is not mentioned, but wood pellets are also a renewable resource, which could be explored by Stations, particularly in woodland areas. Pelleting machines are available on the market where logistics might complicate delivery. Going off-grid has capital costs which have to be borne by the Station's operational budget, but it is a one-off cost and there are ways to absorb and spread this cost through financing packages, which are proposed by various governmental and private financing possibilities. Savings from reduced fuel use would end up financing the outlays.

Table 5. Current energy type used at INTERACT Stations.

ENERGY TYPE	NO	%
NO DATA	8	10,0%
ELECTRICAL GRID	40	50,0%
DIESEL GENERATOR	32	40,0%
WOOD BURNING STOVE	0	0,0%
SOLAR	11	13,8%
WIND	4	5,0%
HYDRO-ELECTRIC	4	5,0%
GAS	3	3,8%
GEOTHERMAL	1	1,3%

Sample size = 80

The significant number of Stations already using solar power could share their experiences with others that intend to start (Figure 4).

Figure 4. Several INTERACT stations have installed solar panels, here at the CEN Whapmagoostui-Kuujuarapik Research Station in Canada.

Age of infrastructure

The age of the Station infrastructure will reflect in the building techniques being characteristic of the period during which they were built. Older Stations will use the construction technologies of the region in which they were built, while more recent Stations might incorporate more modern building materials, triple glazing, and high performance insulation methods. There are advantages to both traditional and modern builds. Traditional builds use local materials, and tested construction methods while the newer stations will already have incorporated the latest in energy efficient building techniques (e.g. Canadian High Arctic Research Station; Figure 5).

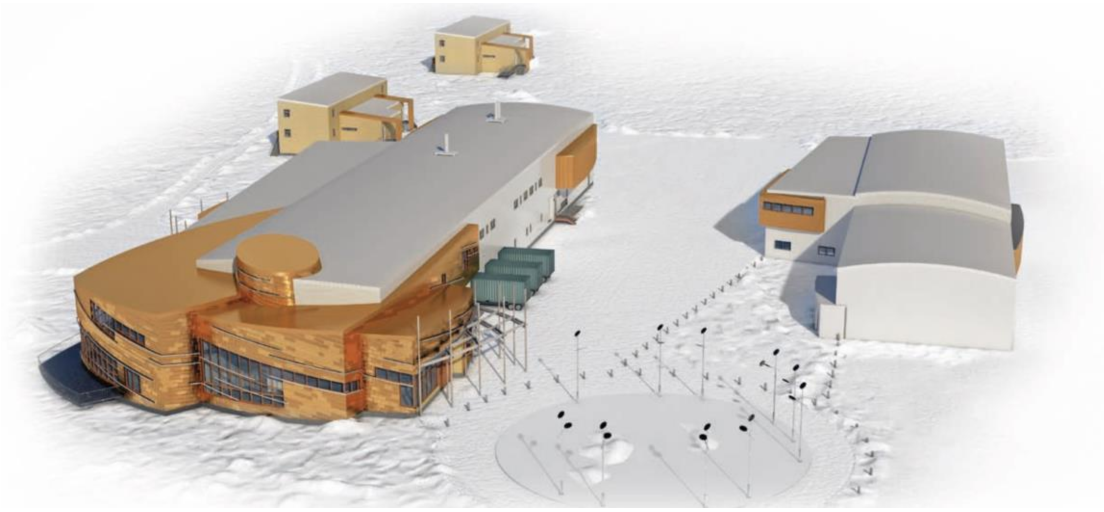

Figure 5. The newly built Canadian High Arctic Research Station (CHARS) have incorporated the latest energy efficient building techniques.

About a third of the INTERACT Stations are over 50 years old, and about 60% are over 20 years old (Table 6). The constructions vary in style and techniques used to build. No common approach can be applied uniformly across the whole group. Most of the Stations adopting new methods for environmental impact reduction will be looking to retrofit their structures, or to construct add-ons for renewables delivery. The more recent Stations will have efficient insulation, and triple glazing, while older Stations may have retrofitted their Stations during their maintenance cycles.

Table 6. Age of infrastructure reflects the building techniques used and hence affect the energy efficiency.

AGE OF INFRASTRUCTURE	NO.	%
NO DATA	5	6,3%
0-10	14	17,5%
11-20	14	17,5%
21-50	21	26,3%
>50	26	32,5%

The difference in age of the infrastructure will influence the choices made to reduce environmental impact. The older stations will possibly have infrastructure that could benefit from improved insulation, and other retrofits to reduce heat loss from the building.

Comparing the Antarctic & the Arctic

The Antarctic Treaty Regime

The Antarctic regulatory framework, or Antarctic Treaty System, provides an operating environment that varies considerably from the Arctic case, with all activities being governed by the Antarctic Treaty of 1 December, 1959 and the Protocol on Environmental to the Antarctic Treaty (1991) (also known as the Madrid Protocol), setting out rules for the reduction of environmental impacts due to operations below the 60th parallel. There is, thus, a uniform set of rules applicable to all nations operating in the Antarctic. Annual meetings called the Antarctic Treaty Consultative Meetings (ATCMs) are held annually to examine the issues raised by the application of the rules under the Antarctic Treaty System.

The Antarctic Treaty System is comprised of the Treaty, the Protocol and other Conventions regulating, among other things, the protection of cetaceans[4], and sea mammals[5]. The Treaty area also benefits from the work of organisations like the Committee of Managers of National Antarctic Programs (COMNAP) and the Committee for Environmental Protection (CEP). The new wave of Stations built during the IPY 2007-2008 period were also subject to the environmental protection regime introduced in 1991, under the Madrid Protocol, and great care was taken to apply the provisions to the greatest extent possible. This involved a lengthy process of Environmental Impact Assessment via an Initial Environmental Evaluation (IEE), followed by a Comprehensive Environmental Evaluation (CEE), which was submitted to the Consultative Parties for comment.

As part of the annual evaluation of activities, and self-regulation by the community of the Antarctic signatories, National Operators are required to communicate annual plans for operations in the Antarctic to their National Competent Authorities, prior to each season. Activities are subject to a permit, based on different levels of expected impact. For activities, which have a *less* than minor or transitory impact, under the Protocol no permit is required, but in practice the provisions are transposed into national legislation to the effect that operators are required to carry out an evaluation of the potential impacts leading to an Initial Environmental Evaluation of the planned activities. For activities that are considered to have a more significant and enduring impact, operators are required to apply the rules with regard to Environmental Impact Assessment laid out in the Annex I to the Protocol on Environmental Protection. The Annexes to the Protocol address key aspects of environmental protection:

Annex I *Environmental Impact Assessment*
Annex II *Conservation of Antarctic Fauna and Flora*
Annex III *Waste Disposal and Waste Management*
Annex IV *Prevention of Marine Pollution*
Annex V *Area Protection and Management*
Annex VI *Liability arising from environmental emergencies*[6]*.*

Issues that arise with regard to jurisdiction due to the special status of the Antarctic as a *terra nullius*, or a land that belongs to no state or person, are rare. The chief objective of the Antarctic Treaty is to avoid conflict and to encourage international collaborative research in the Antarctic area. Some Consultative Parties (or countries with voting rights at the Antarctic Treaty Consultative Meetings (ATCMs)) who have historical territorial claims in Antarctica, have passed legislation which extends national jurisdiction to the areas claimed and can thus apply sanctions to acts which are counter to the legislation of those States. However, for the most part, countries prefer to deal with the few actions that could be considered to be in transgression of national laws on a case-by-case basis as there are few legal precedents to address these issues. Any failure by the signatory countries to respect the international legal regime based on the Treaty is addressed by the International Court in The Hague. This is in marked contrast to the Arctic framework, where there is no soft law regime like the Antarctic Treaty. The Arctic Region North of the 60°, is divided among several independent Nation States and is governed according to the laws and customs of those States.

The Arctic Council

The Arctic Council was formed in 1996[7] precisely in order to create a forum to examine issues of common interest to the States present in the Arctic. *"The Arctic Council is the leading intergovernmental forum*

[4] Convention on the Conservation of Antarctic Marine Living Resources (CCAMLAR)
[5] Convention for the Conservation of Antarctic Seals (CCAS)
[6] This Annex has not yet been ratified by the required number of Parties and is thus not in force.
[7] Ottawa Declaration of September 19, 1996

promoting cooperation, coordination and interaction among the Arctic States, Arctic indigenous communities and other Arctic inhabitants on common Arctic issues, in particular on issues of sustainable development and environmental protection in the Arctic"[8]. The Arctic Council, therefore, has not installed a common regulatory framework applicable to the Arctic Region. The Arctic Council proceeds to coordinate joint initiatives through the efforts of its Working Groups, namely:

- The Arctic Contaminants Action Program (ACAP)
- The Arctic Monitoring and Assessment Programme (AMAP)
- Conservation of Arctic Flora and Fauna (CAFF),
- Emergency Prevention Preparedness and Response (EPPR),
- Protection of the Marine Environment (PAME)
- Sustainable Development Working Group (SDWG)

Under the Finnish Presidency (2017-2019), the SDWG launched a project on Environmental Impact Assessment - *Good Practices for Environmental Impact Assessment and Meaningful Engagement in the Arctic – including Good Practice **Recommendations***, published in May 2019. This initiative defines Arctic EIA as "*as practice that has proven to work well and has produced good results, and can therefore be recommended as a model*". The Project goals are: *"Arctic EIA aims at providing Arctic-specific recommendations that can be applied in the vulnerable and changing Arctic environment, taking into account the indigenous peoples and other inhabitants living there. Since economic activities are likely to increase in the Arctic, the role of environmental impact assessment (EIA) in project planning will become increasingly important. Mapping good practices, sharing experiences, learning from each other and co-creating recommendations form the core of the project. The deliverables of the project will include Good Practice Recommendations for EIA and Public Participation in the Arctic to be delivered to the Ministerial meeting of the Arctic Council in the spring of 2019".*

A questionnaire on Environmental Impact Assessment and Public Participation in the Arctic was sent out to stakeholders by the SDWG to find examples of good practice, in order to inform the process of making recommendations on environmental impact assessments. The analysis of the responses[9] concluded that traditional knowledge and the participation of locals and indigenous peoples should be incorporated into the process. This is not a consideration in the Antarctic, as there are no indigenous populations, and no land rights. The population of the Antarctic during the summer season is also a few thousand spread over a land mass which is approximately equivalent in size to the US. The EIAs under consideration in the Arctic, related to large public projects and so the process does not throw much light on how to approach EIAs on a more restricted level, where impacts are heavily localised, as is the case for research Stations. EU Countries are, meanwhile, also subject to the Regulations and Directives of the European Union under Articles 11 and 191 of the Treaty on the Functioning of the European Union on environmental integration and protection. In this context the Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment will also affect countries of the EEA.

A report from the European Commission published in 2017[10], recognises that implementation of Directives will follow different paths:

[8] Arctic Council website: https://arctic-council.org/index.php/en/about-us
[9] Aino Voutilainen, University of Jyväskylä

[10] Brussels, 15.5.2017 COM(2017) 234 final

"*All Member States have transposed the SEAD (Strategic Environmental Assessment Directive). The legislative framework transposing the SEAD varies across the Member States and depends on their administrative structure and arrangements. Some Member States transposed the SEAD through specific national legislation, while others have integrated its requirements into existing provisions, including those transposing the Environmental Impact Assessment Directive ('EIA Directive')."*

The Arctic is also subject to several international conventions governing trans-boundary pollution and environmental impact[11]. In addition, the UN IMO Polar Code also applies to the Arctic Region. National regulations, governing environmental issues for certain INTERACT partners, overlap with the European Regulations either through membership of the European Union (EU)[12] or the European Free Trade Area[13] (EFTA) the European Economic Area[14] (EEA). In short, while there is a complex regulatory framework of national and international laws and conventions affecting the reduction of environmental impact in the Arctic, there is no single unified framework of rules and regulations that can be applied uniformly across the Arctic Basin or the Arctic Region. This heterogeneity spreads to other aspects of the task of environmental impact reduction for terrestrial research stations in the Arctic.

Environmental Impact reduction at Antarctic Stations

Environmental protection is a key objective of the Environmental Protocol to the Antarctic Treaty, and provides the impetus for the reduction of environmental impacts, at Antarctic Stations. Article 3 states:

"1 The protection of the Antarctic environment and dependent and associated ecosystems and the intrinsic value of Antarctica, including its wilderness and aesthetic values and its value as an area for the conduct of scientific research, in particular research essential to understanding the global environment, shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area.

2 To this end:

(a) activities in the Antarctic Treaty area shall be planned and conducted so as to limit adverse impacts on the Antarctic environment and dependent and associated ecosystems;

(b) activities in the Antarctic Treaty area shall be planned and conducted so as to avoid:

(i) adverse effects on climate or weather patterns;

(ii) significant adverse effects on air or water quality;"

Despite the imprecise language of the Protocol, which frequently leads to the necessity for clarification of the meaning of the terms used, (such as "*wilderness values*") it has been key in promoting the drive towards the reduction on environmental impacts. The ATS applies a unified management framework to the Antarctic south of 60°, which allows for a certain amount of self-regulation, due to the fact that the Treaty recognises no national jurisdiction or application of sanctions. In a few isolated instances, certain countries party to the Treaty have passed legislation to extend national jurisdiction, to administer the areas under their control, and in a few limited cases sanctions have been applied. However, the environmental management of the Antarctic is characterised by all parties respecting the spirit of the law, which is considered a soft law regime, because of the lack of coercive elements.

[11] Espoo Convention, "Convention on Environmental Impact Assessment in a Transboundary Context" (UNECE) – 25 February, 1991
[12] Austria, Belgium, The Czech Republic, Denmark, Finland, Poland, Sweden, UK
[13] Iceland, Norway, Switzerland
[14] Iceland Norway

The situation of the Arctic Stations is more complex, because (as mentioned above) each country has its own set of legal and administrative rules containing the environmental management framework. The heterogeneous nature of this management is to some extent overlaid in some cases by the Regulations and Directives issuing from the European Union, from international conventions and from Arctic Council initiatives.

Environmental Best Practices of the Antarctic post 2007 still have some relevance to Arctic Research Stations despite the differences in local legal frameworks, because of some similarities in the environmental parameters, (such as the latitudinal constraints), the extremes of temperature, the requirement to handle snow deposition in site management, the remoteness and the logistic difficulties. In reality, the earliest Antarctic Stations were using technologies learnt from operating in the High North, and structures built in the early period of exploration, such as the huts built by Scott and Shackleton were a reflection of this “traditional” polar influence. In the spate of Antarctic Station building in the 1950’s, around the International Geophysical Year of 1957-1958, some lessons had been learnt and the new Stations were frequently raised several metres off the snow level in order to combat the snow-drift, which would have buried the earlier constructions. Some Stations however, were still victims to the particularities of the Antarctic, and ended up being lost under the slow moving ice sheet, such as the Roi Baudouin Station of Belgium, built in 1957, the Asuka Station of Japan, and the Neumayer Station II (Germany). The movement of the ice sheet has always presented challenges for Antarctic Station builders. The movement of the Roi Baudouin Ice Sheet (RBIS), measured in 1964 was of approximately a metre a day. The stresses imposed on buildings which were caught in the ice, were irresistible, and led to the buildings being warped and destroyed.

In the next phase of building, during the International Polar Year 2007-2008, a new wave of Stations saw the day, among them several of which were designed to combat the movement of the ice sheet. Among these, Neumayer III, which was built on the Ekström Ice Shelf. To avoid the same fate as that experienced by the Neumayer II, the new concept allowed the Station to be raised on hydraulic supports on a regular basis to prevent the snow accumulation from burying the building. The Halley Station (UK), which was on the fast moving Brunt Ice Stream, was designed in such a way that the whole station could be moved. The design concept using individual interconnected pods allowed for the Station to be raised to allow the snow drift to pass under, while it could also be lowered and separated into individual units for transport upstream to a new site. The Princess Elisabeth Station was built inland, at 220 km from the coast to take advantage of anchoring on a granite ridge. The Station was divided into two parts with an upper module which was placed on the ridge itself, and a lower technical and accommodation area spread along the leeward side of the ridge, where it could benefit from a cantilever support combined with hydraulic supports on “floating” foundations.

One of the most significant impacts of any activity in Antarctica is the use of fuel. This can be addressed first and foremost through the use of renewable energies. Use of renewable energy at Antarctic Stations is not a new phenomenon, and several Stations have experimented with different approaches to reducing environmental impact through the deployment of renewables[15]. The Princess Elisabeth Station is perhaps different from other Stations in that the key driver in the design process from concept to operation of the Station was the aim of reaching a zero emissions target. The choice of materials, and building technologies implemented were also based on this objective. The Princess Elisabeth Station was built in 2007-2009,

[15] Energy efficiency and renewable energy under extreme conditions: Case studies from Antarctica, Tin et al, Renewable Energy, 2009

during the International Polar Year, in the Queen Maud Land Region of East Antarctica. The construction was subject to the provisions laid out in the Antarctic Treaty and its Environmental Protocol, the key components of the Antarctic Treaty System (ATS) relative to human activities on the Antarctic continent. A Comprehensive Environmental Evaluation was prepared prior to beginning any activities on the site.

Challenges

There are a number of challenges going forward in addressing the question of Best Practice for Environmental Impact Reduction for the Arctic research stations concerned by this study listed below.

Regulatory Framework
In addition to the kaleidoscope of national and supra-national regulatory measures existing for the countries which participate in the INTERACT Station Managers' Forum, there are local directives and technical standards, among the range of other factors to be taken into account. Providing detailed Environmental Impact Assessment guidelines on a country-by-country basis is a task, which would require significant time and resources. An undertaking of this scale lies beyond the scope of this study and would require other tools and means to be able to complete with any level of assurance that the activities planned in each case have fully met with the requirements of their international, national, regional and local obligations, particularly where the transposition along the chain from international to local might have stalled due to local particularities. Nevertheless, establishing Best Practice guidelines with regard to self-assessment concerning environmental evaluations does not need to be an onerous task if it addresses non-mandatory initiatives. Furthermore, those willing to start can benefit from the pooling of Best Practice across the member countries and Stations of INTERACT.

Funding
Funding opportunities vary enormously across the Arctic Region with some countries having generous grants schemes to allow their citizens to accede to clean energy technologies, while others will have to rely on commercial loan instruments. Some Stations will be able to access local funds, or will have access to grants provided by the Arctic Council bodies, or the European Union. However, the mechanisms are complex and frequently aimed either at municipal authorities or large commercial projects. Identifying funding will require recourse to advisors or research funding bodies for assistance.

Technical Expertise
The take up of clean technologies and technology service providers varies from country to country. Some Stations will be based in areas where access to service providers and technology are relatively simple and financially accessible, while in other countries the costs will be prohibitive and the technical services scarce. Stations may also have in-house resources, but with the growing complexity of cutting edge energy management and automation technologies, some degree of expert assistance might still be required, depending on the level of complexity being sought. Consultancy services might be required to help at various phases of the project, again depending on the complexity of the technology and the impact reduction level being sought. Having an environmental impact analysis carried out professionally will also help to convince eventual funding sources of the financial feasibility of the project. The installation of energy efficient and renewable energy technologies will immediately begin to provide savings, which can be offset against loan repayments. Energy and fuel savings can therefore be monetized more easily than impact reduction from water treatment. It may also become necessary to obtain engineering services for more specialised installations. The range of complexity of solutions to environmental impacts throws up differing configurations depending on the available funds, and the ambition of the project undertaken.

As the cost of hardware begins to diminish, the cost of technical services becomes a more significant part of the equation. For small pilot projects, if funding is not required, the Station Managers could immediately select a suitable solution or combination of solutions to carry out the first steps towards impact reduction. For example, installing a solar panel is simple and could serve as a demonstration of what could be achieved with a larger array. Similarly, installing a small wind turbine is cheap and could allow the potential to produce energy to be assessed better, as not all areas will have sufficient wind potential to make it a viable source of energy. This aspect is discussed further in the report.

Mind Sets

Another important consideration limiting adoption of renewables at Arctic Stations could be that of mind-sets[16]. While the technological culture of one locale will be favourable towards the early adoption of new practices and technologies, this might not be the case across the board, with significant differences from one case to another, even in the same countries. The resistance to new technologies is likely to be a very local phenomena, dependent on the distinct realities of each geographical location, the availability of funding, the availability of technical services, the availability of logistic means, the solar or wind potential of the site. A step-by-step approach could be useful in convincing people of the benefits of the technologies available. A gradual familiarization can often work miracles in obtaining enthusiastic buy-in.

The adoption of renewable energies is becoming cost effective when compared to the cost of burning fossil fuels. The concept of the “levelised cost of electricity” (LCOE) has allowed costs to be compared across different types of energy production technologies. Solar PV has shown the greatest falls in cost of the whole system from panels, to storage.

Logistic Challenges

Which solutions Station Managers choose to implement from the available possibilities will depend to some extent on logistical constraints. Some Stations are situated not far from towns and have an easy vehicle access, connection to the municipal grid, refuse collection, water supply and wastewater treatment (WWT). Others are based hundreds of kilometres from the nearest settlement, and logistics could take any form including helicopters, horseback, snowmobiles or ski lifts. Installing large infrastructure will require significant logistic capabilities, and the more remote a Station is, the less likely it is to have the means to carry out large projects without significant heavy logistics and consequent funding.

For Antarctic Stations, the cost of delivering energy in the form of fuel is very high and involves the use of ice-breakers and specialised heavy logistics. This leads to the cost of fuel being multiplied by a factor of 5 or more depending how far inland the Station in question is. No accurate costs are available, because often the ice-breakers that deliver the fuel and supplies belong to the operating country and the capacity utilisation is not optimal, as would be the case for a cargo carrier. In this heavy logistic scenario, implementing renewable energies is immediately cost effective due to the high cost of fossil fuels, and this has been show in Stations such as Scott Base (NZ), where a large wind-turbine installation largely provides all the energy required for operation of the Station. In this way, Scott Base was able to reduce approximately 300,000 litres of fuel[17] used to power generators. Fuel use for vehicles at Scott Base over the same period was almost 100,000 litres, but until a viable solution exists for electric vehicles this cannot be reduced significantly, except by finding a solution for the heavy logistics required to transport fuel.

[16] https://www.forbes.com/sites/uhenergy/2017/06/30/good-intentions-why-environmental-awareness-doesnt-lead-to-green-behavior/3/#1006fcc74290

[17] An Investigation into Fuel Utilisation and Energy Generation in Antarctica, ANTA504, 2007

The Australian Station, Mawson, installed wind energy even earlier and was able to reduce fuel use by 32%[18] prior to 2004[19]. However, the 300 KW wind turbines required large cranes capable of handling up to 100 tonnes, to be able to carry out the construction on site. The maintenance will also require sophisticated logistic delivery capabilities. This type of turbine would not be an option for remote Stations which do not have access by road or sea. According to the same source, the McMurdo Station (US), which has 1000 inhabitants in summer, took delivery of 8 million gallons of fuel by ice-breaker in the 2004/2005 Antarctic season to run the McMurdo Station, the South Pole Station and their vehicle park. Princess Elisabeth Station is able to function in Zero Emission mode, thanks to its wind park and its solar park, but the vehicles delivering cargo to the Station require fuel, as do the flights that bring the researchers and Station personnel to the site. The fuel savings are nevertheless significant. Delivering fuel to Princess Elisabeth, via the Antarctic coast by ship, and then 220 km inland requires heavy logistics, which in turn require additional fuel. The logistic chain costs lead to the cost of a drum of Polar Diesel or Jet A1 being multiplied by 5 from the time it is delivered on board ship, to the time it arrives at the Station.

It cannot be stressed enough: the cost of fuel is a major incentive driving the use of renewable energies. In addition, reducing the environmental impact of fuel use (burning) also includes the impact associated with refuelling and associated risks from fuel spills. The refuelling operations comprise an elevated risk of fuel spills and the Committee of Managers of National Antarctic Programmes (COMNAP) offers instructions for the handling of fuel and for reporting spills in the fuel management handbook which collates Best Practice in the field for the Antarctic. Despite Best Practices, fuel spills should be avoided at all costs. The impacts of fuel spills on marine wildlife are significant and the hostile environmental conditions mean that even the clean up operations are sometimes not feasible.

The IMO Polar Code has brought in new and more stringent requirements for vessels operating in the polar regions, north and south of 60° latitude. Ships providing a re-supply to coastal stations have to be able to comply with the requirements, which include the use of lower sulphur fuels (Medium Grade Oils) in the place of heavy sulphur rich fuels, to reduce emissions of sulphur dioxide. In practice, the ships supplying Antarctic Stations have to either be Ice Class 1A or ice-breakers and are usually double hulled to resist the pressure of the ice. Despite these requirements, accidents are possible as the bathymetric charts for the Antarctic coastline are incomplete and the risks of operating close to an unknown coastline are immense.

Despite the fact that many of the Arctic Stations will not be using icebreakers for re-supplying Arctic Stations, there are still many advantages for Stations to becoming less dependent on fuel:

1) Lower logistic costs, and lower costs for operations.
2) Reduction of risk associated with the fluctuation of prices.
3) Lower costs for delivering scientific results, which allows finances to be used for science instead of fossil fuels.
4) Reduction in environmental impacts from burning fossil fuels (air, snow, biotope).
5) Reduction in risks associated with the storage and handling of fuel – the majority of the environmental incidents arise from fuel spills whether from leaks or from re-fuelling operations, or handling of drums.
6) Reduction in the risk to operations from the failure of delivery of fuel to the Station.
7) Reduction in the cost of infrastructure through the redundancy of transport, storage, and fuel delivery logistic capacity.

[18] Energy efficiency and renewable energy under extreme conditions: Case studies from Antarctica, Tin et al, Renewable Energy, 2009

[19] An Investigation into Fuel Utilisation and Energy Generation in Antarctica, ANTA504, 2007

8) The establishment of clean air zones to allow for atmospheric research into long-range transport of volatile organic compounds.
9) Improved health, from cleaner environmental conditions, and from uncontaminated water sources.

There are few pristine environments left on the planet, and the possibility of being able to function in these without significantly degrading them has to be a priority.

Water Management

The status of water management at Arctic Stations is less clear. No statistics have been collected within the group, which address the source of drinking water or the existence of water treatment facilities. The available national statistics on water treatment will not reveal any challenges faced by remote stations because they consider only municipal supplies. While statistics for water treatment in urban areas in the Arctic show rapidly improving treatment rates, off-grid the picture is difficult to ascertain.

In a 2016 study carried out by the Arctic Council SDWG "*Results of an Arctic Council Survey on Water and Sanitation Services in the Arctic – Improving Health through Safe and Affordable Access to House-hold Running Water and Sewer (WASH)*, some statistics were collated on access to water and sanitation services, but again these were provided largely by governmental sources. The sample size is 51 cases from across the Arctic, with the exception of Russia. *"While the data for access to water and sanitation from the JMP are used to track progress towards SDG #6, the situation in many rural Arctic regions is not reflected in the national reports for those nations since large population centres with water and sewer services dominate national statistics. For example, the JMP report for the USA indicates 99% access to improved water and sanitation, but these data cannot be generalised to Alaska. Thus, the SDG indicators for water and sanitation development in Arctic nations should not be applied without appropriate caveats and are best augmented by local data, such as provided in this report. This is particularly important for understanding the situation in remote communities in Alaska, Russia, Greenland, and subarctic Canada[20]".*

Several other sources confirm this finding: *"Conventional wastewater treatment is challenging in the Arctic region due to the cold climate and scattered population. Thus, no wastewater treatment plant exists in Greenland, and raw wastewater is discharged directly to nearby waterbodies without treatment. Treatment methods used were application of poly-aluminium chloride, peracetic acid, and UV irradiation[21]".* "*Another major concern is the low level of water and wastewater treatment. Operators of water utilities in Russia cannot always guarantee safe and continuous drinking water supply. In some cases, especially outside big cities, applied traditional water treatment technologies are insufficient to fully remove high level of contamination. In the case of wastewater treatment, huge improvements are also required, with only 10% being treated according to national sanitary standards and almost 17% of wastewater discharged into water basins without any treatment[22]".*

While some Nordic countries reported universal access to water services, there were reported to be some gaps by region, which do not show up in the statistics, and the individual case of each Station would have to

[20] "*Results of an Arctic Council Survey on Water and Sanitation Services in the Arctic – Improving Health through Safe and Affordable Access to House-hold Running Water and Sewer (WASH) –(2016)*

[21] Treatment of Arctic wastewater by chemical coagulation, UV and peracetic acid disinfection. Chhetri RK, Klupsch E, Andersen HR, Jensen PE. Environ Sci Pollut Res Int. 2018 Nov; 25(33):32851-32859. doi: 10.1007/s11356-017-8585-5. Epub 2017 Feb 16. https://www.ncbi.nlm.nih.gov/pubmed/28210951#

[22] Russian Waste Water Market Report 2011, Paulina Szplinska, industry analyst, Frost & Sullivan

be explored further in the event of any initiative to address a lack of municipal handling. According to the Arctic Council survey, some small communities in Alaska and Greenland were reported as having no access to municipal water or sanitation. *"With regard to water and sanitation, the concentration of Arctic populations around urban and municipal centres skews coverage figures such that almost all of the population appears to have access, while small communities very far from urban areas have little or no access. Low-population and remote communities in Alaska, Russia, and Greenland with no connections to infrastructure, such as roads or power grids, are often entirely lacking water and sanitation services……[23]".*

Logic dictates that municipal water treatment capabilities in the Arctic region will be closer to urban centres. For the more remote Stations lying outside of the areas served by municipal waste-water treatment, there were traditionally few options available. Frequently, it would be a question of discharge into the surroundings in the hope that there would be enough capacity in the environment to handle the waste. Again, the waste-water situation from one Station to the next will vary in function of geography, climate and other factors. The effects of climate change on infrastructure, due to permafrost thaw, are also raised in the Report, as are the existence of more pathogens due to the warming of water bodies. The presence of pathogens is found throughout the whole Arctic Region, with water borne diseases being present in all the countries and regions surveyed. The risks of drinking untreated water are therefore not to be under-estimated.

Table 7 from the Survey Report shows the extent to which disease pathogens are present in water bodies throughout the Arctic. In some countries the access to clean water and sanitary practices can keep disease in check, but where there is no municipal water supply, actions have to be taken for waste treatment and disinfection of water supplied from untreated water bodies.

The management of wastewater (grey and black water) in the Antarctic has historically also been very difficult because of the hostile conditions and the impossibility of using practices common elsewhere on the planet to dispose of sewage into the ground. The existence of deep soils is rare in the Antarctic, and quantities of waste produced make long-term containment an impossibility. The practice amongst the earlier Stations was to dump untreated sewage directly into the ocean. This has had unintended long-term consequences, which have been studied and the results have under-lined the importance of water treatment technologies even in remote areas where it could perhaps be imagined that the environment might have the capacity to dissipate the waste. In reality, this has not been the case, and certain Stations have had a reminder of this with warming of the Antarctic revealing piles of human waste, which were considered to be locked for eternity in the ice, or discharged without consequence into the ocean.

The impacts of this waste, on the biotope of the Antarctic, are still not completely understood. Studies have been carried out providing data to confirm[24] cases of the presence of antibiotic resistant *E. Coli* in the environment, and indicating long-term survival of faecal microorganisms[25] in areas where waste was habitually dumped on land or into the ocean. The 2012 study states:

[23] *Results of an Arctic Council Survey on Water and Sanitation Services in the Arctic – Improving Health through Safe and Affordable Access to House-hold Running Water and Sewer (WASH), 2016, page 4*

[24] Human-associated Extended Spectrum β-Lactamase (ESBL) in the Antarctic - Jorge Hernández, Johan Stedt, Jonas Bonnedahl, Ylva Molin, Mirva Drobni Nancy Calisto-Ulloa, Claudio Gomez-Fuentes, Ma Soledad Astorga-España, Daniel González-Acuña, Jonas Waldenström, Maria Blomqvist and Björn Olsen - Appl. Environ. Microbiol. doi:10.1128/AEM.07320-11 - Copyright © 2012, American Society for Microbiology.

[25] Long-term survival of human faecal microorganisms on the Antarctic Peninsula – K.A. Hughes, S.J. Nobbs - Antarctic Science 16 (3): 293–297 (2004) © Antarctic Science Ltd DOI: 10.1017/S095410200400210X

"At present, we cannot tell whether ESBL-producing bacteria are present in Antarctic wildlife, or the consequences that would have for animal health. However, the presence of anthropogenic bacteria in the Antarctic environment is worrisome in itself and indicative of how widespread the global antibiotic resistance situation has become. The existing precautions and sewage treatment at the research bases seem inadequate".

Table 7. Water-related infectious diseases reportable to public health authorities in the Arctic, as reported by survey respondents, 2016.

		Canada: Northwest Territories	Canada: Nunavut	Canada: Yukon	Greenland	Finland	Iceland	Norway	Russia‡	Sweden	U.S.: Alaska
Water-washed diseases†	Skin infection hospitalizations (impetigo, furunculosis)										
	Lower respiratory tract hospitalizations in children		X								
	Influenza, all ages	X	X	X		X				X	X
	Influenza, children	X	X	X		X				X	X
	Invasive *Streptococcus pneumoniae* infections	X	X	X	X	X	X			X	X
	Invasive *Staphylococcus aureus* infection		X								
	Methicillin-resistant *S. aureus* infection	X	X	X	X	X	X			X	
Water-borne diseases*	Hepatitis A	X	X	X	X	X	X	X	X	X	X
	Enterohemorrhagic *E. coli* (EHEC) infection	X	X	X	X	X	X	X	X	X	X
	Typhoid fever	X	X	X	X	X	X	X	X	X	X
	Cholera	X	X	X	X		X	X		X	X
	Bacillary dysentery (Shigellosis)	X	X	X	X	X	X	X	X	X	X
	Campylobacter sp. infection	X	X	X		X	X	X	X	X	X
	Salmonella sp. infection	X	X	X		X	X	X	X	X	X
	Giardia sp. infection	X	X	X		X	X	X	X	X	X
	Legionella pneumophila infection	X	X	X	X	X	X	X		X	X
	Cryptosporidia infection	X	X	X		X	X	X	X	X	X
	Vibrio species infection		X				X	X		X	X
	Naegleria fowleri (amoeba) infection							X			
	Gastroenteritis hospitalizations		X	X				X			
	Norovirus infection		X	X		X		X	X		

*Water-borne diseases are those that can cause infection by being present in drinking water.
†Water-washed diseases are those where personal sanitation practices involving water can interrupt transmission.
‡Reportable diseases in Russia vary by region, and are not necessarily reportable nationwide.

The impact of such a situation for the Arctic which has inadequate water treatment options in many remote communities would be far worse, as the human populations are much larger than in the Antarctic.
Antibiotic resistant strains of bacteria pose a real threat to human health as population density increases in regions with few final disposal options. It becomes imperative that the areas, which are remote, and are closer to concentrations of wildlife, should as a matter of urgency address the issues raised by lack of water treatment facilities. A number of solutions exist which could be adapted to the Arctic environment. The adoption by the Arctic research stations of good practice would also serve as a test case for rural populations, leading to a knock on effect that would lead to wider community benefits.

The 2000 EU Directive on water states that "*Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such*[26]". This opening statement demonstrates a language that will have to evolve as the pressure on water resources continues to escalate, even in remote

[26] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy *Official Journal L 327 , 22/12/2000 P. 0001 - 0073*

locations. Water is essential to life, and a lack of safe drinking water rapidly becomes an existential threat. Perhaps it is time to consider water less as something owned by right, and more as a responsibility. Needless to say, a more stringent approach to management will be required to assure continued access to this precious resource in the future.

Waste Management

While Stations close to urban centres will benefit from the removal of waste to municipal handling facilities, those operating in more remote locations will have to manage storage and handling of solid waste. In the Antarctic case, the waste could only be removed by ship during the annual re-supply, and for the most part the older Stations were compelled to create waste dumps. The Committee for Environmental Protection set up under the Antarctic Treaty System publishes a "**Clean Up Manual**" which provides guidance to Station Operators, on applying Recommendations made under Annex III to the Environmental Protocol. In the 2014 edition, it states that: *"Based on extrapolation from a few well-documented sites, it has been estimated that the volume of abandoned, unconfined tip materials in Antarctica may be greater than 1 million m^3 and that the volume of petroleum-contaminated sediment may be similar (Snape and others, 2001[27]). Although this is a relatively small volume compared to the situation in other parts of the world, the significance of the associated environmental impacts is magnified due to the fact that many Antarctic contaminated sites are located in the relatively rare coastal ice-free areas that provide habitat for most of the terrestrial flora and fauna".* The Clean Up Manual also states that "*In general such contaminants degrade very slowly in Antarctic conditions*".

Annex III has recognised the practical difficulties in dealing with historic waste under Art. 1.5: *'Past and present waste disposal sites on land and abandoned work sites of Antarctic activities shall be cleaned up by the generator of such wastes and the user of such sites. This obligation shall not be interpreted as requiring: a) the removal of any structure designated as a historic site or monument; or*

b) the removal of any structure or waste material in circumstances where the removal by any practical option would result in greater adverse environmental impact than leaving the structure or waste material in its existing location.'

The Clean Up Manual looks at the objectives, the urgent reasons for clean up (such as potential further contamination from leaking oil drums, potential hazards to human health), and the principles guiding a clean-up strategy (information management, site assessment, environmental assessment, quality targets, clean up actions). Clean up techniques suggested include those from other parts of the World "*adapted for Antarctic conditions*", containment, *in situ* remediation, removal from site, where this does not cause more damage to the site.

Next Steps

The realities of each Station are vastly different, and applying a one size-fits-all approach is of limited value. To be able to provide each Station with the means of addressing their own needs will require the development and use of tools for assessment of current impacts, and the audit of needs in terms of energy needs, and water use and treatment. There are rapidly implemented solutions available, which one could consider as "*low hanging fruit*", financially accessible and with immediate impact. Reaching Zero Emissions will not be possible for every Station in the group, because there are still many elements, which are under development and delivering a solution, which is cost effective, will depend on the cost of energy and

[27] Snape, I., Riddle, M.J., Stark, S., Cole, C.M., King, C.K., Dubesque, S., & Gore, D.B. 2001. Management and Remediation of contaminated sites at Casey Station, Antarctica. Polar Record, 37(202), 199-214.

utilities in each location. Zero Emission has to be built into the concept from the design phase to be able to optimise the management of energy and this also comes at a cost.

In discussions with the members of the Station Managers' Forum, it became clear that the best way to approach this complex issue (further complicated by the regional, national and local realities) would be to create a platform on the Internet to allow the members to share challenges and Best Practices from each Station site. As INTERACT already has a platform for the collaborative activities of the Consortium, it would be perfectly feasible to add to this another layer where Station Managers could access success stories from others having comparable constraints. Resources would be made available to help individuals assess the potential of their Station sites, the technologies available, and the sources of funding, nationally and internationally. This would lead to "stepped" impact reductions which would make the process less daunting.

This report will examine how to approach the reduction of environmental impact from the perspective of Station Managers looking to navigate through the complexities of legal frameworks, technical regulations, funding and the technologies and processes available. As environmental technologies are evolving at a rapid pace, fixing Best Practice in a rigid format (such as a printed Manual) will be of limited use going forward. An Internet platform for the sharing of Best Practice will therefore become the format of choice in delivering an optimal service.

The content and functioning of the web-based tool will be discussed within the Station Managers' Forum to see what information would be of most use. In addition, case studies of projects undertaken could also be posted to provide concrete examples of how to approach the tasks outlined. Links to service providers and technology providers could be included to allow access to the most recent technological solutions on offer, and this would have the benefit of allowing each Station to choose providers on the basis of up to date information and recommendations from other members of the Consortium. Having a trusted network to make recommendations is of enormous value where on-line reviews are often suspect. With regard to training of personnel, it would be possible to share information on the training courses available, as well as for Stations using the same technology providing training to those wishing to adopt similar methods, again via the web based platform.

The Impact Reduction Road Map

The network of Station Managers and their existing know-how will be used to find ways to share Best Practice in the reduction of environmental impacts of Arctic research operations. While this Task addresses to a significant extent the roll out of renewable energy technologies, smart grids, automation, energy efficiency and water treatment, it is not limited to that aspect. Environmental impacts of operations involving field science campaigns in the Arctic often imply other types of environmental pollution, as well as other types of environmental impact related to effects on the ecosystem from a human presence. The IPF as an Antarctic operator, and in particular the operator of the Princess Elisabeth Antarctica, uses the lessons learnt from Antarctic operations carried out under the framework of the Madrid Protocol to the Antarctic Treaty. From the experience gained from the Antarctic, it emerges clearly that pre-activity assessment is a key element of reduction of impact.

Environmental Impact Assessment tools have been developed by national and international bodies, *inter alia,* by the Committee of National Antarctic Program Managers, (COMNAP). While certain EIA tools exist for the European Union or for the lower latitude Arctic countries, the particularity of operations in remote and ice bound areas may require a more targeted approach taking into account the specific conditions of the area being assessed. For this, the Antarctic tools may be useful, and can be devolved to some extent for an Arctic context. There are limits to this exercise as the context of the Arctic Region is not the same as for the Antarctic Continent, which has a unified administrative framework for environmental questions, and a very small human population. A lot of information on this and other aspects of preparing an environmental impact reduction strategy have already been provided in Management Planning Handbook (*referred to below*), and it would not be useful to duplicate this effort.

The INTERACT network is so diverse and faced with such different conditions and challenges, that any advice should include customizing the approach to a specific set of circumstances. The subject matter is also in an area of rapid evolution, with technological advances arriving very rapidly and rendering any specific advice given, obsolete within less than a year. In this case, the most valuable elements to provide as Best Practice are ways of proceeding to set and reach impact reduction goals in an economically accessible way.

A key INTERACT I project deliverable was the publication by the Station Managers' Forum of the Management Planning Handbook – entitled "*Management Planning for Arctic and Northern Alpine Research Stations – Examples of good practice*". The issue of environmental impact reduction was covered at length in this handbook, which goes into extensive detail on the best practices currently in place for a variety of management related topics. Legislation and Standards were also addressed: *"National legislation on environmental protection may include regulations on a number of issues relevant for operating a research station, e.g. sustainability in construction, energy consumption, emissions, use of hazardous substances, recycling, garbage and waste handling, water consumption/disposal, etc. While it is important that stations stay updated on some legislation relevant for station operations (research permits, dispensation from specific legislation), other relevant legislation can be visited on an ad hoc basis when activities so demand (e.g. developing new infrastructure, revising management plans, etc.). Station management should establish good contact and communication routines with authorities in order to stay updated on relevant legislative developments related to station management and environmental issues. A record of relevant legislation can be useful especially if there are frequent staff change".*

It is taken as a base-line that each of the 86 stations in INTERACT II will already have a good appreciation of the legal and regulatory constraints with which they are confronted in their daily operations and prescribing a one fits all approach in this Manual would, again, be counterproductive.

The Management Planning Handbook also looks at the question of accreditation, and **ISO standards** applicable to Environmental Management Systems, Sustainability in building and greenhouse gasses and carbon footprints, and finally Environmental Management and Life-cycle assessment. Examples of Environmental Impact Assessments, Guidelines and checklists from various sources[28] are also provided. Access to these tools is thus available and it is not necessary to furnish additional information on this aspect of environmental strategy planning. Rolling out a new strategy for environmental impact reduction requires some prior investigation of the physical environment. The work of the research stations is in itself part of the process, and much of the required information on physical resources present on the site will be known. The main focus of this Report will be on the technological developments, which can help to reduce the impacts from operations.

[28] Page 151-2, Section 7.3

The technologies available today for reducing environmental impact are growing in an exponential manner, and it is often confusing even for those who are working specifically in this field. The transfer of technology from other sectors such as the Space Sector has led to a burgeoning new industry not only for energy production, but also for waste treatment, new materials, communications technologies and procedures for building. However, one should not lose sight of the fact that sometimes, traditional methods are perfectly well adapted for the environment in which a Station will operate. Operating a balanced approach and assessing when it is good to introduce new methods and technologies, and when it will be simply an expensive exercise with little additional benefit for operations, is a complicated exercise.

The cost implications are an important part in deciding how to roll out new technologies. Other considerations are linked to the ease of deployment and operation. Will the logistics available allow the solutions to be implemented? Will the new technology require specialised personnel? Station managers should be aware that acquiring expensive hardware may result in you finding that you need to employ specialised engineering personnel to be able to operate it. An examination of the legislative and regulatory frameworks and other discretionary frames of reference such as international standards is also recommended. The choice of method is open to each Station Manager. There are active measures, and passive measures that can be employed to reduce environmental impacts. There is also the consideration of the human aspect of the issue. *"Key elements in minimising the impacts of station activities are to regulate user behaviour and limit resource use. User behaviour can be regulated through policies, regulations, procedures and guidelines communicated to staff and visitors in relevant documents. Emissions to the natural environment can be minimised by limiting resource consumption and ensure safe handling and disposal of waste, garbage, contaminants and hazardous substances. Limiting the number of people is another way of limiting impacts and ensuring that environmental conditions do not deteriorate. The size of the area and the environmental impact mitigation measures developed at the station determines how many people the station can support without significantly impacting the environment"*[29].

A number of strategies for the reduction of environmental impacts are discussed, including limiting numbers, limiting resource use, minimising packaging, using digital methods to save paper, regulate user behaviour, oil spill handling, the three "R"s (reduce, re-use, recycle) and "green" procurement. The take away Key Considerations in the Manual (*pg 166*) point out how to manage Resource Use and Waste Handling:

- Energy Consumption: limit, and identify alternative energies/ sustainable energies.
- Chemicals and other hazardous substances: find alternatives, limit use, export for disposal and treatment, clean up spills
- Waste Management Strategy
- Water consumption: limit consumption, find disposal mechanisms to avoid excessive pollution

The aim of this Report is then not to be repetitive, but to find ways to facilitate action where it will have the most impact. One of the ways in which this can be achieved is through the development of tools to help assess needs and also to help in decision making concerning the choice of technology which will be adapted to the needs of each individual site. Following on from the Workshop held at the Station Managers' Forum in the Tyrol (Vahrna) in March 2018, a number of aspects of the exercise were identified as being of potential interest based on the experience of individual Stations, and the diversity of environmental conditions with which they were confronted.

[29] Elmer Topp Jorgensen

The Station Catalogue produced under INTERACT I, as mentioned previously, has detailed information concerning the Arctic Stations, which are members of the Consortium. Statistics, however, are not available for the more extensive analysis of energy needs, or water treatment options. The technical audit element should be addressed by each Station Manager, individually. Questionnaires cannot address this type of information adequately, and the experience with this investigative tool has shown that the number of responses is generally very low, and that the sample size is too small to allow any general comparisons to be drawn. The intention is, therefore to provide a tool for those who wish to proceed to implement some of the measures suggested.

Elements of a Road Map

A Road Map for impact reduction could be suggested to allow for the step-by-step adoption of impact reduction and mitigation using passive and active solutions to reach a pre-defined objective (Figure 6):

1) Carry out an Environmental impact assessment of current operations – for example: types of pollution, quantities of pollutants (how much carbon dioxide produced, how much solid waste, how much wastewater), contamination of water sources, impacts on local habitats (flora and fauna) of operations, noise pollution, degradation of soils, etc.
2) Audit current energy production and consumption (including all devices using electricity and their load profile), and water use.
3) Carry out a site survey to examine the environmental parameters for your project (wind potential, solar potential, hours of insolation, measurement of the solar potential, topography, water sources, etc.).
4) Define your impact reduction strategy (energy, water, waste).
5) Examine energy efficiency options that are practicable for your case (*passive building technologies, innovative building materials or techniques, automation, remote operation, low energy devices*).
6) Choose your renewable energy technologies based on the local conditions (availability of solar energy, wind potential).
7) Define solid waste management strategy.
8) Examine water treatment options in function of the site conditions.
9) Establish a Green Procurement strategy.
10) Assess the environmental impact reduction from combined strategies.
11) Identify funding sources.
12) Find technical partners to carry out Energy and Water Treatment projects, or train in-house personnel.
13) Identify competences required for the operational phase.
14) Install the selected solutions.
15) Train crew in the use of new technologies.
16) Collect statistics on the operation of the new technology.

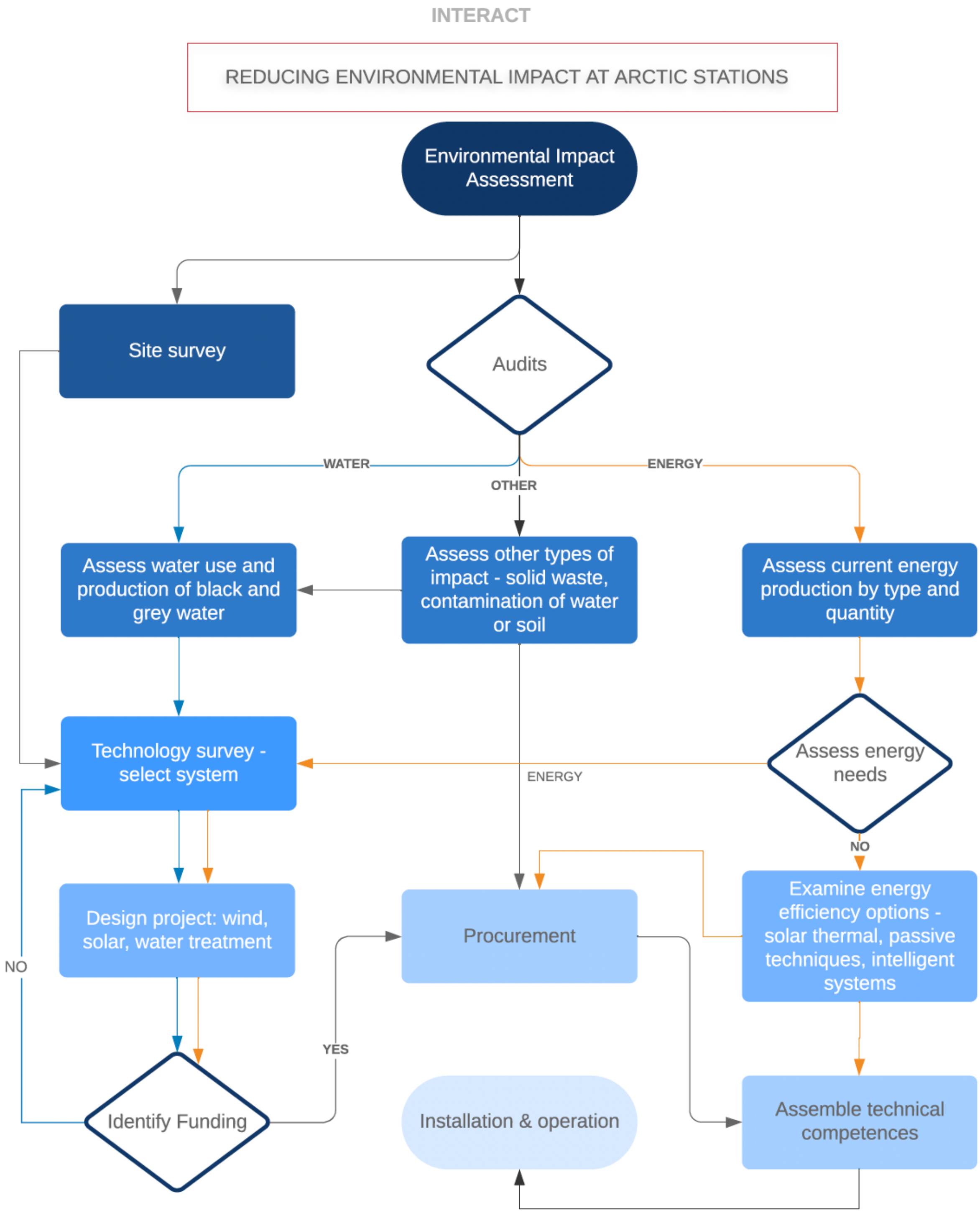

Figure 6. An example of a Road Map for impact reduction that follows step-by-step adoption of impact reduction and mitigation at a research station.

Environmental Impact Assessment

In addition to the guidelines supplied in the INTERACT Management Planning Handbook[30], There are several approaches and guidelines available for carrying out an Environmental Impact Assessments (EIAs). The approaches suggested by the EU, the Arctic Council, the ISO 14000 family of standards, and the Committee of Managers of National Antarctic Programs (COMNAP), all have elements that are relevant to the situation of Arctic Research Stations. An INTERACT Station Manager will have the choice of which approach to adopt, and can also combine different approaches that meet the local circumstances.

The EU Approach

For EU Member States, elements of the EU approach will be mandatory or discretionary depending on the application of the relevant legislation and the transposition of enabling legislation. Most Member States have passed enabling legislation to give effect to the environmental directives such as the Environmental Impact Assessment Directive, and the Strategic Environmental Assessment Directive (SEAD). Under this measure any plan or programmes likely to have a significant impact on the environment are required to carry out environmental assessments. EU legislation tends to be aimed more frequently at public authorities and larger scale projects[31]. Some of the requirements would be too onerous for a small-scale project, where the scale is not large enough to merit such a deployment of time and resources.

The Arctic Council Approach

The Sustainable Development Working Group of the Arctic Council (SDWG) has published the report "*Good Practices for Environmental Impact Assessment and Meaningful Engagement in the Arctic – including Good Practice Recommendations*", also referred to as the Arctic EIA[32], which was initiated during the Finnish Presidency of the Arctic Council. The objective of the Report is to provide guidelines, which are Arctic specific, and which take into account the needs of the indigenous populations of the Arctic. The sharing of Best Practice was considered primary to the exercise. However, most of the projects listed in the report are relating to mining and large-scale developments, which impact the local population. The approach will not be relevant to the small-scale localised changes that Station Managers will be considering. It should be borne in mind that any larger scale modifications to a site should be discussed with neighbours, in particular if there are any impacts on them. For example, the erection of wind turbines may have some negative reactions from neighbours who are situated in the immediate vicinity, as the noise generated by larger turbines can be an annoyance. Equally, if large areas are given over to water treatment projects that use the land for filtering, there may be some issue over olfactory disturbances. The concerns of neighbours in the community should be addressed before any project is begun. The SDWG report refers to Impact Benefit Agreements (IBAs) signed with communities, particularly indigenous communities, and this avenue can also be explored should it be relevant to the situation of the research Station.

Antarctic Approach

The Antarctic approach may not be entirely relevant to the Arctic Station situation, as there are existing laws and regulations that will govern the planning of new projects, particularly in built-up areas. The

[30] INTERACT Management Planning for Arctic and Northern Alpine research stations - Section 7 Environmental Impact – pg. 151-166 – Appendices pg. 312 - 318

[31] Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment Text with EEA relevance.

[32] Good Practices for Environmental Impact Assessment and Meaningful Engagement in the Arctic – Including Good Practice Recommendations -Arctic Council, Sustainable Development Working Group (SDWG), Arctic Environmental Impact Assessment (EIA) project – 2019 - Editors: Karvinen, Päivi A. & Rantakallio, Seija, Ministry of the Environment of Finland assisted by the Arctic Centre, University of Lapland. © Arctic EIA project - ISBN: 978-952-361-005-7

general methodology as laid out under Annex I to the Protocol is of interest as it provides some useful indicators of the type of information that should be collected. In short EIA's should be able to provide the following information:

i) *the scope of the activity, including its area, duration and intensity;*
ii) *the cumulative impacts of the activity, both by itself and in combination with other activities in the Antarctic Treaty Area;*
iii) *whether the activity will detrimentally affect any other activity in the Antarctic Treaty Area;*
iv) *whether technology and procedures are available to provide for environmentally safe operations;*
v) *whether there exists the capacity to monitor key environmental parameters and ecosystem components so as to identify and provide early warning of any adverse effects of the activity and to provide for such modification of operating procedures as may be necessary in the light of the results of monitoring or increased knowledge of the Antarctic environment and dependent and associated ecosystems; and*
vi) *whether there exists the capacity to respond promptly and effectively to accidents, particularly those with potential environmental effects'.*

The basic principles are that the information collected should allow informed judgements to be made about the potential impacts. In this scenario there is an external adjudicator, whether the National Competent Authority (usually the Ministry of Environment) or the Committee on Environmental Protection (CEP) of the Antarctic Treaty. There are different levels of assessment going from the summary approach used in the Initial Environmental Evaluation, to the in-depth applied to the Comprehensive Environmental Evaluation depending on whether the impact is minor or transitory to whether the impact is more than minor or transitory. The use of legal terminology creates some issues in the interpretation of the intention of the Parties[33]. Frequently, the terms are virtually impossible to define, and the Parties will apply themselves to ensuring that in practice damage is limited to the extent possible to allow operations to proceed without long-term harm.

The Antarctic case sets the bar very high, and for most Arctic Stations in the sample, the requirements may be overly demanding. Some elements can be adopted from the Best Practice, such as for the management of fuel in remote locations, but other concepts may be difficult to adhere because of the imprecise nature of the wording.

Conclusion
The INTERACT Station Managers Handbook provides useful guidelines for addressing environmental management and impact assessments at Arctic Research Stations. The experience within the group is wide enough to allow a customised approach to be adopted for the local conditions and regulatory frameworks, allied with a rigorous methodology seeking to cover the intended objectives of real and measureable impact reduction for the Arctic context. The intention of this Report will be to focus on the areas where achievable targets can be set for impact reduction from waste management and the deployment of technologies for water treatment and energy production.

[33] CEP Guidelines – pg 110. **Res 1 (2016)** Although the key to decide whether an activity shall be preceded by an IEE or a CEE is the concept of "*minor or transitory impact*", no agreement on this term has so far been reached. The difficulty with defining "*minor or transitory impact*" appears to be due to the dependence of a number of variables associated with each activity and each environmental context. Therefore the interpretation of this term will need to be made on a case-by-case site-specific basis. As a consequence, this document does not focus on seeking a clear definition of "minor or transitory impact", but rather is an attempt to provide basic elements for the development of the EIA process.

Elements of the EIA

All Stations will have a history of environmental assessments carried out in the operations of the research station. The objective here will be to assess the impacts from the roll out of sustainable development technologies to improve performance. Virtually all EIAs require some degree of baseline information, or information about the current state of the site. In order to have a fully coherent approach, the EIA should consist of baseline elements and assessments of proposed modifications:

- Site Survey
- Assessment of the current situation (with regard to energy use and impacts on the environment, water use and waste-water production, solid waste, including types of waste and quantities generated). Audits will need to be carried out.
- Current methods used for mitigation of environmental impact, and an evaluation of their effectiveness.
- Proposed impact reduction strategies with regard to energy use, water treatment, waste management.
- Evaluation of the impact of the planned modifications.
- Some EIAs require that an assessment be made also of the evolution of the site if the planned modifications are not carried out.

Site Survey

The site survey is a key part of the base-line assessment. The kinds of information collected will depend to some degree on the technological strategies to be implemented at a later stage in the process. The groundwork has already to be carried out in order to have the information required on the site characteristics, which will determine what solutions are technically feasible. The parameters to be studied will depend on the technologies to be introduced. For example, for wind production the site survey will have to examine the site topography and the wind potential using wind speeds and direction to assess the size of turbine and its siting. The size of the turbine that can be built will also depend on the logistics possibilities and the availability of heavy machinery. The position of the turbine will also depend on the presence of bird colonies in the area. The site survey will also include a mapping of the area in order to assess options with regard to water treatment. The level of treatment will depend on the quality of water that can be discharged into the environment. Discharge into water bodies will take into account whether these are connected to the sea or whether they are enclosed.

Assessing Sources of impact

In order to address environmental impacts to create the base-line data, will require an assessment of the current situation with regard to sources of impact. The most significant sources of environmental impact of human activities are water use and fossil fuel use (leading to the production of greenhouse gases (GHGs) and other forms of pollution of the surrounding areas). Reducing GHG emissions will lead to a localised and a wider impact reduction. Locally, the reduction in the use of fuel for generators leads to an immediate improvement in air quality and noise reduction, as well as a measureable reduction in the contribution to global carbon emissions. Particulate matter, and emissions of gases (CO_2, CH_4, NH_3, NOx, PM2.5, PM10, SO_2, VOCs (volatile organics)) are also reduced leading to better air quality, boosting human health. The use of less fossil fuel will inevitably lower the risk of oil spills, reduction in the fuel required to deliver fuel to the site, reduced maintenance of generators, etc. One modification will, therefore, have several knock-on effects. Addressing waste-water treatment (WWT) will lead to less contamination of local water bodies and reduction of impact on wildlife. The human health considerations are also evident.

Assessing solid waste management will allow for a targeted approach to procurement, applying the 3R rules of reduce, re-use, & recycle, but also introducing green procurement where reduction in plastics can selectively be applied across the whole range of supplies.

Setting reduction targets
The base-line assessment will allow the setting of realistic targets for the site based on geographical location, logistic constraints, and financial means available. Setting targets will be an iterative process, with choices being examined and assessed according to technical characteristics and cost, with an eventual choice being made to balance objectives and resources. The internationally recognised ISO standards series can also be helpful in setting targets for operations. These are a set of discretionary guidelines for improving environmental performance, and can lead to certification of good environmental practices. The ISO 14000 series can help to shape strategy and allows for customisation of approach in function of the size and other constraints of the enterprise being considered[34]. The ISO 14000 family of Environmental protection standards can be of help in setting up an Environmental Management System. The basic standard ISO 14001 provides useful methodology to apply when beginning the exercise of impact reduction. The Station Manager can opt for self-certification or for apply a system recognised by a National Accrediting Body, which implies additional costs. Self-certification is recommended for those Stations who have qualified personnel to carry out the procedures.

Monitoring Outcomes
An important part of the process is to monitor the impact reduction outcomes using key indicators such as fossil fuel consumption, energy generation using renewables, percentage of water being treated before release into the environment, improvement in water quality and reduction in the presence of pathogens in the surrounding water-courses. Monitoring the outcomes helps in refining the strategy adopted in order to continuously improve the environmental performance of the Station. This commitment to review operations and to continuously seek improvement is also a part of the ISO 14001 approach.

EIA - Audits

In order to create a full base-line scenario of current significant environmental impacts, it is necessary to audit the energy consumption, water use and waste generation of the Station. This data will be crucial in defining what steps can be taken to address impact reduction through strategies such as waste reduction, waste treatment, energy efficiency and the use of renewable energy technologies. Energy, waste, and waste water related audits can be carried out either by a consultant, or by the Station crew, depending on the final use to which the audit will be put (in-house, local authorities, funding body, external financing). Guidelines exist for different cases depending on various factors, including the local authority regulations. Local building guidelines may also be able to provide a standard form audit procedure.

Energy audit
An energy audit is the first step in any planned action for environmental impact reduction, and will take into account all types of energy use, whether these are electrical or thermal (such as from gas heaters or cooking appliances). The energy audit will also look at heat loss from a building, whether through windows, walls, or roofs. Transport is also something that can be covered in the audit if this concerns means of transport owned by the Station.

[34] The INTERACT Station Manager’s Handbook provides references for the ISO standards that could be relevant to the exercise under consideration.

The EU provides a Guidance note on Energy Audits and energy management systems[35], which is instructive. It defines energy audits as follows: *"An 'energy audit' means a systematic procedure with the purpose of obtaining adequate knowledge of the energy consumption profile of a building or group of buildings, an industrial or commercial operation or installation or a private or public service, identifying and quantifying cost-effective energy saving opportunities, and reporting the findings";* The Guidance Note further states: *"Energy audits are* ***an essential tool*** *to achieve energy savings. They are necessary to assess the existing energy consumption and identify the whole range of opportunities to save energy. This should then result in proposals of concrete saving measures for the management, public authorities or home owners. Furthermore, energy audits allow the identification and prioritization or ranking of opportunities for improvement.* ***In this way, energy audits tackle the information gap that is one of the main barriers to energy efficiency****".*

While the Energy Efficiency Directive has made it a requirement since 2015 to have professional energy auditors who are supervised by National Authorities, or to have in house expertise subject to external supervision and quality control, this is not a requirement in the non-EU country research Stations, and generally will not be mandatory except for larger institutions. The criteria for energy audits, because of their mandatory nature, are that they must be "*cost-effective, undertaken by qualified/accredited experts and supervised by independent authorities*." It is also a mandatory requirement in EU countries to have an **energy performance certificate** for buildings, whether public or private. The situation with respect to energy auditing and building performance certification in non-EU countries is not investigated here, as it will be assumed that where no mandatory requirement exists, Arctic research stations can elect to carry out audits of energy and performance as a form of self-certification.

Relevant international standards (ISO) relating to energy audits are:

- EN ISO 50001 (Energy Management Systems - energy consumption)
- EN ISO 5002 (Conducting an energy audit),
- EN ISO 16247-1 (Energy Audits) or
- EN ISO 14001 (Environmental Management Systems falling under the EU's Eco-Management and Audit Scheme)).

These standards can be applied to ensure Best Practice, where necessary. The EN ISO 14000 is the wider family of tools for environmental management. Some of the standards from the ISO 14000 family look at environmental performance (ISO 14031), Life cycle assessments (ISO 14040), Eco design (ISO 14006), and Green House Gas Accounting (ISO 14064). If an ISO standard is to be used, the best place to start is the ISO 14001. The claim for the ISO 14000 family is that used together the tools can lead to "*tangible economic benefits*", resulting from reduced raw material use, reduced energy consumption, improved efficiency, reduced waste generation and disposal costs, and re-use of recoverable resources. However, there are a large number of standards and it would be easy to get lost in the complexity if the Station Manager is not conversant with this approach. More information is available on the ISO web site www.iso.org

For the Stations that opt for a simplified methodology, the recommendation is to carry out the audits in line with available resources at the Station, be they human, material or financial. To apply the simplified methodology, proceed to make a full inventory of all the electrical loads at the Station, as well as all adjuncts to the use of energy:

[35] Commission Staff Working Document SWD(2013) 447 final – Guidance Note on Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EC, and repealing Directives 2004/8/EC and 2006/32/EC – Article 8: Energy audits and energy management systems

1) Inventory of all electrical devices (loads) on your station – including a “load profile” defining the operational characteristics of the load (two phase, three phase, intermittent, continuous, current, voltage, etc.)
2) Consumption of energy (max) – the total consumption of all electrical loads should be established in a table called the “Load balancing table”.
3) Operating profile – the daily profile of energy use for the Station should be established
4) Inventory of all energy generation possibilities, including heat – heating systems, fossil fuel generators, grid supply, solar panels, wind turbines, hydro-electric energy, geothermal energy.
5) Establish the amount of greenhouse gases, and other by products produced from the burning of fuel, including from vehicles, and logistics means for delivery of supplies to the Station. This can be achieved either by direct measurements, or by calculating the theoretical generation of gases and by products of combustion depending on the type of fuel used.
6) Availability of energy, ease of procurement and cost of energy currently on site by KWh. The ease of delivering energy to the site will be a function of whether or not the site is grid – connected or off-grid. Flying in fuel drums will be a restrictive condition adding greatly to the cost of energy.
7) Air conditioning systems, including heating and ventilation, heat exchangers at the Station.
8) Energy storage capacity (fuel, or batteries)
9) Assess transport related energy consumption – cost of delivery to site
10) Carry out risk analysis of the possibility of fuel spills from current operations.

The data will allow a Station operator to identify where energy savings can be made, as well as where auxiliary impact reductions could be achieved. This would be the theoretical target, to be refined in function of other factors that could influence the feasibility of the actions designed to make the reductions.

Greenhouse Gas Audit

A number of tools are available for auditing the greenhouse gas emissions from Station operations. After the mitigation strategy has been deployed, the reduction of impact can be assessed using the same methodology. The following web sites provide tools and excel sheets for the calculation of Greenhouse Gas (GHG) emissions (Table 8). The impact is calculated in terms of tonnes carbon dioxide equivalent (tCO_2e) taking into account the other gasses emitted such as methane and nitrogen oxides (CH_4, and NO_x), which have a higher global warming potential than carbon dioxide. Simple calculations will allow you to estimate emissions for all operations including fuel use in diesel generators, and vehicles.

Table 8. Web sites that provide tools to calculate Greenhouse Gas Emissions

Organisation	Web site
US Environmental Protect Authority	https://www.epa.gov/ghgemissions
Carbon Calculator	http://www.carbon-calculator.org.uk
UK Government	https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018
GHG Protocol	https://ghgprotocol.org/calculation-tools

The Princess Elisabeth Station uses Jet A1/Polar diesel for running all vehicles, tractors and also back up generators because the freezing point is much lower than for ordinary diesel at -47°C. Diesel freezes at -

40°C. This permits the procurement and management of only one fuel for all uses. The conversion factor taking into account the specific density, and the calorific content of Jet A1 is 2.54 tCO_2e for a thousand litres of fuel, or 3.181 tCO_2e /tonne, or 0.257 Kg/kWh. (*Note: The specific density of Jet A1 varies between 775 and 840 g/L. At 15°C it is 804 g/L*). Every 200L drum of fuel saved represents a reduction in emissions of 0.5 tCO_2e. A wind turbine of 6 kW running 10 hours a day at only *half* its maximum output represents an impact reduction of 30 kWh or 0.08 tCO_2e. Over a year this would be approximately 3 tCO_2e. Diesel has a slightly higher rate of emissions at 3.209 tCO_2e/tonne. The difference means that for every drum of Jet A1 used instead of diesel, the reduction in emissions is in the order of 20 Kg CO_2.

Estimations of cost savings

Estimates of cost savings over time for the reduction in the use of fossil fuels (for example) will be useful for attracting financing, from a funding agency or a bank, if own resources are not sufficient for the investments under consideration. A 200 litre drum of diesel will have an energy content of 2,111 kWh. Operating a 6 kW turbine over a year at half its maximum output represents a saving of 5.2 fuel drums. As a rule of thumb, you could estimate fuel savings in the order of *1 drum per kW* of installed wind power (varying according to the price per drum and the wind potential of the site). The same exercise could be carried out for any solar PV or solar thermal heating installations. Additional savings could be from becoming grid connected for those Stations that have this option. Contacts with the local electricity provider should be established early in the process, as this would be a good source of information and advice. EU guidelines promote the use of Life Cycle Cost Analysis, to be able to assess long term cost savings. However, for financing capital expenditure it might be of use to know how long it would take to recover the outlay for new installations. The quality of an energy audit will often be a key factor in gaining access to funding, whichever scale is concerned. For research stations in EU Member States, it would be worth checking with local authorities if financial and technical support exists for Energy Audits, in line with EU policy and recommendations.

Water Audit

A water audit should be carried out where improvements can eventually be made to the current situation with regard to water use and discharge of waste-water.

1) Number of users
2) Types of use in the Station.
    - Kitchen
    - Laundry
    - Sanitary facilities producing grey water
    - Sanitary facilities producing black water
3) Types of use in field camps or logistics traverses.
4) Source of water – some Stations will be connected to municipal supplies, while others may have to resort to melting snow in order to obtain domestic water supplies.
5) Quantities of clean water used per capita
6) Quality standards applied.
7) Connection to municipal waste-water treatment facilities.
8) Type of water treatment used on site (direct discharge, filtering, mechanical, natural processes, high grade treatment (MBR)).

Arctic Research Stations, as we have seen are very diverse in their size, location, and distance from urban centres. This reality will affect not only the sources of drinking water, and domestic sanitary water, but also the strategy adopted for the handling of waste-water. Discharge into enclosed water bodies is likely to create problems from cumulative impacts, in particular as the environment cannot handle natural treatment in very low temperatures. Bacterial breakdown will be slowed or stopped. In very cold regions, wastes can remain intact over extremely long periods, and it can be expected that contamination by pathogens will lead to epidemics as the ground warms. This is yet another adverse effect of global warming that has been experienced already on the Antarctic Peninsula, and in other remote locations, where the retreat of the ice has uncovered organic matter thought to have been "disposed" of more than a half century ago. The decisions with regard to water treatment will also depend on whether or not a station is being served by the municipal sewage collection and treatment services.

Needless to say, even the municipal handling of waste-water is unequal throughout the Arctic region[36]. Even in countries with high grade municipal water treatment capabilities, the situation in remote areas will differ. Remote Arctic communities with access to the sea will practice a direct discharge. These findings are corroborated by several studies. "*In general, the Nordic countries share a number of similarities related to environmental protection and sanitation regulations. However, there are substantial differences among the member countries regarding the governance of wastewater treatment systems outside sewage networks*[37]".

Direct discharge to the sea may be seen as a viable option in areas where populations are low, but is not an option beyond a certain size. From the Norwegian case (see below), it can be seen that the cut-off point appears to be around 5000 inhabitants. Mechanical treatment and natural purification, can be seen to be practised in population centres up to 20 000 inhabitants (Figure 7).

Water use and treatment options will depend on several factors.

1) Statistics will establish the use profile. The number of occupants of the Station, and the amount of water used by an individual will vary from Station to Station, and on the methods used for reducing consumption. A use profile can be established on the basis of occupancy rate and quantities of water required for sanitary use (showers, toilets, etc.) and water required for cooking and drinking.
2) Distance from an urban waste water treatment plant
3) Distance from a water body, or the sea.
4) Climatic conditions, in particular maximum and minimum temperatures during the year.
5) Characteristics of the substrate – a Station built on deep soil will have more options for building containment and ground filtration infrastructure.
6) The amounts of wastewater generated by person per day for grey and black water.
7) The quality of the water required. A Station can opt to have a single supply of standard quality, which will be of potable quality.

[36] European Environment Agency – urban waste water treatment - https://www.eea.europa.eu/data-and-maps/indicators/urban-waste-water-treatment/urban-waste-water-treatment-assessment-4

[37] Finnish Environment Institute (Suomen ympäristökeskus / Finlands miljöcentral)
Small-scale wastewater treatment systems: governance, efficiency, resources recovery, environment contamination risks and innovative solutions for processes optimization

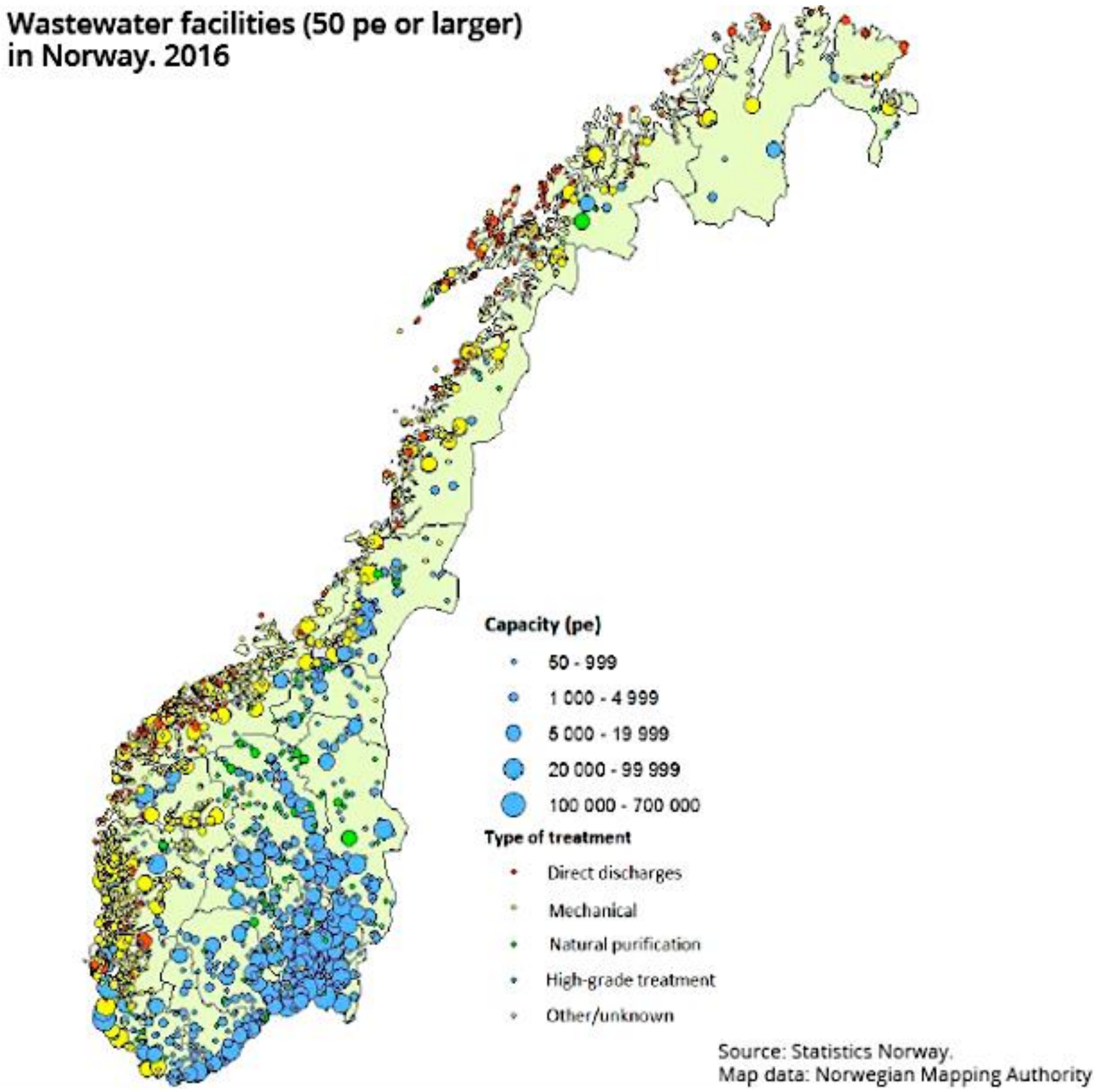

Figure 7. Waste-water facilities in Norway 2016 (Statistics Norway).

The quality of the station water supply should be assessed, in particular if this is a river, or stream, or a lake. Even spring water should be analysed before being used for drinking water. This will require laboratory analysis and biological culture to establish whether the water source is already drinkable of whether it requires further treatment. Is the water supply sufficient? If not, can it be increased? If the supply of water for all uses is limited, then the introduction of water treatment and recycling could provide an additional source. Where water is obtained from melted snow, the use of energy for melting the snow will have cost implications (unless this is provided by renewable energy).

At Princess Elisabeth Station, the water cycle begins with snow. The only source of water is melted snow, so the Snow-Melter Unit is a key part of the "Life Support Systems". The water is produced almost exclusively using heat from solar thermal panels, although excess electrical energy is also dumped into the snow-melter resistances when the storage capacity is full. The cost implication in this type of system is in capital investment (panels, heat exchangers, pumps, valves, sensors, and anti-freeze) and engineering costs. Once the installation is running, the payback time is very short. The production capacity is over a thousand litres a day, which means that the investment is recovered in *less than two years* from the reduction in cost of bringing fuel on site for water production. Circulating hot water is also used for space heating. The thermal energy flows are managed by automation. The final automation step adds to the cost of running the installation, but the investment can also be recovered by the reduction in the number of people required to manage the water production.

The statistics for water use and waste-water generation will be applied to defining the capacity of the system to be used for water treatment. If a system is selected that will treat water up to the level where it can be re-used this can help to reduce the use of energy for melting snow to obtain clean water. Recycled water can be used in sanitary systems (toilets) or for washing clothes, or other uses where potable water is not required. The quality of water required by any treatment system will help to define options for treatment. A very efficient system can produce water of potable quality, as is the case at Princess Elisabeth Station. Despite the fact that there are no cost implications to producing excess water, there is a psychological aspect to the use of recycled water, and at the end of the season this is usually dumped into a crevasse, even though it is clean.

The other aspect of using water that has been recycled is that if this is to be used for drinking water the quality controls are more stringent, and require more manpower than if the recycled water is used in non-critical end-uses. The water audit will be combined with the site survey and logistic framework to allow the disposal options to be considered. As a final step in the preparatory phase, the technology survey will be required to assess the cost versus impact reduction possibilities prior to selecting the preferred solution.

Solid Waste Audit

The situation with regard to solid waste has also to be assessed, in particular as there are growing efforts across the globe to reduce the amount of waste being generated, and this will apply also to Arctic and Alpine Research Stations. The difficulty of evacuating waste from remote locations will come into play. The more remote a site, the more expensive it will be to arrange for evacuation of solid wastes. Handling waste on site will lead to questionable practices, such as incineration, which can also lead to the release of noxious fumes, and particulate matter to the surrounding environment. Municipal waste handling statistics do not reflect the particular challenges faced by Arctic Stations. The general evolution within a country does not always mean that all those possibilities are available to a remote, rural location, far from urban centres. Projections on waste handling[38] indicate that certain municipal solutions will plateau (Figure 8).

This is logical when you consider that, e.g. recycling can only address a theoretical maximum of waste generated. This will be the case also for Arctic Stations, particularly if the waste is sent to a recycling plant. There is a limit to how much can be recycled in remote locations. When sorting of items is carried out for recycling, the Station Manager will have to be certain that the handling facility that will receive the waste has the means to treat it, in particular where chemicals, and waste electronics are concerned. Toxic chemicals from spent fuel and electronic waste[39] are a high-risk type of waste (high probability, high impact), and legislation on the handling is present in most Arctic countries.

[38] “Development of a Modelling Tool on Waste Generation and Management” Appendix 1: Baseline Report Final Report for the European Commission DG Environment under Framework Contract No ENV.C.2/FRA/2011/0020 (CRI, Eunomia Consulting).

[39] Arsenic, Cadmium, Chromium, Nickel, 1,3 Butadiene, Benzene, PAH, Formaldehyde, Dioxins/ furans

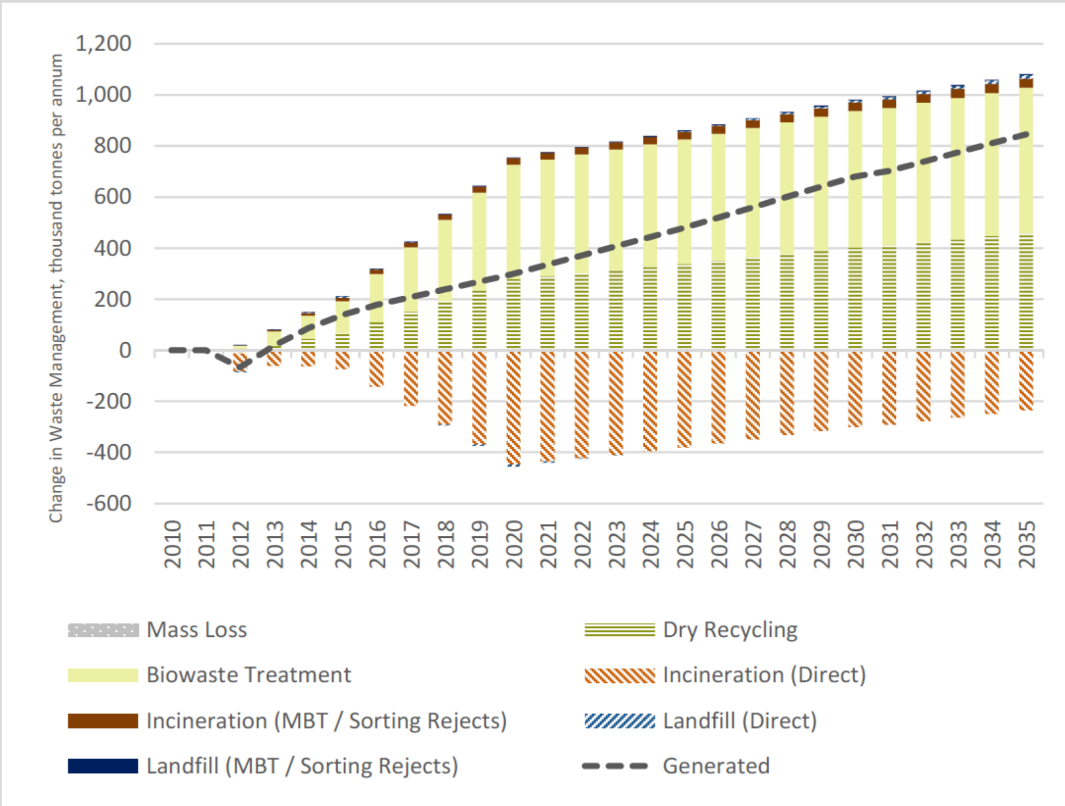

Figure 8. Predicted baseline change in waste management from 2010 in Denmark (ktonnes).

In general the further away from an urban centre the Station is situated, the fewer options are available for handling waste streams. The use of landfills is not something that can be considered as a long-term solution, as the cumulative impact will be significant, and will require expensive logistics to handle. For most remote Stations, the final disposal will include evacuation of waste, properly prepared (compressed, in sealed containers) to a handling facility (Figure 9). The costs of operation will reflect the approach reduced for waste reduction not only in mass, but also in volume. As amount of waste generated continues to grow, new techniques such as bio-waste treatment could be brought on stream. Incineration, using high temperature plasma has the advantage of reducing noxious gases, but requires energy to launch the process. The trade-off between heat energy produced and electrical lost in initiating the process would have to be assessed for each individual case.

The strategy for waste handling should include a rigorous approach to packaging. Reduction in packaging waste should be practised *from the planning and procurement stages*. Plastic packaging should be reduced to a minimum, and supplies can be conditioned in advance to restrict the amount of packaging required. A step-by-step approach is recommended for impact reduction. This should include a continuous assessment of performance to be able to evaluate the effectiveness of the strategy being adopted. Waste streams generated by different operations will eventually overlap (Figure 10) and customised solutions will have to be applied in function of the quantities of waste being generated. For Stations that are situated in remote locations, the cost implications of waste generation are an incentive for scrupulously examining waste streams for improvements in reduction and containment of waste. For stations that require heavy logistics, such as ships, or expensive logistics, (e.g. helicopter flights), to evacuate waste, the incentive for local treatment, and waste reduction initiatives is even higher. Logistic means for evacuating solid wastes will also affect the conditioning of waste – e.g. containers that are too big cannot be loaded on to helicopters.

Assessing sources of waste should be followed by the categorization of waste and evaluation of quantities in order to choose the optimal strategy in each case.

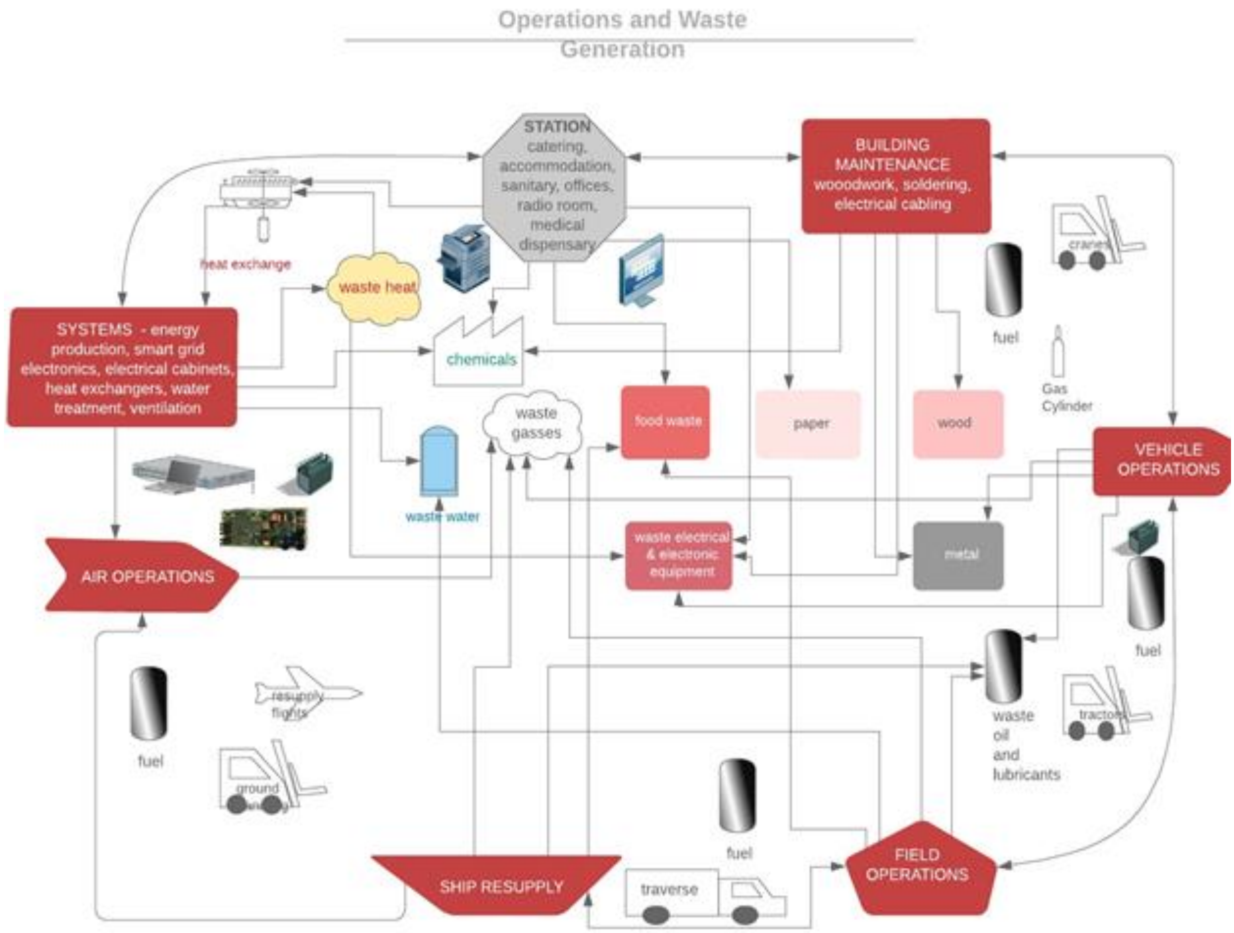

Figure 9. An example of waste generated from a research station

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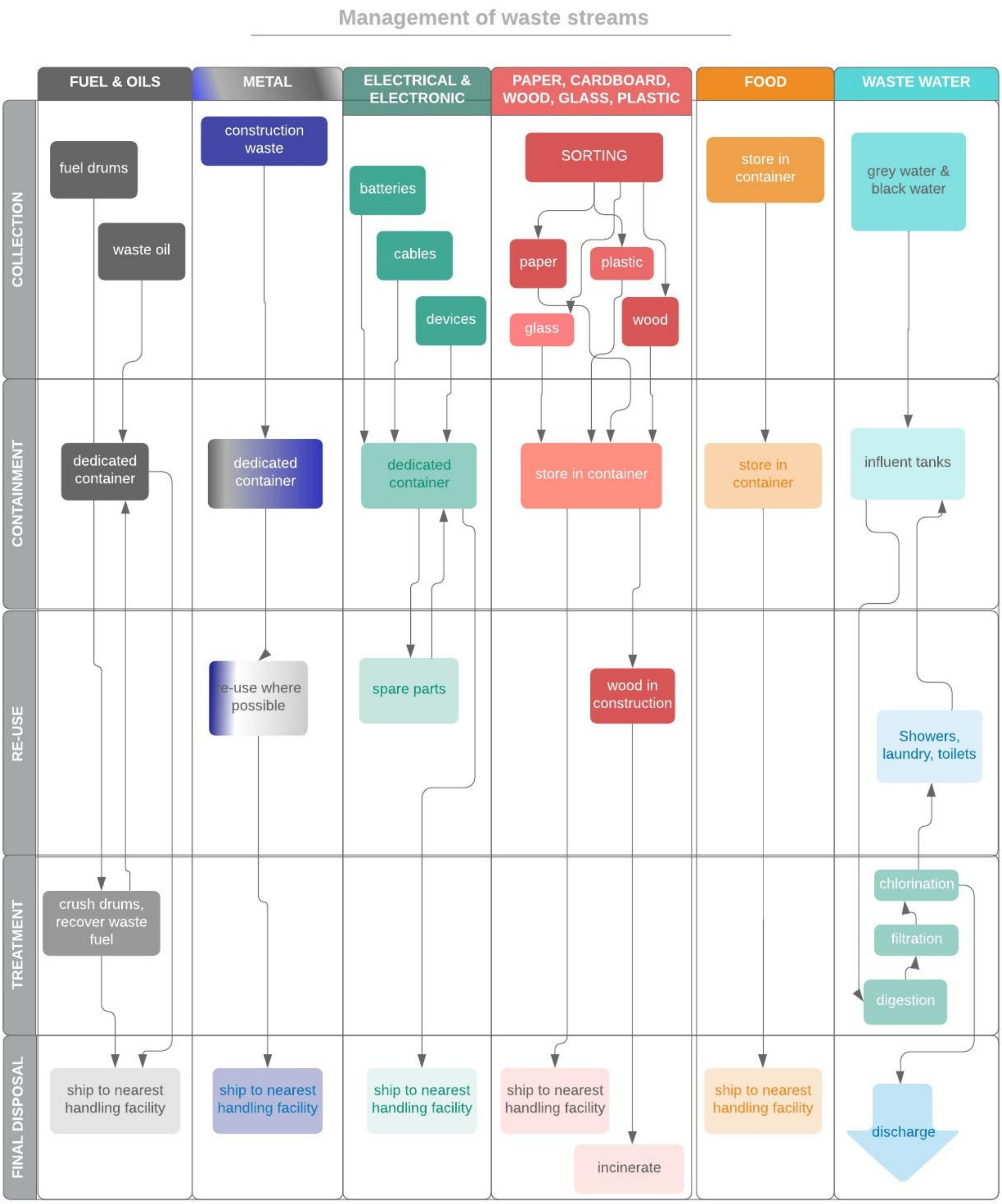


Figure 10. An example of how to deal with the different waste from a research station.

EIA – Site Survey

In addition to audits, the carrying out of a site survey will form an important part of the environmental impact assessment and the designing of a strategy for impact reduction. The key elements to assess in a site survey are:

- Topography, situation – this will affect key variables like solar and wind potential which will affect the amount of energy that can be harvested from the site
- Substrate, and soil characteristics
- Solar irradiance profile for different periods of the year
- Daylight hours
- Biotope – flora and fauna, existence of bird nesting sites in the vicinity;
- Access routes;
- Existing infrastructure – layout of roads, buildings, hangars, cabins, supply infrastructure etc.;
- Distance from other public or private infrastructure;
- Status of the land (public, private, National Park);
- Climatic conditions (minimum and maximum temperatures, wind speed, wind gusts, wind direction, relative humidity); and
- Existing levels of pollution in the area.

The site survey will provide a baseline for the implantation of different types of infrastructure such as wind turbines and solar arrays, as well as identifying potential areas for water harvesting and waste water disposal. The site survey will also provide the information required to assess the potential for wind and solar energy of the site, allowing *the dimensioning* of the RE installations to optimize delivery of energy. The GIS tools developed by the INTERACT project will be ideal for the purposes of the site survey allowing the integration of information from different sources to create maps of land use and potential. Some Stations near urban centres will have to apply for planning permission, and contact should be taken with the local authorities in order to clarify the constraints applicable in the area.

Energy Efficiency

While the Clean Energy for All strategy touts the central role of energy efficiency, the targets for 2020 will not be reached unless further measures are taken, according to a recent Report[40] published by the EU Commission. The goal of reducing energy consumption by half by 2050 compared to 2005 seems to be slipping away. While greenhouse gas (GHG) emissions can be reduced by the switch to renewables for energy production, the reduction in consumption can only be addressed by greater efficiency. Energy efficiency can be approached by several routes:

1) *Building techniques*, including better insulation and triple glazed windows to reduce heat loss (whether by retrofit or new build). Since a large part of the energy bill in the Arctic Region is due to the heating of living space, anything that can reduce the losses from the system will reduce consumption. So insulation and improved window glazing, and joints around windows will reduce the heat leakage out of a building. The shape and position of a building will affect how much incoming solar energy to allow into a building as well as keeping the heat inside the building. The rounder a building the less surface area that there is available through which to lose heat. The more wall surface that is present, the more surface that has to be insulated. The shape of a building will influence the final cost of retro-fit. It is interesting to note that large surfaces need to be oriented in a particular way for the deployment of Building Integrated Solar Photovoltaic panels. Taller buildings can be used to optimise

[40] Report of the Work of the Task Force on Mobilising Efforts to Reach the EU Energy Efficiency Targets for 2020 - Report prepared January 2019 by the Commission services to reflect the work of the Task Force on mobilising efforts to reach the EU Energy efficiency targets for 2020

the production of wind energy through Building augmented wind turbines. These solutions will not be available to all.

2) *Space heating from renewable sources* – Solar thermal heating and heat exchangers drive down fuel use. Using ambient heat or heat generated from machines for other uses, such as heating water will also drive down electric consumption.

3) *Smart technologies*: management of energy consumption, digitalisation and automation. Automation also provides the possibility of conditioning energy flows, and infrastructure in such a way as to be able to reduce losses in the system.

4) *Reduction in the energy consumption* of appliances and electronics (loads on the system). New low energy devices are continuously coming on the market. Light bulbs are a good example of this trend, but it stretches to virtually every type of electrical appliance. Energy efficiency in electrical installations addresses the amount of energy lost in the form of heat in components by the use of materials designed to reduce resistance in the connections.

5) The *reduction in waste in transformation, transport and distribution* of energy can be addressed by producing energy locally wherever possible. The distributed grid is the face of the future, and will drastically reduce costs in energy delivery. Going completely off-grid may be the extreme form of distributed energy, but in some places this will be the only option.

The EU has suggested a number of initiatives including mobilising funds for achieving energy efficiency targets, but access to the funds is generally reserved for municipal bodies, or large-scale projects.

Energy Performance of Buildings

The European Directive on the energy performance of buildings of 2010 has been widely transposed and applied, but earlier EU legislation already introduced the requirement for an Energy Performance audit and an EPB rating for new builds. All buildings, private and public, need to be rated before they are put on the market. Recent amendments[41] came into force in July 2018 with the intention of promoting a near zero energy building stock. *To achieve a highly energy efficient and decarbonised building stock and to ensure that the long-term renovation strategies deliver the necessary progress towards the transformation of existing buildings into nearly zero-energy buildings, in particular by an increase in deep renovations, Member States should provide clear guidelines and outline measurable, targeted actions as well as promote equal access to financing, including for the worst performing segments of the national building stock, for energy-poor consumers, for social housing and for households subject to split-incentive dilemmas, while taking into consideration affordability*.

The full panoply of energy efficiency possibilities from the design phase to operations is difficult to retro-fit as the shape of the building, and the position of the windows have to be calculated to reduce energy losses to a minimum. However, some possibilities exist with retro-fitting for insulation and space heating. Efficient insulation drastically reduces the amount of energy required to heat a space. Every surface of a building, which could potentially lose heat, has to be addressed in retro-fitting to reduce heat loss. Different types of materials exist for use in insulation, such as:

- Polymers – expanded polymers, polystyrene, polyurethanes, etc.
- Mineral – rock wool, glass wool, etc.
- Natural materials – paper and card, wood shavings, cork, flax, wool, cotton

The best performing materials for insulation of roofs and walls are polymers. The trade-off between materials and performance will depend on the costs of available building supplies.

[41] Directive (EU) 2018/of the European Parliament and the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

The insulating performance of materials is measured in their capacity to retain heat. There are a number of different measures of this performance.
λor *k* = thermal conductivity of a material in function of its thickness (*Units = W/m.K*).
φ = Heat flux is a measure of the amount of heat transmitted per unit area through a surface. (*Units = W/m^2*). Structural elements of a building (walls, roofs, floors, and windows) are given a U value.
(*U = the conductive heat transfer coefficient*). U = φ/**Δ**T. (*Units = W/m^2K*)
(where ***Δ****T = the difference between internal and external temperatures of a surface (wall, roof, window) measured in Kelvins*).
(The measure of thermal resistance of materials is their R-value, which can be expressed either in SI units (R-SI), or in British Imperial Units (R)).
R is the inverse of U = (*Units = $K.m^2/W$*)
Δ*T /R = heat loss per unit surface* (*Units = W/m^2*)

The cumulative U values for different element and insulation material combinations will indicate the overall performance of a building. The whole building is given a E rating depending on the energy performance of the whole structure. New builds in Europe are required to have an Energy Performance value (E) of less than 40, but recent legislation will look to improve on this. In the energy performance spectrum the following categories exist:

- Low energy – high performance insulation (E< 30).
- Passive – minimal heat loss (E<30), no natural ventilation, minimal heating required.
- Zero energy – passive + installed renewable energy generation (E<15)

The Princess Elisabeth Station used high-density extruded polystyrene, with graphite, treated with flame-retardants, sandwiched between two wooden panels. The insulation layer is 40 cm thick (Figure 11). Older buildings have the choice of improving insulation from inside the building, or by installing outside the building, which is considered the more effective option. Windows are also part of the external surface of a building, and their U values make up part of the overall energy performance of a building.

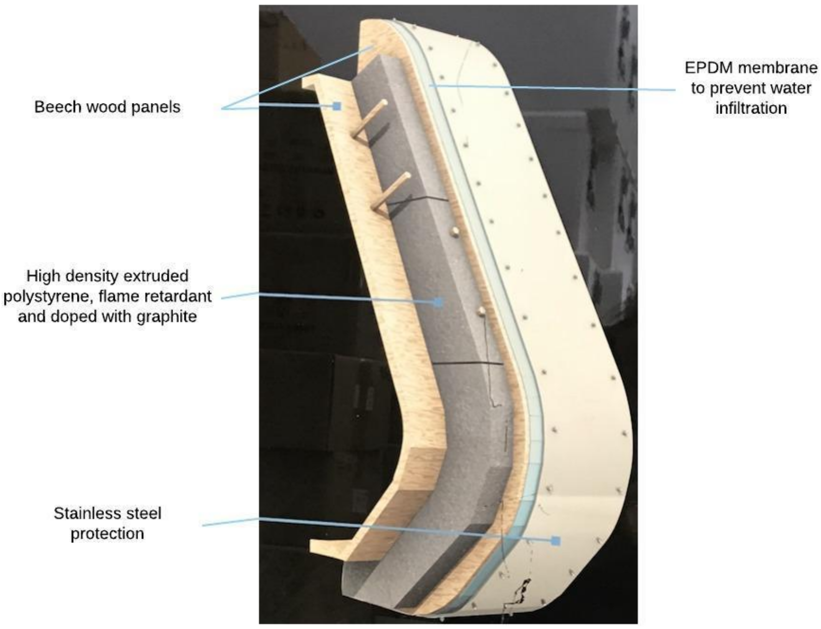


Figure 11. High performance insulation is completely sealed into the wall modules by engineered wood panels, combining a traditional material with cutting edge technology for passive buildings.

Windows allow incoming radiation, but should prevent outgoing conductive heat transfer. The window configuration varies from frames plus single glazing, or double glazing, through to triple glazing (which is almost double the price and considerably heavier, because of the need for reinforced frames). Windows are a key structural and energy balance element. The PE Station window units were designed to be incorporated into the wooden structural modules, and are composed of two layers of triple glazing separated by an air gap of 35cm. The conductive heat flux through the windows has been reduced to 0,01 W/m^2K, compared to conventional triple glazing (which is in the region of 0.6 W/m^2K), thanks to the air gap. The windows did not need additional “frames”. Alternative choices of structural material to frame windows is limited to aluminium, (which would introduce thermal bridges into the building), or PVC, which would not resist the high UV radiation prevalent in the Antarctic and would rapidly deteriorate. Wood has all the material and thermal characteristics to meet the needs of a cold climate building.

The efficient insulation of the walls and the eradication of all thermal bridges reduce the heat loss through the walls and the floor to virtually zero. The efficiency of the insulation is such that it only requires a human presence inside the Station for it to begin to warm up considerably. In an air-tight building, all heat fluxes have to be handled using a ventilation system with a heat recovery unit allowing incoming air to be warmed, and for heat to be removed from exhaust air. Combining effective insulation and ventilation systems with heat recovery will deliver a building requiring very little fossil fuel energy for heating. When this target has been reached, the next step is Zero Energy, or rather zero fossil fuel energy. To reach this step, it will be necessary to add energy generation capabilities to the building, and frequently this will mean solar energy, whether PV or solar thermal for heating of domestic hot water (DHW). Some buildings will integrate wind turbines or other systems, but the constraints are higher, particularly if a Station is situated in an urban area. Planning, and permitting restrictions will be stricter.

As PE Station was based in Antarctica, and there were no neighbours (not even bird colonies in the direct vicinity) noise was not a consideration. It was possible to install a dedicated wind park with nine 6kW wind turbines. The energy performance of the building measured against conventional buildings of the time was off the charts. An energy audit carried out by a certified engineer in 2008 (Figure 12), using the standards and software of the time, delivered an EPB for the Princess Elisabeth Station with an E value. of -50[42]. Most of the technology used was off-the-shelf, and the performance has continued to improve with every year in function of new products coming to market. This continuously evolving prototype is a valuable test bed for new materials and methods.

[42] Niveau E – Station Princesse Elisabeth – Performance Enérgétique des Bâtiments (PEB) – Benoit Spies, 2008

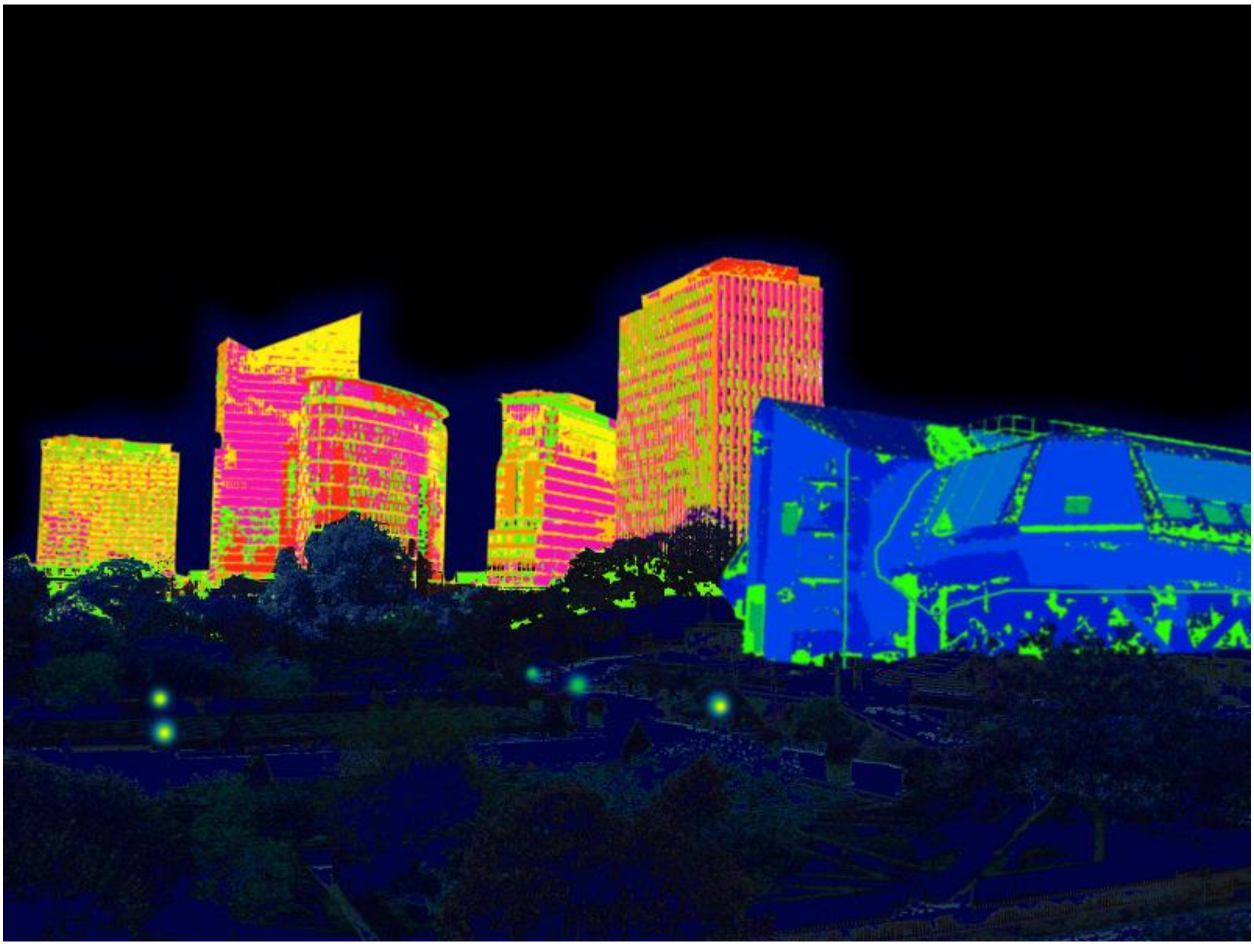


Figure 12. Infrared image of the thermal performance of the PE Station compared against buildings of the time in Brussels.

Space heating

To aim for a low energy building, the use of space heating from fossil fuel sources has to be reduced. However, this does not mean that there is no heating, but that the sources can then be diversified. Space heating in remote communities will often use a common heat generation source, with the heat then being channelled to the individual end users. As the heat is produced in combined heat and power (CHP) plants, which run frequently on oil or coal, a common move towards a non-polluting method would reduce impact for the whole community. For end-users who are connected to these community-heating grids, adopting another method alone might not be feasible, or have much mitigation merit attached to it, as it would not affect the overall quantities of GHG emissions for the area. Using *renewable energy* for space heating is an easily accessible technology. Using solar collectors, with heat exchange, and heat pumps will allow the heat captured by this method to be used for numerous functions, including domestic hot water. Solar thermal technology is continuing to evolve, with more efficient panels, and heat exchangers. Fragile tube collectors used in the first generation of solar thermal power at Princess Elisabeth are being replaced by more resistant flat panels which can be building integrated and can provide both space heating and hot water.

In the Arctic region, there will however be areas where the winter period might be too dark, and the absence of sunlight will reduce the possibility of using solar thermal all year round. In these cases, the system of space heating will need to be a hybrid, using wind turbines, and harvesting heat throughout the Station, including heat produced by electrical devices, battery banks, etc. A dedicated ventilation system would have to be installed to recover heat before emitting waste gas to the environment. Integrating other sources of energy, such as electrical energy from wind, is a good source of energy for the production of hot water as well as space heating. The sanitary hot water and the space heating circuit need to be completely separate, as one will contain anti-freeze for the solar panels, and one will be used for general purposes, such a showers, and kitchen. Hybrid systems allow energy to be harvested from various sources and the management of electricity and heat flux allows for the optimal use of available energy (Figure 13).

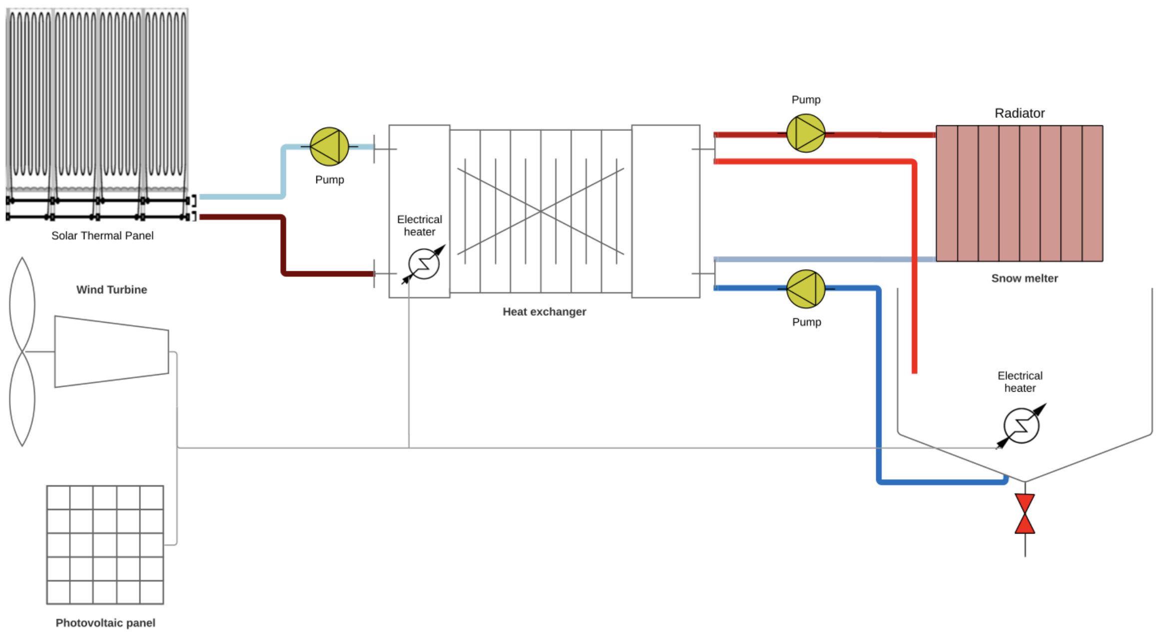


Figure 13. Set up for a hybrid solar thermal system which harvests excess electrical energy from wind turbines when there is not enough sun

Space heating in the remote Arctic can also benefit from the use of biomass, such as wood pellets. Wood pellet stoves are already in use in some installations, and pelleting machines can be used to manufacture pellets in sites that are situated in forested areas. New wood pellet stoves are becoming increasingly efficient, and can be automated up to a certain extent. They are considered CO_2 neutral, and produce very little ash (<1%). However, they need an electrical supply for automation, and require regular maintenance. While the raw materials are carbon neutral, and cheap, the maintenance cycle might prove to be too onerous.

Smart technologies

The EU strategy for achieving energy efficiency targets includes smart technologies, or technologies that are able to automate energy flux functions and can monitor and record usage statistics. At the Princess Elisabeth Station the entire management of energy use by all systems (heating, lighting, water treatment, ventilation, single point use, etc.) is managed by a programmable logic controller (PLC), that acts as the brains of the Station, setting use priorities and juggling loads to optimize the delivery of energy to different end-users, whether it is the kitchen appliances, or a pump in the water treatment system, the entire installation is wired to the internal logic. With new technologies rapidly coming on-stream, the possibility now exists for wifi connections to this “brain”.

An interface software (Supervisory control and data acquisition or SCADA software) captures all the data from the installations and presents them in graphical format. The human operative can interact with the screen to change parameters for the automation of functions, e.g. increase temperature, or the flow rate of the ventilation. The software will continuously log all data and can generate reports regarding any aspect of the system, such as total energy produced by the wind and solar park, or consumed by any connected load. The spin-off of industrial process control hardware and software into the management of smaller infrastructure has gained pace rapidly in the last few years. Today, less expensive devices are freely available on the market for ordinary domestic use. Mini programmable computers are available to automate most common functions in a home, or research Station. Suppliers of monitoring and automation devices are numerous, and the related costs will vary according to the level of sophistication required in the management of the grid, and the level of integration of all "services". Installing monitoring and management for heating and lighting do not require major investment, but when other services begin to be added the complexity increases in function of the inter-operability of the systems being considered. Integrating all functions, as is the case with Princess Elisabeth will require an industrial level of automation, and this will lead to greater expense as the level of technical competences required for installation and programming are much higher. Customisation of process control algorithms also requires specialized engineering competences.

The PE Station uses SCADA software developed by Schneider Electric (Vijeo Citect) along with a PLC programmed with algorithms developed specifically for the Station. The experience with automation has demonstrated that frequently there will be some resistance from the human inhabitants, but that gradually as the benefits of relinquishing control to the PLC become manifest, the Station occupants will accept that energy might sometimes be limited and that tasks have to be organized in function of availability.

Reduction in Energy Consumption

Reduction in consumption of energy is an integral part of energy efficiency. Reducing the energy e-required to perform the same function is an effective way of decarbonizing operations, and simultaneously reducing costs (depending on LCA integration into this calculation). Reducing consumption can go via several routes:

- *Use of energy efficient devices.* Wherever possible, smaller more efficient devices can be installed to replace inefficient older technology. Reduction of losses in energy conversion reduces consumption. This market segment is in continuous evolution. The use of Solid State technologies in communications and memory devices has been accompanied by a significant reduction in the energy consumption for carrying out the same tasks. The Energy labelling of appliances, e.g. in the kitchen or office will be useful in helping to make procurement decisions.
- *Use of low energy devices.* Low energy light bulbs (e.g. LEDs) have a Life Cycle Analysis (LCA) which continues to improve, and the potential of this technology to significantly reduce material use, due to the long-life time of the bulbs, and a reduction in energy consumption will change the energy use profile of buildings.
- *Consolidation.* Removing individual end-user devices from the grid, and consolidating infrastructure has been shown to be effective in reducing loads on the electrical grid. At PE, individual laptops were replaced with a single server having multiple access points. Consolidation of data storage is also possible in this set up, facilitating management of data and power.
- *Avoid unnecessary travel.* Communication strategies help to reduce costs of managing remote infrastructure. Radio and satellite links help to repatriate data from the field without having to make long and arduous journeys to sites to replace memory cards. Information can also be channelled along mesh networks doing away with the need for visits to multiple sites.

Reduction in waste of energy during transformation, transport and distribution

Electrical energy produced on site will have fewer losses than the energy delivered by a commercial grid operator. This might, however, be difficult to quantify for an energy audit. Other types of energy flux can also be managed to reduce waste, such as heat energy related to solar heating, and domestic hot water. Pipes should be insulated to prevent heat loss, and building design should take into account the ducting required for the high performance thermal insulation to reduce heat loss from pipes. Heat conservation and heat management using ventilation and heat-exchange as an adjunct to space heating will also help to reduce waste. In well-insulated spaces, the amount of input heat required is very low, and comfortable temperatures can be maintained even from the heat generated by electronics, batteries, computers and communication racks.

Renewable Energy Technologies

The Clean Planet for All[43] strategy that the EU is advocating posits the deployment of renewables and the use of electricity as a means towards decarbonisation. The objectives of decarbonising the European sphere has registered some success with the rates of renewable energy uptake in Europe increasing to over 17% in 2016 while registering growth and reduction in GHG emissions of 22%. The EUs 2020 strategy is delivering economic and environmental benefits while driving down the cost of renewable energy technologies. The same phenomenon is witnessed to different levels across the globe, with some countries moving ahead faster on introduction of renewables than others. This trend is not homogeneous and it will be clear that the cost of technology on different markets will be influenced by many factors, including the price of fossil fuels.

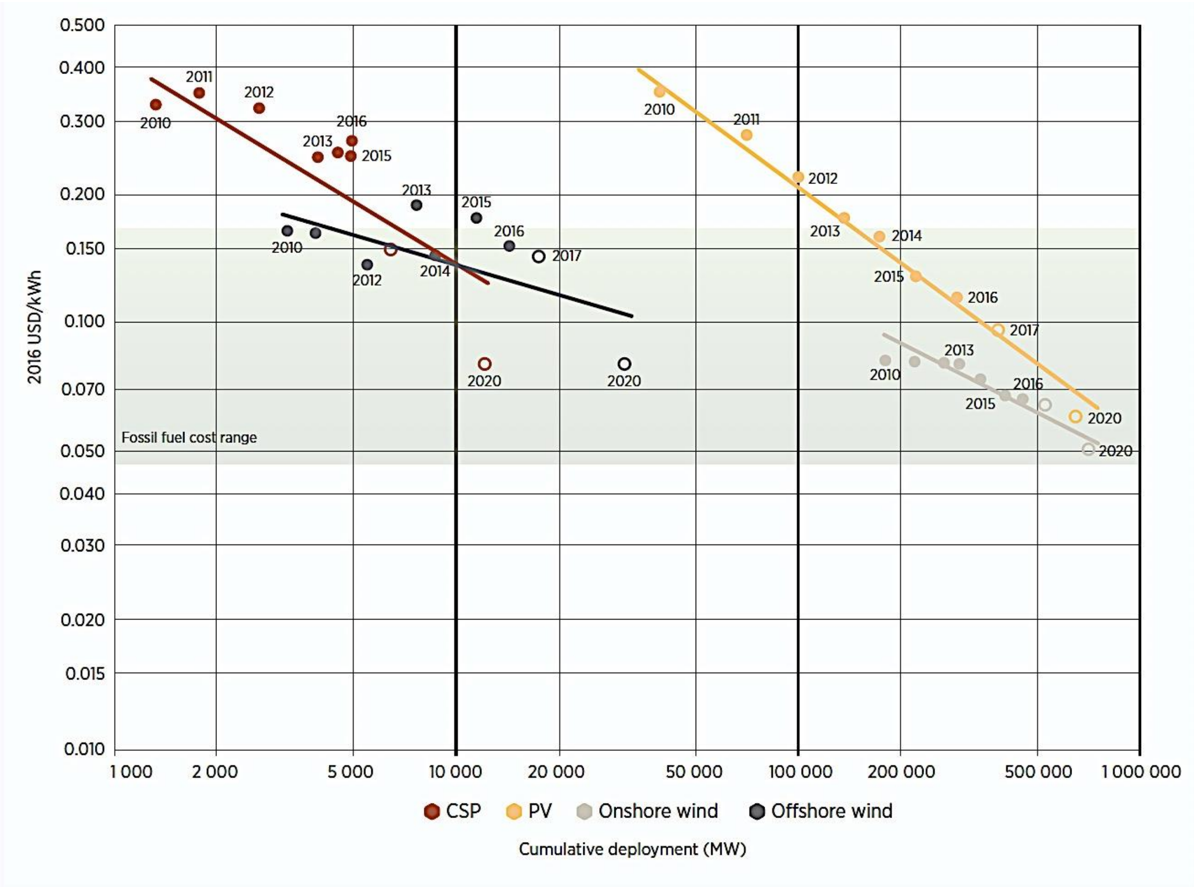
Global trends point towards increased penetration of the energy market by renewables according to a recent International Energy Authority Report. "*The share of renewables in meeting global energy demand is expected to grow by one-fifth in the next five years to reach 12.4% in 2023. Renewables will have the fastest growth in the electricity sector, providing almost 30% of power demand in 2023, up from 24% in 2017. During this period, renewables are forecast to meet more than 70% of global electricity generation growth, led by solar PV and followed by wind, hydropower, and bioenergy. Hydropower remains the largest renewable source, meeting 16% of global electricity demand by 2023, followed by wind (6%), solar PV (4%), and bioenergy (3%)*[44]." The rapid growth in the renewable energy (RE) sector demonstrates that the aim to make renewables the chief source of energy to replace fossil fuels is rapidly taking hold in the popular consciousness. While most of energy worldwide classified as "renewable" comes from hydroelectric power, the wind and solar sectors remain an attractive choice for small off-grid installations.

The primary interest for remote Arctic stations in the increased adoption of renewables is that it renders electrification by off-grid means more accessible, and this will become a feature of future energy developments across all the regions where there is no access to a centralised electrical grid. The use of renewable energy as a primary source of electricity is a key element of the strategy for reducing the emissions of greenhouse gases (GHGs) and other pollutants associated with the use of fossil fuels. The level of incentive to adoption of renewables will, as was expressed during the Station Managers Forum, vary between the different members of the consortium. Some are connected to the grid, and will not experience

[43] Communication COM(2018) 773 final from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions, and the European Investment Bank - A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy

[44] IEA Report - *Renewables 2018* is the IEA market analysis and forecast from 2018 to 2023 on renewable energy and technologies. It provides global trends and developments for renewable energy in the electricity, heat and transport sectors.

an immediately noticeable reduction of impact. However, in areas where energy is continuing to be produced by power stations burning fossil fuels (oil, coal and gas to a lesser extent), there remains an incentive towards adopting renewables due to higher fuel prices that will affect users of grid electricity, in the coming years. For those Arctic Stations connected to the grid, it will be possible (in certain countries) to install renewables and then to sell the surplus energy generated back to the grid. The "feed in tariff" (FiT) is the rate at which the electricity company buys energy back from the small producer. Depending on the FiT applied, there might be some interest in recovering capital investments for RE installations made through this means, where this is a possibility. For off-grid Stations the situation is more clear-cut. The financial incentive to install renewable energy is much higher, so long as the initial capital costs can be met. It will be reassuring to know that the move towards decentralisation of energy production has led to a lower cost for renewable energy technologies. The cost of solar and on-shore wind power has dropped to such an extent, that they are now considered as being competitive with conventional energy sources, such as oil and coal. This break-even point is known as "Grid Parity". The price per kW of installed PV has dropped to almost one quarter of what it was ten years ago[45], from 4900 USD/kW in 2009 to 1200 USD/KW in 2019. By 2025, it is expected to reach around 800 USD/kW.



Based on IRENA Renewable Cost Database and Auctions Database; GWEC, 2017; WindEurope, 2017; MAKE Consulting, 2017a; and SolarPower Europe, 2017a.

Figure 14. A comparison of the global weighted average levelized cost of electricity (LCOE) per kWh from CSP, Solar PV and on-shore and off-shore wind energy from 2010-2020.

[45] Renewable Energy Innovation Policy – Success Criteria and Strategies -IRENA - International Renewable Energy Agency, 2018

Figure 14 compares the global weighted average levelized cost of electricity (LCOE) per kWh from CSP, Solar PV and on-shore and off-shore wind energy from 2010-2020. Solar and on-shore wind prices are set to converge by 2020. The incentive to install renewables will depend on the cost of technology and of fuel, with higher fuel costs providing more rapid recovery of investment and offering reduced overall operating costs going forward. The costs of mini grids are also decreasing. Figure 15 shows the unsubsidized cost for renewable mini-grids from 2005 to 2035 for two types of system.

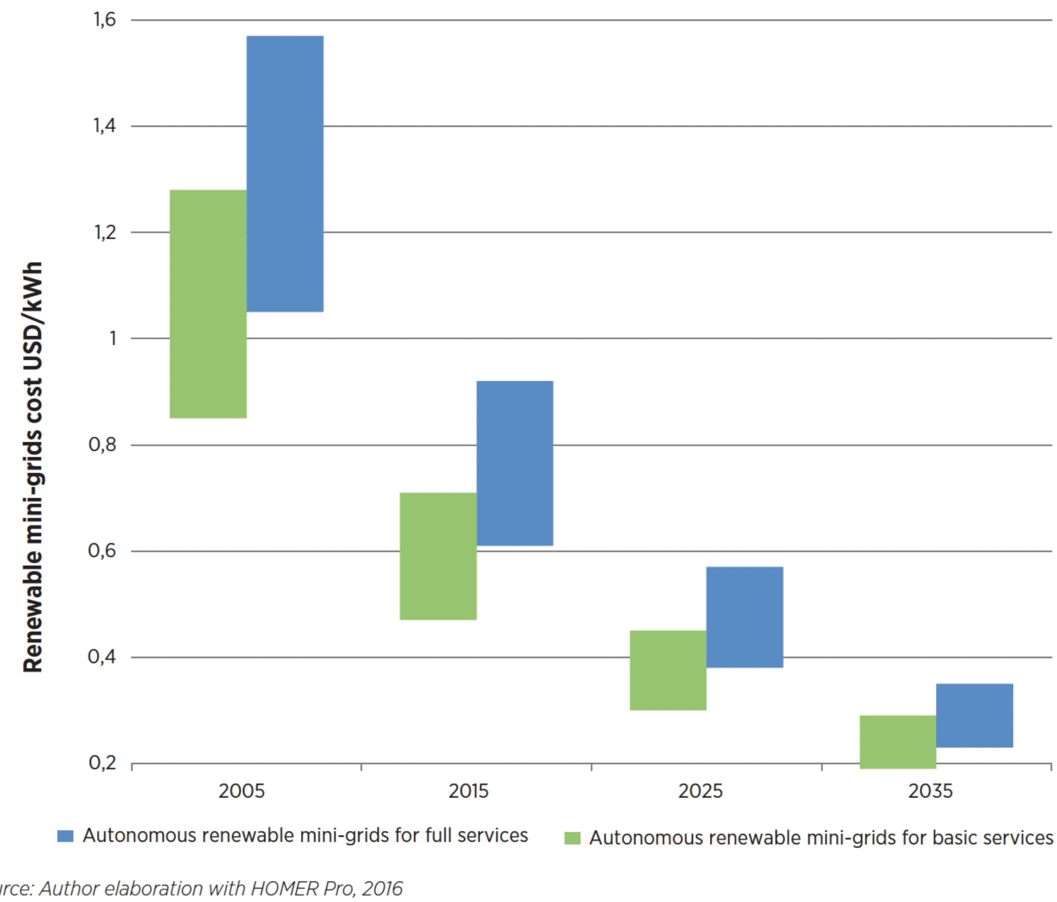


Figure 15. Unsubsidized cost for renewable mini-grids from 2005 to 2035 for two types of system. Source: SE4ll 2015

In an autonomous *basic* grid the sources of power generation include solar PV, hydro, biomass, and diesel as back up. Storage is limited, and power is off when there is no energy being generated (no wind, or sun). This type of installation is used mainly for simple loads like lighting and communications. The autonomous *full service* grid has storage capacity, and can provide uninterrupted energy. Both types of set up are becoming less expensive as the technology matures and more manufacturers enter the market. At Princess Elisabeth, the grid is a *full service* grid because it has a large storage capacity and an intelligent management system making it also a "smart" grid. At present, energy sources include building-integrated photovoltaic panels (BIPV), standalone PV arrays, flat tube arrays, bi-facial arrays, solar thermal tubes, and nine 6kW wind turbines. Combining different sources of generation allows for the *optimisation of energy production* to cover different climatic conditions and solar availability. The range of solar and wind generators at the PE Station is constantly growing as new products and systems configurations are tested. The Station production capacity can continue to grow through, for example, the increased efficiency of conversion of the new generation of solar panels. The grid management is limited by a multi-cluster three phase inverter set up, but this does not prevent testing new devices and configurations to improve grid stability, and optimization of energy. The incremental modifications in efficiency of electronics, and devices, as well as new energy management profiles are helping in this fine-tuning of the *load balance*.

Currently, the excess of energy can be stored in batteries or "dumped". Dumped energy can be used for other functions, when the batteries are full. Combining solar and wind energy with adequate storage at Princess Elisabeth has demonstrated that the Zero Emissions target is perfectly achievable using existing off-the-shelf technologies. While the objective of Zero Emissions target has been reached, as a safety precaution, the fossil fuel generators remain on-site in case of failure of the grid, but also to promote the lifespan and health of battery bank through a charge equalisation. The stage when humanity can do entirely without fossil fuels is not yet upon us, but continuous improvements are taking us closer to the target.

Solar Photovoltaic

Solar energy is an abundant and a virtually limitless source of energy. Photovoltaic panels are the easiest way of harnessing this energy source to produce electricity, giving a rapid and measureable reduction in fuel consumption and related environmental impact. Solar PV is perfectly scalable to fit needs, and financial means available and a vast number of options are on offer with regard to technology choice, and price of systems. The ease of installation, and low level of maintenance is also a factor in making solar PV an attractive proposition for Arctic Station Managers. "*The solar resource is significantly larger than every other energy source available on earth. Roughly 174,000 terawatts (TW) of power are continually delivered by solar radiation to the upper level of the earth's atmosphere. Given that global average power consumption totals roughly 17 TW, the solar energy that strikes the earth in one hour is more than enough to supply all of humanity's current energy needs for one year*[46]".

The solar potential of a site is the starting point and can be measured using sensors, or calculated using mathematical models. Models incorporate climate data from existing sites to provide greater reliability of results, where direct measurements are lacking. Calculating the solar potential for a given site is always going to deliver an approximate value, even where several years' worth of a weather station data is available giving incoming solar radiation. If this data exists, it can be used to calculate the design of a solar array depending on the intensity and other variables. Solar energy is by nature intermittent, and unpredictable. It is *attenuated* by cloud cover (because solar energy can still penetrate haze, and thin clouds) and shade. It is blocked by nightfall, and seasonal variations. Its energy is less dense according to the incident angle at which it hits a given surface, which is linked to the incident angel of incoming radiation. The more oblique the incident angle, the less energy per square metre is being delivered. Every location has a different solar potential in function of these variables. This can be calculated using available data, or can be generated by any number of on-line tools, or with the aid of consultants who will help design installations.

Solar irradiance arrives at the Earth's surface greatly diminished. The atmosphere will absorb and scatter some of this energy, as will clouds. The variation in the day length will then account for further reductions.

[46] The Future of Solar Energy Copyright © 2015 Massachusetts Institute of Technology. http://mitei.mit.edu/publications/reports-studies/future

The further north you go, the more oblique the angle of incidence, leading to further drops in density of incident radiation. Around the winter solstice, north of 60° there will be a period without any sunlight at all. The amount of incoming energy that is actually available will be much reduced.

Figure 16 shows the solar radiation profile 60Km North of the PE Station. The maximum daily average incoming shortwave radiation at the summer solstice of 500 W/m^2 is the equivalent of 12000Wh/m^2 where there is perpetual daylight.

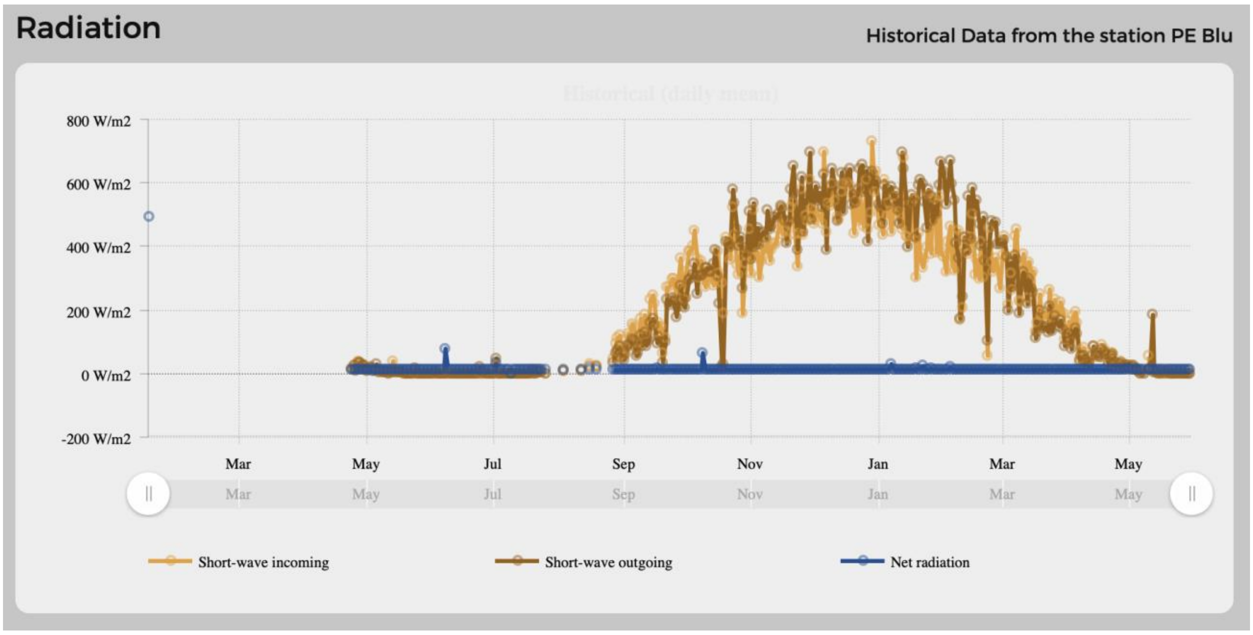


Figure 16. Solar radiation profile 60Km North of the PE Station.

"*The total solar irradiance (TSI, or solar constant) acquired a new value: 1361W/m^2 instead of 1365 W/m^2. However a long-term variation of TSI was not detected. The solar irradiance at the earth's surface is considerably smaller (170 W/m^2) than previously believed (e.g. 198W/m^2 of IPCC AR4). The previous overestimation is due to the underestimation of the absorption of solar radiation in the atmosphere.*[47]"Finally, only 12.5% of the total energy will actually arrive at the surface of the planet. Further reductions in availability or incoming energy will operate in the Arctic region, as some models show. "*Solar radiation data plays an important role in pre-feasibility studies of solar electricity and/or thermal system installations. Measured solar radiation data is scarcely available due to the high cost of installing and maintaining high quality solar radiation sensors (pyranometers). Indirect measured radiation data received from geostationary satellites is unreliable at latitudes above 60 degrees due to the resulting flat viewing angle*[48]".

[47] Present status and variations in the Arctic energy balance -Atsumu Ohmura - 2012 Elsevier B.V. and NIPR. doi:10.1016/j.polar.2012.03.003

[48] Bilal Babar, Tobias Boström, Estimating solar irradiation in the Arctic, Renew. Energy Environ. Sustain. 1, 34 (2016) Renew. Energy Environ. Sustain. 1, 34 (2016) DOI: 10.1051/rees/2016048

A model for Tromso, Norway, compares theoretical values, observations and models to generate the expected amount of daily energy arriving at the ground in Wh/m^2. This varies from 0 Wh/m^2 in January to 12000 Wh/m^2 in June.

A study on the introduction of renewable energy to off-grid settlements in the Russian Arctic[49] pointed out several difficulties associated with the exercise, and stated that until reliability of supply from renewables was addressed, most of the population would prefer to use a newer generation of diesel generator. Some of the difficulties raised were related to the extreme cold. Metal fatigue experienced at -50°C was given as one example of the specific location related difficulties. Areas of high solar potential are limited to further south-east in Russia and wind potential is restricted to coastal zones. Inland areas appear to have a low wind potential (Figure 17).

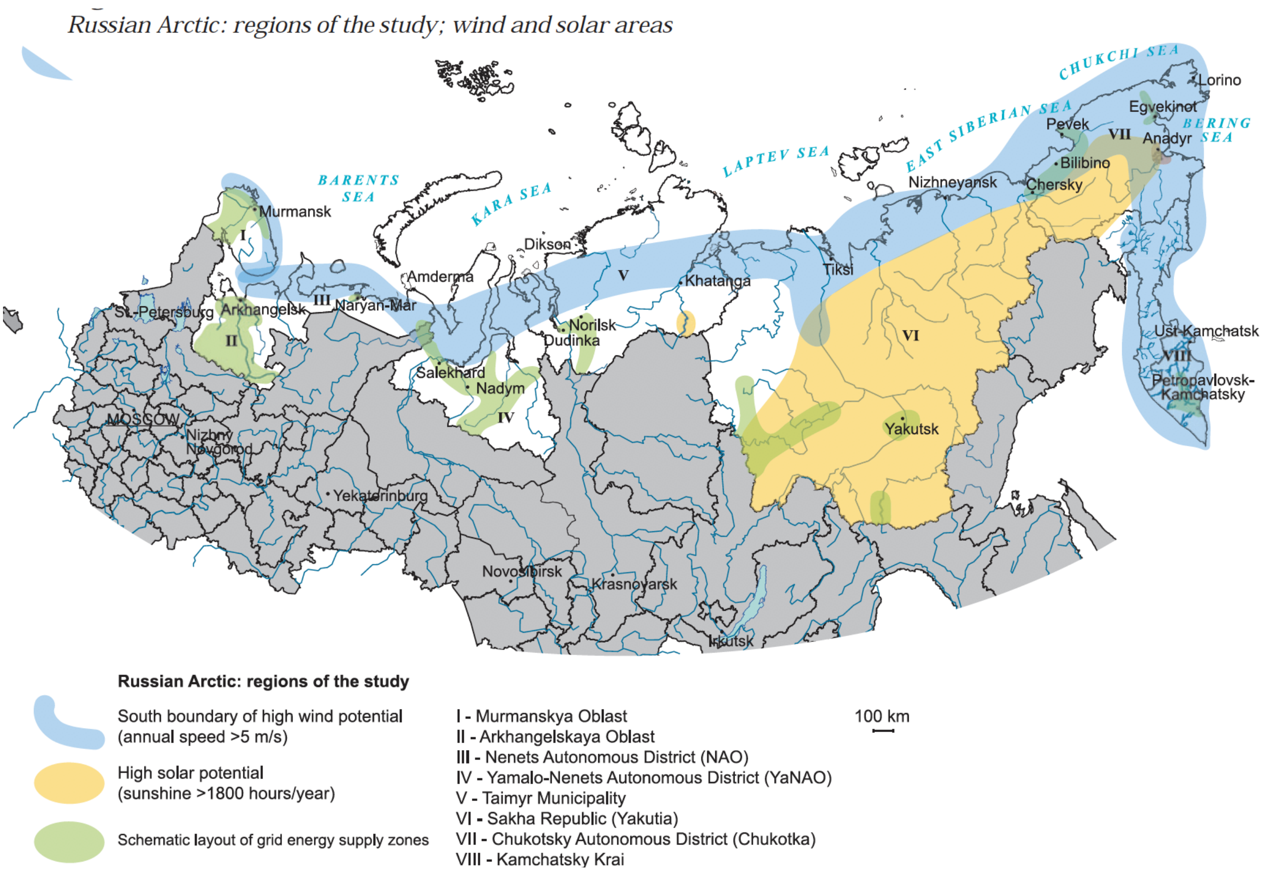


Figure 17. Areas with high solar and wind potential in Russia.

49 Renewable energy in off-grid settlements in the Russian Arctic - Berdin V.Kh., Kokorin A.O., Yulkin G.M., Yulkin M.A. WWF, Moscow. 2017. – 45 pp. ISBN 978-5-906599-30-8

Assessing solar potential

A range of methods and tools exist to derive or calculate solar, and wind potential, from observations and models and even to calculate theoretical electricity output from solar panels. As the number of high performance observing stations is limited, models have proliferated, including on-line.

1) The **observation** reference is provided by the WRMC-BSRN – World Radiation Monitoring Centre – Baseline Surface Radiation Network. *"In 2004 the Baseline Surface Radiation Network (BSRN) was designated as the global baseline network for surface radiation for the Global Climate Observing System (GCOS). All radiation measurements are stored together with collocated surface and upper-air meteorological observations and station metadata in an integrated database. These pages offer both: Information for all scientists who will use BSRN-data as well as information to any station scientist who delivers data. BSRN is a project of the Data and Assessments Panel from the Global Energy and Water Cycle Experiment (GEWEX) under the umbrella of the World Climate Research Programme (WCRP) and as such is aimed at detecting important changes in the Earth's radiation field at the Earth's surface which may be related to climate changes. The data are of primary importance in supporting the validation and confirmation of satellite and computer model estimates of these quantities. At a small number of stations (currently 64) in contrasting climatic zones, covering a latitude range from 80°N to 90°S (see station maps), solar and atmospheric radiation is measured with instruments of the highest available accuracy and with high time resolution (1 to 3 minutes)".*https://bsrn.awi.de

2) **On-line** atlases of solar potential incorporate different mathematical models. Examples are listed in table 9.

Table 9. Examples of tools that can be used to calculate solar potential.

Online source	**Web address**
Global Solar Atlas	https://globalsolaratlas.info
Arctic Renewable Energy Atlas	http://arcticrenewableenergy.org
PV Education.org	https://www.pveducation.org/pvcdrom/properties-of-sunlight/calculation-of-solar-insolation
Power Single Point Data Access	https://power.larc.nasa.gov/data-access-viewer/
Cableizer Solar Radiation calculator	https://www.cableizer.com/tools/solar_radiation/
SOLARGIS	https://solargis.com/products/prospect/overview

Once the available annual solar density has been worked out for a location, it does not mean that this energy is fully available for conversion to electricity. When the solar energy at a given density reaches the surface of the PV panel, the amount of electricity produced will depend on a range of factors. Energy will be lost due to the limits intrinsic in the conversion efficiency of the materials used, defects in the connections, losses in conversion systems, shade due to poor spacing in arrays, and angle of incidence of sunlight on the panel (Figure 18). The final amount of electricity produced will vary as a function of the cumulative impact of these factors.

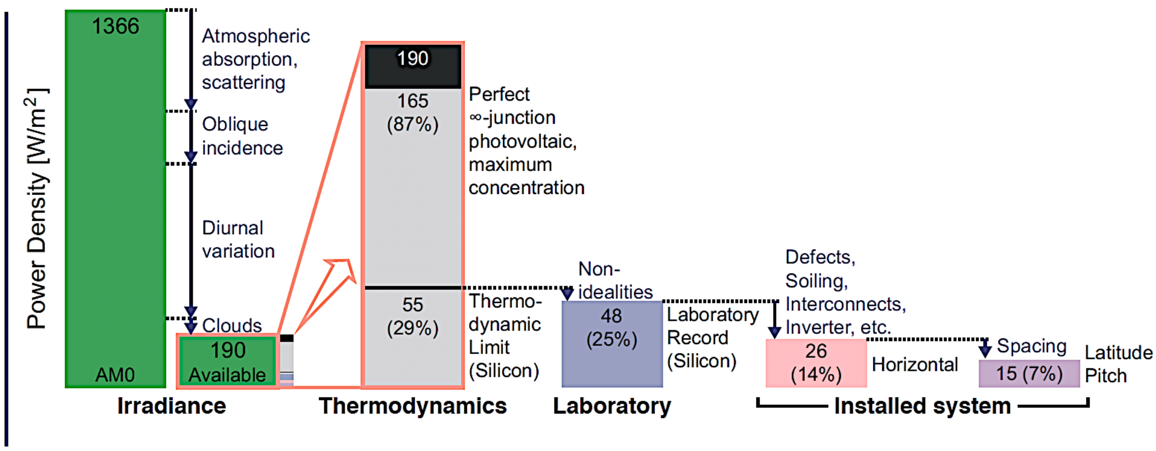


Figure 18. Power conversion losses for solar PV[50]

The "performance ratio" (PR) of the system takes into account the energy losses at each step, at standard environmental conditions (ambient temperature, wind speed):

- PV module temperature – energy produced is inversely proportional to the temperature of a module – the standard temperature of 25°C is used for operational specifications
- defects in the panels which can be in the material or introduced during the production
- varying irradiance conditions – clouds, hours of daylight, seasonal variability in the incident angle of radiation
- soiling of the panels, or obstruction by shading
- cable resistance – damaged cables or junctions will affect production
- losses in the inverter – particularly heat losses
- Angle of the array with regard to the solar elevation.

Systems

A solar PV array consists of one or more electrically connected PV modules — each containing many individual solar cells — integrated with balance-of-system (BOS) hardware components (charge controllers, inverters, transformers, racks, wiring, batteries, etc.). PV modules are built of individual silicon cells doped with other elements to create semiconductors that generate electricity when solar energy hits the surface. PV modules can be used alone, or in set ups called systems, and also be combined in groupings called "strings". Strings can be assembled to create arrays. Because of this modularity PV panels can be linked to create a customized capacity depending on the type of panel used and the need of the end-user. If the panels are to be connected to a grid to power more than one device, grid management devices will be required to provide transformation to AC current and stability of supply. The whole assembly is called a system.

Systems comport:

- PV panels (different types exist at vastly varying prices depending on their efficiency and their reliability. It is always advisable to check certification of panels before choosing.
- Inverters to transform direct current (DC) power to alternating current (AC) for the grid

[50] The Future of Solar Energy Copyright © 2015 Massachusetts Institute of Technology.

- Inverters to convert AC from the grid to DC to store in batteries
- Cables
- Structural components (racks, cable trays, etc.)
- Management and monitoring systems
- Batteries

All hardware elements in system, which are not PV modules, are referred to as the balance of system (BOS). Other elements in the pricing of whole systems are referred to as soft costs.

PV modules

PV modules have been improving in efficiency and decreasing in price over the last ten years, making energy from a PV installation as cheap as energy delivered by the municipal grid (depending on the country). The most prevalent solar cells are either single-crystalline or polycrystalline silicon. Various technologies and materials have been explored to improve the efficiency of panels (e.g. using thin films (TF) of cadmium telluride (CdTe), copper-indium-gallium-selenide (CIGS), or amorphous silicon (a-Si)), multi-junction cells from space applications, hybrid PV-thermal panels for heat and electricity). Concentrated solar or CPV is also growing in popularity for larger installations, but because they require moving parts, these work less well in colder regions.

In terms of cost, the conventional poly or multi-crystalline panels have had the greatest uptake, and are likely to be the most appropriate currently for first time installers. The evolution of Silicon modules over the last ten years has seen a growth in the types of module available on the market and increased efficiency of conversion. The introduction of bifacial modules has helped to increase the power output over a single day, allowing capture of incident radiation from different angles. A comparison of earlier modules and the more high performance modern modules on the market shows an increase in power production for panels of the same size.

The peak power rating for the new generation module is *more than double* that of the earlier module, going from 130W to between 289 and 292 W for a module of a comparable size. The production of electrical current is a function of the solar irradiance. In the old generation module, at a fixed cell temperature of 25°C about 1.8 A of output current is produced at a solar irradiance of 200 W/m^2. Output current does not seem to be affected by temperature.

In a conventional panel only one side is covered with silicon cells. In bifacial panels, both sides can produce power. In addition, the efficiency of conversion is greater. The maximum current at 1000W irradiance for a new generation multi-crystalline silicon panel is 10 amps, a 25% increase in maximum current. At 200 W irradiance it is around 2 amps, or an 11% increase from the previous generation panel. Output increases with colder panels, so the low irradiance level losses will be slightly offset by higher production due to the colder ambient conditions.

The configuration of solar panels can be horizontal or vertical, building mounted or free standing (Figure 19). Panels are versatile and have been shown to work in extreme conditions, and at high latitudes.

Figure 19. At the Summit Station in Greenland, the solar panels have been installed on a tower.

Life-cycle analysis

While PV promises zero emissions energy for the end-user, the manufacturing processes of the panels and systems used to harness solar energy produce greenhouse gasses. The question arises as to how long it will take for the GHG emissions reduced through the use of panels during their lifetime, to offset the amount produced during their manufacture. Previously, life cycle analysis (LCA) of the modules and systems suggested an energy and GHG offset at between 2-5 years. Estimations for GHG produced during manufacture are decreasing, for silicon panels, due to improved manufacturing processes. Greater efficiency in energy conversion rates for panels (from 8% to 20%) has also influenced the downward trend in the amount of time required to offset the impacts due to the manufacturing cycle. Where solar PV is replacing a diesel generator, as opposed to grid electricity, the operational period required to offset the emissions from manufacturing will decrease even faster.

The EU Waste Electrical and Electronic Equipment (WEEE) Directive[51] requires European PV manufacturers to take back 85% of modules for recycling at end of life. This will not apply to manufacturers from outside the EU. As most suppliers of panels are from outside the EU (Figure 20), there will be no end of life recycling foreseen for panels procured from outside the EU. This might be a consideration for some projects that will need to integrate this in an LCA for their projects.

51 Directive 2002/95/EC of the European Parliament and the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment – L37/19 - 13/02/2003

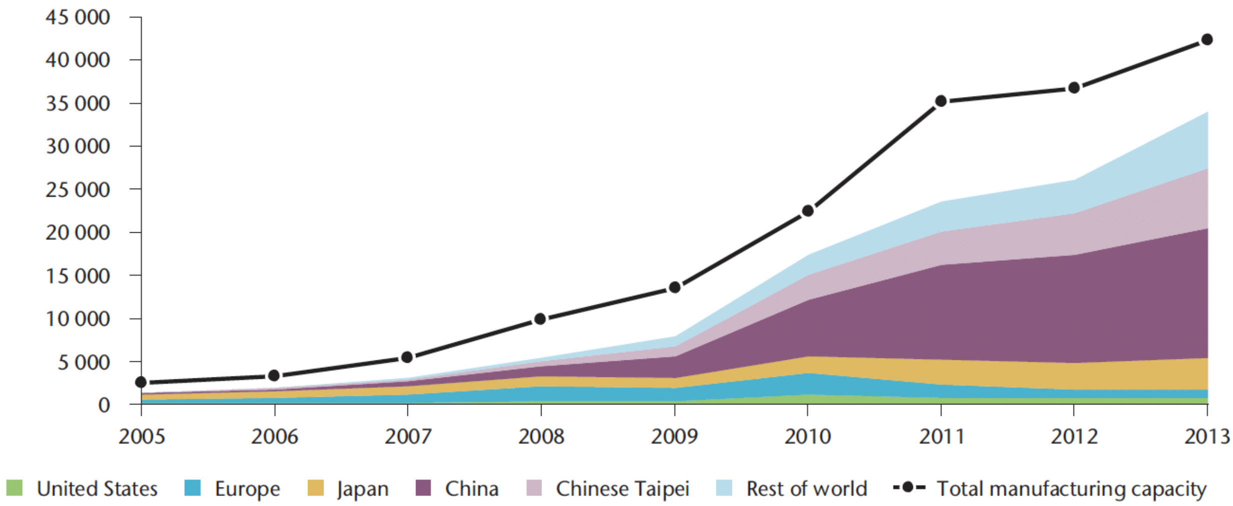


Figure 20. Most of the principal suppliers of PV panels are outside of EU (Source SPV Market Research 2014).

Costs

The cost of installed PV is conventionally divided into two parts: the cost of the solar module and so-called balance-of-system (BOS) costs, which include costs for inverters, racking and installation hardware, design and installation labor, and marketing, as well as various regulatory and financing costs. PV technology choices influence both module and BOS costs. Prices of PV modules began to fall after 2008, (with subsidies being offered to first adopters), and then stabilized because of a shortage of Silicon feedstock (Figure 21). With the arrival on the market of thousands of new manufacturers the price of modules varies significantly. There is a general trend towards cheaper panels, but the quality and the certification should be checked in order to ensure a longer life.

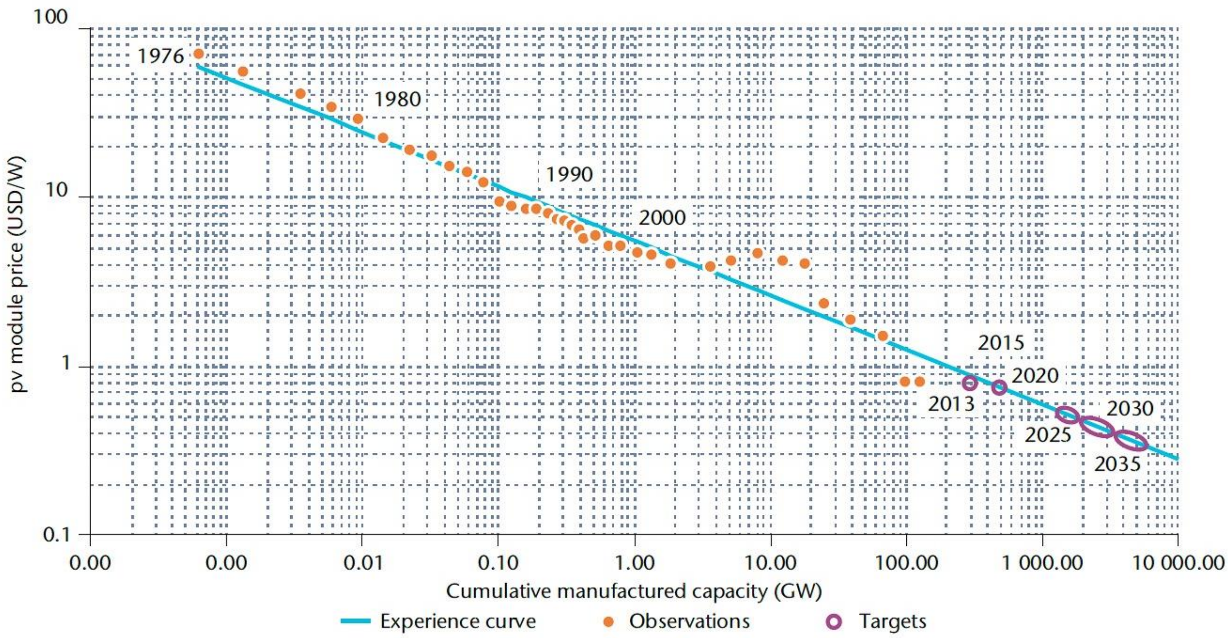


Figure 21. *Evolution of module prices and projections to 2035 (IEA, 2016)*[52]

[52] Technology Roadmap – Solar Photovoltaic Energy, IEA, 2014, www.iea.org/books

When the cost of electricity (LCOE) from decentralised solar PV systems becomes lower than the electricity price (per kWh), it is referred to as "grid parity. **Grid parity** is the moment when it becomes interesting for electricity company customers to build a PV system and to generate part of the electricity they consume, and possibly sell some back to the grid. It is reported that PV systems in Germany reached this tipping point in 2013, but this might be influenced by the fact that the power stations in Germany use coal. In other countries, grid parity will also depend on the energy source for the commercial grid, and the level of solar irradiance in the area. For off grid Stations, in the low irradiation zones north of 60° latitude, grid parity will be driven more by the local price of diesel fuel. Depending on the logistics of fuel delivery, grid parity in some areas may already have been reached for solar.

Solar Panel Suppliers

With thousands of module manufacturers, quality and prices vary enormously. Suppliers can be identified by various methods, including at solar "fairs", which take place all year round, and where the industry meets. One of the biggest is the Intersolar, in Munich. https://www.intersolar.de/en/home.html

Manufacturers' websites also provide useful technical information. "*The excellent, constantly controlled quality, the enormous efficiency levels, and the long service life of our products, coupled with our position as a highly-renowned and world-famous major corporation are just some of the benefits that more and more Kyocera customers have chosen to enjoy. You too can profit from the over 38 years of experience of one of the real pioneers in the solar cell market. You can choose between a wide range of modules to be sure that you find the optimum solution for your project"*. http://www.kyocerasolar.eu

"With more than fifty years of experience in pioneering electronics technology, LG has made breakthroughs in technologies designed to harness the power of solar energy. Module efficiency going up to 21%" https://www.lg.com/us/business/solar-panel/products

"*As a global leading provider for PV module and smart energy solution, Trina Solar delivers PV products, applications and services to promote global sustainable development. Through constant innovation, we continue to push the PV industry forward by creating greater grid parity of PV power and popularizing renewable energy. Our mission is to boost global renewable energy development around the world for the benefit of all of humanity*". https://www.trinasolar.com/en-apac/product/residential

Eventually, a Station Manager will have to choose between managing the entire project with internal engineering competence, or bringing in an outside consultant. Manufacturers of inverters will also provide consultancy services and can advise on the type of panel to use.

Wind Energy

Wind energy is the most efficient and price competitive source of renewable energy for a Polar research station, where the conditions are right. Wind is complementary to solar PV that might be installed as wind energy continues to be produced even in winter when the solar irradiance will be too low to cover all the energy needs of a Station. The Princess Elisabeth Station has a wind park of 9 Proven wind turbines of 6kW each, and this is the principal source of energy in summer and in winter (Figure 22). As with solar PV, wind energy is intermittent and unpredictable, and works best in conjunction with good storage capacity.

Before considering installing a wind turbine, or a wind park it is recommended that the Station Manager carry out a feasibility study in order to assess the potential of the site to produce electrical energy from wind. In function of the environmental parameters (such as average wind speed, and topography) it will be possible to evaluate to what extent the turbine, or turbines, will be able to produce sufficient energy to be a viable solution.

Figure 22. Wind Park at Princess Elisabeth Antarctica.

The average and maximum wind speeds for a site will be critical in deciding whether the site will be able to either produce sufficient energy or to survive the local gust conditions. It will also be important to assess whether the average wind speed is above the start-up wind speed at which the turbine will begin to turn and produce energy. The available wind resources also provide data for the dimensioning of the turbines. "*In relation to the influence of wind conditions on turbines' performance is absolutely essential, however, to carry out a thorough environmental analysis of the wind resource prior to the installation in order to identify the most suitable turbine model and its optimal location. Even in the presence of a good average wind speed, not all sites can in fact be suitable for the installation of wind energy systems. Maximum and minimum wind speed values that deviate much from the annual average can instead determine the failure of a particular turbine model over another*[53]."

The Wind Resource

The INTERACT Stations have for the most part shared data concerning the wind speed at their sites. Only 25 Stations reported average wind speeds over 5 m/s, which is within the range for the use of small wind turbines. Almost 43% of the Stations reported average wind speeds of less than 5 m/s, which would make these sites of questionable wind energy potential (Table 10).

[53] Small Vertical Axis Wind Turbines for Energy Efficiency of Buildings - Marco Casini, Journal of Clean Energy Technologies, Vol. 4, No. 1, January 2016

Table 10. Average wind speeds at INTERACT Stations

WIND POTENTIAL	AVERAGE WIND SPEED	MAXIMUM WIND SPEED
NO DATA	21	24
< 1m/s	0	0
1-4.9 m/s	34	1
5-9.9 m/s	22	2
10-20 m/s	3	6
21-30 m/s	0	23
> 30 m/s	0	23

An initial wind resource assessment has to be carried out in steps before a site is selected[54]. *"The wind resource assessment is often split in to three levels related to the used data sources and the expected uncertainties in AEP. Level 1 _50%, level 2 _30% and level 3 _10%.*

- *Level 1: screening of public available monitoring data, reanalysis data, and world wind maps etc.*
- *Level 2: modeled wind resource on microscale level, based on public data.*
- *Level 3: on-site measurements or on-site validated microscale modeled wind resource including long-term correction.*

For larger projects long-term high-resolution mesoscale mapping can be used to roughly estimate the wind resource and the extreme wind speeds, turbulence, and so on. For smaller projects (mini and micro turbines), the potential area is smaller, the budget does probably not allow for advanced modeling, and therefore potential sites must be selected based on other sources, as climate station and terrain".

The wind resource assessment for the PE Station was carried out by the Von Karmann Institute, in Belgium, in 2006. The Wind Atlas Methodology (WAsP) was used (Figure 23), integrating data from an automatic weather station installed in 2004 to collect one year of complete data to map the frequency in wind direction and wind speed.

54 Renewable Energy Potential of Greenland with emphasis on wind resource assessment - Kasper Rønnow Jakobsen, DTU Wind Energy PhD-0043 (EN), February 2016

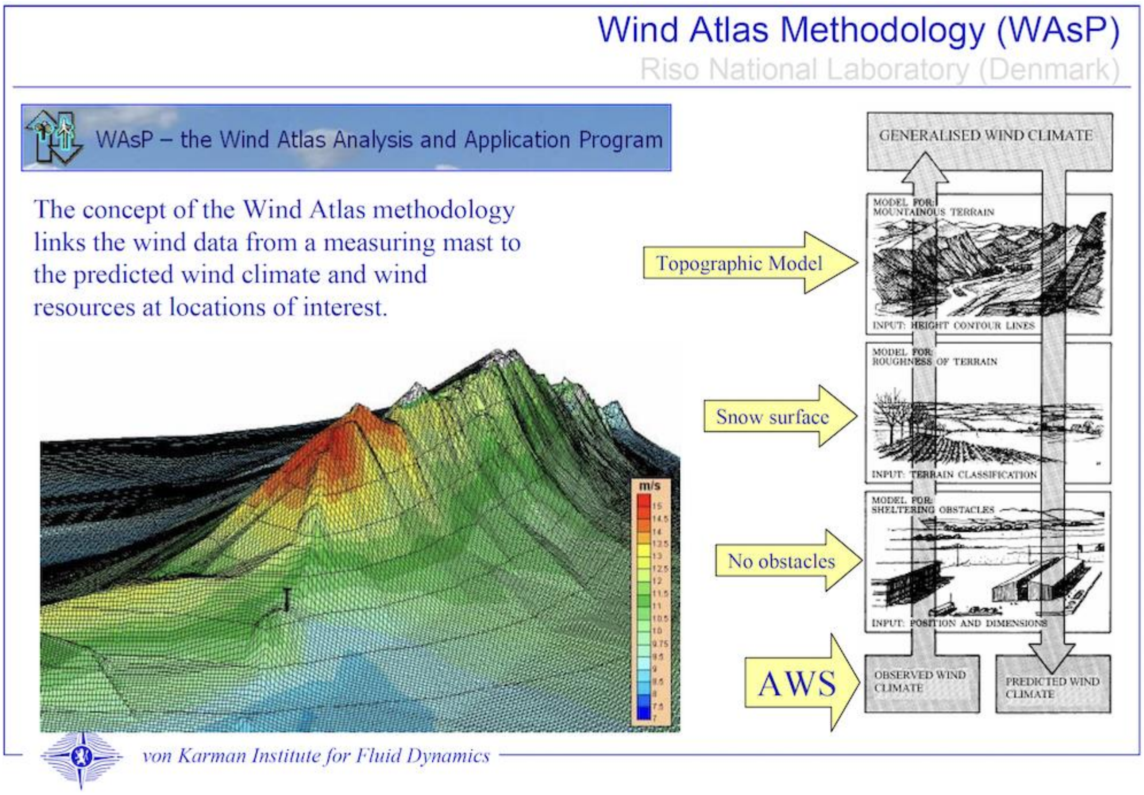


Figure 23. The Wind Atlas Methodology was used to estimate wind resource at PE Station in Antarctica.

A DTU[55] study carried out in 2016 describes the complete methodology for an Arctic site. "*For wind resource assessment, various methods of monitoring and modeling of wind resources were studied with focus on their performance in complex Arctic areas. The existing climate station, was found to be less useful due to insufficient design, and some dedicated wind monitoring stations were designed for the project. Micro- and Mesoscale models were tested against measurement stations and satellite-based ocean wind observations. The microscale models were valid in a very narrow (500m) range. The mesoscale models showed good performance in some areas, but imperfect surface data (sea ice and surface elevation) affected the results, especially in the coastal part areas. The main conclusion in this part is that a high-quality preliminary study (level 1) of available data, such as ocean wind, reanalysis data, inferred pictures of katabatic flow pattern, and station observation, together with good models is the key to a good site selection".*

The DTU study looks at wind resource assessment using wind speed distribution using adapted versions of the Weather Research and Forecasting models: WRF (ERA-1) and WRF (ASR), or Arctic System Reanalysis models. Observations used for validating models showed that the models tended to over-estimate wind speed.

Other sources of wind data investigated were Synthetic Aperture Radar (SAR) satellite images, and products such as QuikSCAT ocean wind from NASA. The study examines the reasons for failures of previous attempts

[55] Renewable Energy Potential of Greenland with emphasis on wind resource assessment - Kasper Rønnow Jakobsen, DTU Wind Energy PhD-0043 (EN), February 2016

to use wind energy in Greenland, and in particular the failure of vertical axis wind turbines installed by the telecoms company, Tele at 20 remote sites.

A 6kW Proven horizontal axis turbine was also tested, with mixed results. This turbine has also been in use at Summit Station for a number of years, and has experienced some problems with icing (Figure 24).

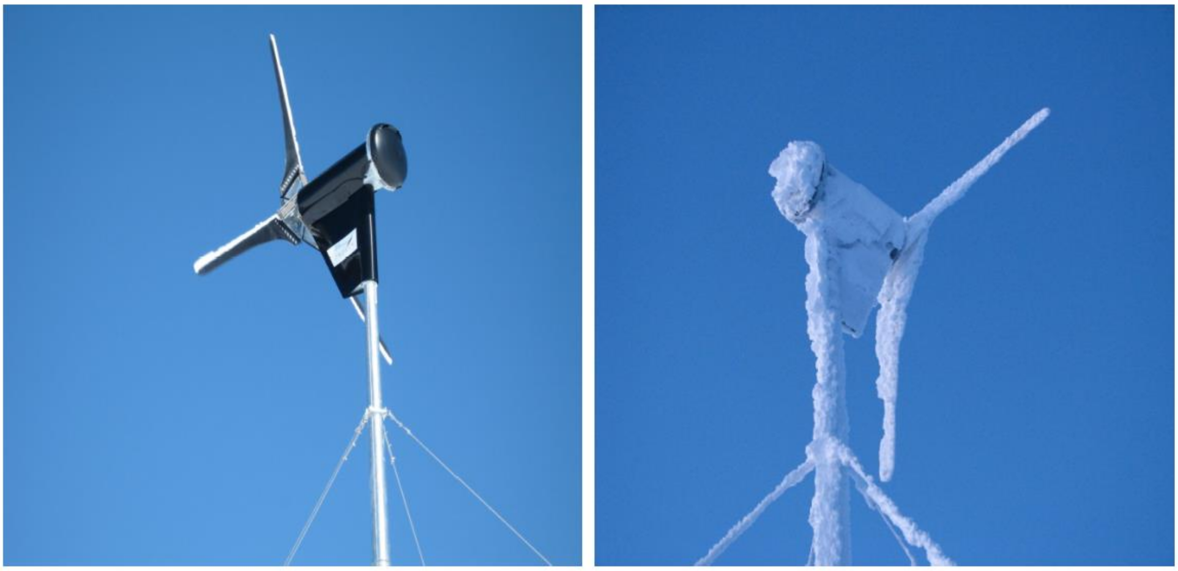


Figure 24. Icing of wind turbine at Summit station, picture on the left shows light icing and to the right a fully iced wind turbine (Figure credit; Tracy Dahl, CH2M Hill Polar Services).

Site Study

Once the wind resource has been assessed using public data, the local wind conditions will allow the area to be evaluated and the ideal site for installation to be identified. To optimize the output from a turbine it will be necessary to map the area topography, obstacles, and infrastructure on the site in order to be able to identify any possible obstructions that might impede wind flow. If the possibility exists, it would be useful to have a 3D topography to model the wind profile over obstructions. Different sources of data can be used from DEMs to GIS or aerial maps using drones. For Stations near urban centres, it will be necessary to contact the local authorities to see if there are any restrictions on the installation of wind turbines, and whether there are permitting considerations. Permitting conditions will influence where a wind turbine can be installed, so that it does not affect other inhabitants, or pose any risks to property, or wild birds, or cause nuisance (e.g. relative to noise regulations).

Turbine Selection

Small wind turbines can be divided into two groups: Vertical Axis Wind Turbines (VAWTs) or Horizontal Axis Wind Turbines (HAWTs) (Figure 25). Each type has its advantages and disadvantages, but the most prevalent are HAWTs. Turbines are also classified by their energy output, by whether they use permanent magnets and gear boxes, by braking systems, by the types of blades they use, by their resistance to cold temperatures, and to strong winds. Vertical-axis wind turbines can be further classified as *Savonius* and *Darrieus*. A Savonius turbine has an “S” shaped horizontal profile, while Darrieus turbines have vertical blades in a semi-helicoidal configuration.

Different strategies exist for resisting over-speeding at high winds, to prevent the electrical coils from being burnt out. Some turbines have mechanisms that allow the blades to fold up when the wind speed exceeds the cut out wind speed, which will lead to production being impossible over a certain speed. The choice of wind turbine will largely be influenced by local conditions. It is recommended that a technology survey be conducted before making a short list of suitable turbines that meet price and technical specifications.

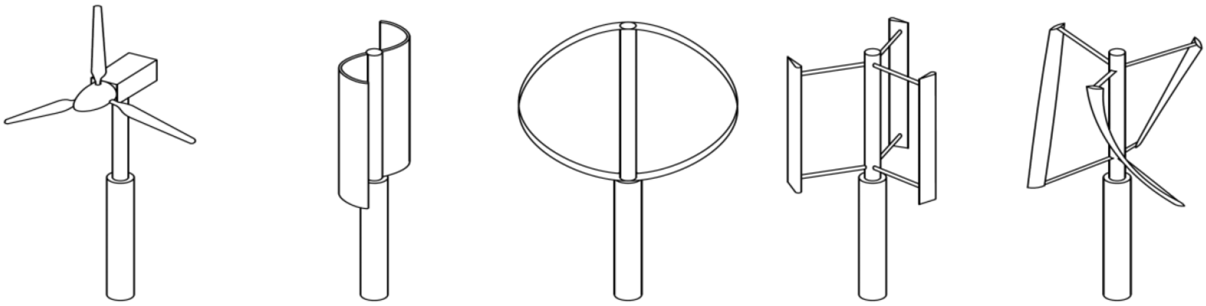


Figure 25. Small wind turbines can be divided into two groups: Vertical Axis Wind Turbines (VAWTs) or Horizontal Axis Wind Turbines (HAWTs)

Size of Turbine

The size of the turbine in terms of its rated energy output will depend on the amount of energy that is to be produced as determined by the energy audit, as well as the site conditions identified in the site survey. Most research stations will not be looking to install a MW rated turbine. The installation and maintenance would require heavy lifting equipment, which would add significantly to the costs of acquiring and running such a turbine. Delivering large turbines to a site will also require specialized logistics. This would disqualify a number of candidate turbines for remote Stations. In addition, the cut in wind speeds for large turbines will be quite high, and the turbine would have to be installed on a very high mast that would require cranes and heavy lifting equipment to erect. For Stations able to erect high masts, this improves the wind resource, because wind speeds are generally higher with increased height. The higher the tower the more likely it is to capture higher wind speeds, and avoid turbulence, which affects the energy conversion efficiency.

The cut in wind speed for most small turbines is in the range of 2.5 - 3 m/s, which means that speeds lower than this would not produce any energy. Average wind speed of less than 5-6 m/s on a site will generally mean that the site does not have the potential for a larger turbine, but might be able to use a turbine specialised for lower cut-in wind speeds. Depending on end-use the size of the turbine may range from 100W to over 10kW. The choice will depend on the site, the energy needs, the wind resources, the terrain conditions and the means available for the installation. For example, installing in permafrost or in rock will pose different challenges. Drilling into rock will require specialized machinery, as the anchoring has to be at least one metre deep, and rock drills will be required. In softer ground, other precautions have to be taken to make sure that the turbines do not risk being blown over by powerful wind gusts.

In the Antarctic, the katabatic winds are of a laminar flow, which also optimizes the delivery of energy to the turbine. This means that a 9 m tower or mast will be more effective than on an Arctic site with low speed, turbulent and humid wind characteristics. The wind turbine towers at PE are free-standing cold temperature steel tubes, which are anchored into the granite on which they are positioned. They can be lowered to carry out maintenance manually or using a winch, which is an important feature to keep in mind when in relation to maintenance.

The theoretical conditions according to regional wind potential maps might indicate a favourable area, but when confronted with the real conditions on a particular site there can be unforeseen problems. In a study of the experience with wind energy in the Russian Arctic[56], a number of problems were highlighted, principally extreme climatic conditions, strong wind gusts, and extreme temperatures which led to metal failure of the components. These were coupled with design issues and complicated maintenance. The unreliability of the wind turbines led the local inhabitants to a preference for diesel generators, which had a higher reliability.

The recommendations coming out of the WWF study were that there should be:

- *"careful selection of a place for the wind units on the basis of wind studies;*
- *wind units must turn off at wind velocity above 25 m/sec, and turn on at 4 m/sec;*
- *hydrophobic coating of wind turbine blades and coloring them black (passive ice protection);*
- *and anti-corrosion coating for stators and rotors of generators;*
- *replacement of pneumatic brakes with electromechanical systems;*
- *redundant sensors to maintain control with strong wind and the basic sensors' failure;*
- *strengthened design and the use of frost-proof steel for the tower;*
- *tower weight segmentation – no more than 3 tons/segment, and no-crane assembly;*
- *placing the inverter and controls into a temperature-controlled container;*
- *special foundation for permafrost soils (considering a potential permafrost degradation)."*

Determining Yield

Once a suitable site has been identified, a micro-scale assessment of wind resource can be produced. This profile will be used to assess the theoretical production of a given wind turbine. The exercise can be repeated with a range of turbines in order to identify the most promising. Wind power density maps are available on a regional scale. For a complete feasibility study the local conditions are still required. This step should not be left aside because wind turbines can be expensive to install and maintain, and optimal choices can only be arrived at with an accurate evaluation of the potential of the wind resource. The maximum amount of energy a site will be able to produce depends on what is known as the Betz Limit, which is the limit for the conversion of kinetic energy to electrical energy due to turbulence and the loss of energy to the surroundings. As the relationship between wind speed and the production of energy is related to the kinetic energy of a three dimensional mass, a reduction in wind speed will lead to an exponential reduction in the amount of kinetic energy being delivered to the turbine head.

Taking into account the intermittent nature of the resource, the actual yield will only be 50% of the theoretical maximum rated power at constant wind speeds. So a rated wind turbine will produce on an annual basis only a proportion of what the power rating states. Some installers will be able to offer computer modeling of the proposed site and turbine to have maximum energy yield. Alternatively, Universities can provide this kind of service.

[56] Renewable energy in off-grid settlements in the Russian Arctic - Berdin V.Kh., Kokorin A.O., Yulkin G.M., Yulkin M.A. WWF, Moscow. 2017. – 45 pp. ISBN 978-5-906599-30-8

Resources

There are many useful online resources that can be used when planning to install wind turbines (Table 11).

Table 11. Useful online tools when planning to install wind turbines.

Online source	Web address
Global wind atlas for calculating wind resources	https://globalwindatlas.info
The New European Wind Atlas. Uses new methodologies to assess wind resources for a site.	http://www.neweuropeanwindatlas.eu/
Search for a wind turbine model, by model, and manufacturer.	https://en.wind-turbine-models.com/models
Guide to best home turbines	https://www.semprius.com/wind-turbine-generator/
Wind Fairs	https://windeurope.org/confex2019/

Energy Storage

Energy storage is a key element in supporting renewable energy integration in an island or off-grid energy system, and is an important element in the EU energy strategy. *"……energy storage can make an overarching contribution to the implementation of the Energy Union, in particular through its contribution to the internal market and decarbonisation dimensions*[57]*."*

There are a variety of energy storage technologies available to Arctic Stations. In the statistical assessments pumped hydro storage will always feature at the top of the list of battery technologies, because of the quantities of potential energy involved, but for a remote Arctic Station battery technologies are of more relevance. A wide variety of batteries exist on the market, and these can be classified either by their composition, the materials used or their energy-to-power (E/P) ratios, which will determine for which applications they are most suited.

Batteries are a portable technology, which will be best suited for the sharing of Best Practice amongst the Stations. Comparing battery types used for different functions, such as vehicles, remote instrument set-ups, and energy storage will reveal preferences, which are likely to be of greater use than a catalogue of available batteries. The very particular context of energy storage for renewable energy based grids requires, however, more specialized battery technologies. "*Secondary batteries are also used in the energy sector to store energy from external sources, including intermittent renewable supplies (e.g. wind or solar), and release it when needed. In this usage, these batteries play a critical role in efforts to mitigate climate change and are often referred to as energy storage devices, although, technically speaking, all batteries store energy. High-energy storage is a critical consideration for these batteries. Power output capabilities are a smaller consideration for such applications*[58]."

[57] Brussels, 1.2.2017 SWD(2017) 61 final Commission Staff Working Document - Energy storage – the role of electricity

[58] Science for Environment Policy (2018) Towards the battery of the future. Future Brief 20. Brief produced for the European Commission DG Environment by the Science Communication Unit, UWE, Bristol. Available at: http://ec.europa.eu/science-environment-policy- ISBN 978-92-79-84040-1 ISSN 2363-278X doi:10.2779/674936 KH-BB-18-006-EN-N

Batteries used for energy storage will generally be either Lithium-ion or lead acid, and there is again a vast range of choices available for this purpose. The battery clusters at the Princess Elisabeth Station (Figure 26) are based on a Valve Regulated Lead Acid (VRLA) battery, which is in the core of the Station where it is protected from freezing. The clusters are in a temperature controlled environment, with hydrogen detection sensors, and the possibility to vent if any gas is detected. This is a mature technology, which has been shown to be reliable, if a little heavy to deploy and cumbersome to accommodate. The 192 cells of the four battery clusters linked to the smart grid, weigh around 15 tonnes.

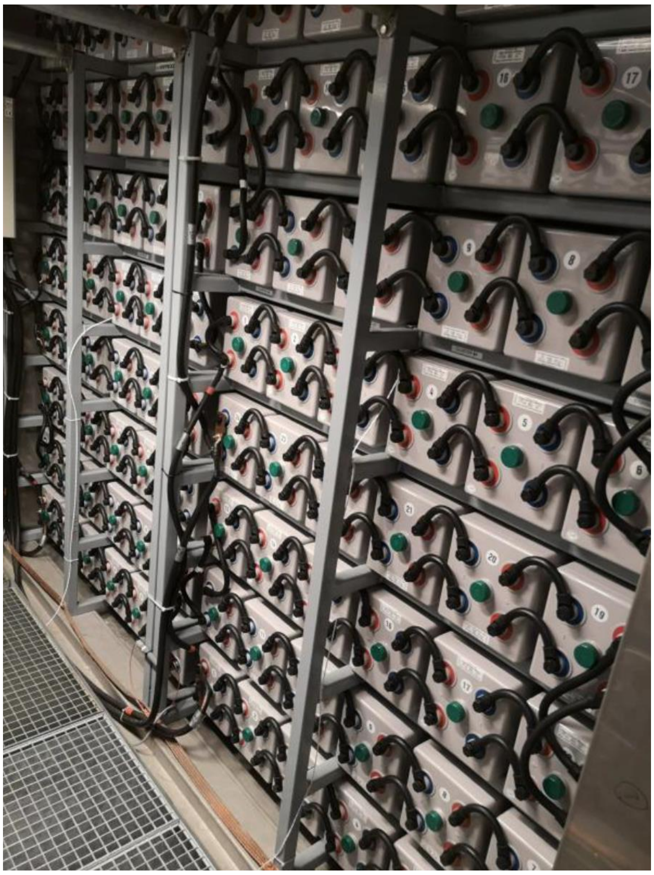


Figure 26. Hoppeke Valve Regulated Lead Acid Battery storage at Princess Elisabeth Station.

The trend towards Lithium-ion batteries for storage devices and electrical vehicles is less attractive in a remote site, despite their smaller size and weight, and thus higher energy density, as these batteries are more sensitive to low temperatures and the risks of explosion associated with their use are less easy to mitigate. VRLA batteries are recovered by the manufacture at end of life for recycling, and as such the life-cycle issues can be mitigated through recycling and re-use of the components.

Battery Choice

Apart from the obvious financial cost, the choice of batteries will depend on factors such as:

- *Energy density:* Energy density is measured according to the unit volume and weight of materials. While it might be important for mobile phones and other portable devices and electrical vehicles, it is less important for fixed storage sites, where space is not an issue. In addition for sites where the only access is by air, Lithium battery storage will be impossible to install because of restrictions in air cargo.

- *Lifespan:* Battery lifespan is measured in charge and discharge cycles. Managing the charge and discharge correctly, can extend the life of a battery e.g. a too deep discharge will reduce the working life. Some VRLA batteries can operate for several thousand charge cycles and can be in operation for over 5-10 years.
- *Recyclability:* While the recovery and recycling of lead acid batteries is well established, recycling of lithium ion is energy and cost intensive, and the by-products are toxic.

Issues with Lithium-ion batteries

Lithium ion batteries are subject of issues with regard to the sourcing of material, and recyclability. As the ability to recycle Lithium ion batteries is something on which there is still some ambivalence, the life cycle analysis of this technology is more important to consider. With the growth in the demand for energy storage in electrical vehicles and in association with renewable energy technologies, the demand for Lithium-ion batteries is also growing in an exponential fashion. The main sources of concern with Lithium batteries are:

- *Possible supply side issues for Lithium*: while reserves are sufficient at present, it is not certain that growing demand can be met in the future. While lithium, manganese, nickel and natural graphite are not likely to be affected, other materials also found in the batteries are more likely to be problematic, such as cobalt, which contributes to the high energy density of Lithium batteries. The supply of cobalt is at risk due to geopolitical issues. The main source of the metal is the Democratic Republic of Congo (DRC), which has been subject to civil war and political upheaval. Attempts are being made to improve recovery and recycling of this metal.
- *High flammability*: batteries can potentially over-heat and explode.
- *Toxic release*: accidental release of electrolytes from lithium-ion batteries or explosion can potentially form a toxic atmosphere through the formation of hydrogen fluoride from the decomposition of the lithium salt ($LiPF_6$).
- *Ozone depleting substances* - fluorinated compounds used in the manufacture of the batteries are implicated in ozone depletion.

Sourcing Batteries

Batteries can be sourced locally throughout the Arctic Region. Some on-line resources are listed in Table 12. The list is not comprehensive, but an indication of the choice available.

Table 12.Online resources to aid sourcing of batteries.

Country	Online source	Web address
	Battery Fairs	http://www.thebatteryshow.eu https://www.oslobatterydays.com
Canada	CanPower	https://www.pbes.com/containerized-ess/
Finland	European Batteries	http://www.europeanbatteries.com/customer-industries/energy-storage/
	Hybria	http://hybria.fi/products/stationary-batteries
	Celltech	https://www.celltech.fi/en/products/ https://celltech.se

	BroadBit	http://www.broadbit.com
	Finnish Minerals Group	https://www.mineralsgroup.fi/battery-mining-ecosystem/finland-battery-production.html
	Tadiran Batteries Gmbh	https://www.celltech.fi/en/products/tadiran-lithium-batteries-for-industrial-applications/
Germany	HOPPECKE	https://www.hoppecke.com/en/
Greenland	Grenland Energy	http://grenlandenergy.com
Norway	Schive	https://www.schive.no/energy-storage-systems
Russia	Li-ion Technologies Limited (Liotech Ltd.)	http://www.liotech.ru/productionen
Sweden	Wärtsilä	https://www.wartsila.com
	GPB Industry	http://www.gpbmindustry.com/en/products http://www.gpbmindustry.com/en/solutions/k-series
	Northvolt	https://northvolt.com/production/#next-generation
	Swedish Micropower Group	https://micropower-group.com
	NorthStar	https://www.northstarbattery.com
	Mastervolt Sweden AB	http://www.mvs.se

Balance of Systems

Parts in addition to the generators of power (turbine and tower, solar panels) are the balance of system (BOS). Soft costs contribution to the BOS comes from the installation, engineering etc. The balance of system devices that are needed will also depend on whether the installation will be grid-connected, stand-alone, or a hybrid system. A simple stand-alone PV set up requires a PV module and an inverter to convert DC current to AC current. Battery storage can be foreseen depending on the use foreseen. For a wind turbine connected to a minigrid, the BOS will include a rectifier, over-voltage protection, and an inverter, as well as foundations, supports and cabling (Figure 27).

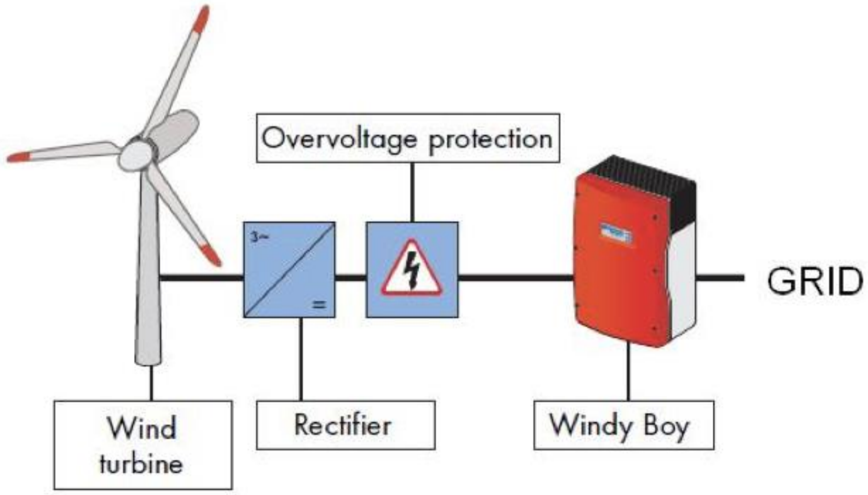


Figure 27. For a wind turbine connected to a minigrid, the BOS will include a rectifier, over-voltage protection, and an inverter, as well as foundations, supports and cabling.

Grids can be as simple or as complex as is necessary to meet the needs of the Station, and the capital investment that would be possible. For a hybrid grid (diesel and renewables), a three-phase cluster of invertors would convert the back to DC to charge the batteries. This process can be replicated to increase the power available on the grid, and integrating other sources of energy production, such as hydro-electric energy (Figure 28). For grids that are connected to the electrical company power supplies, the configuration of the set up has to take this into account.

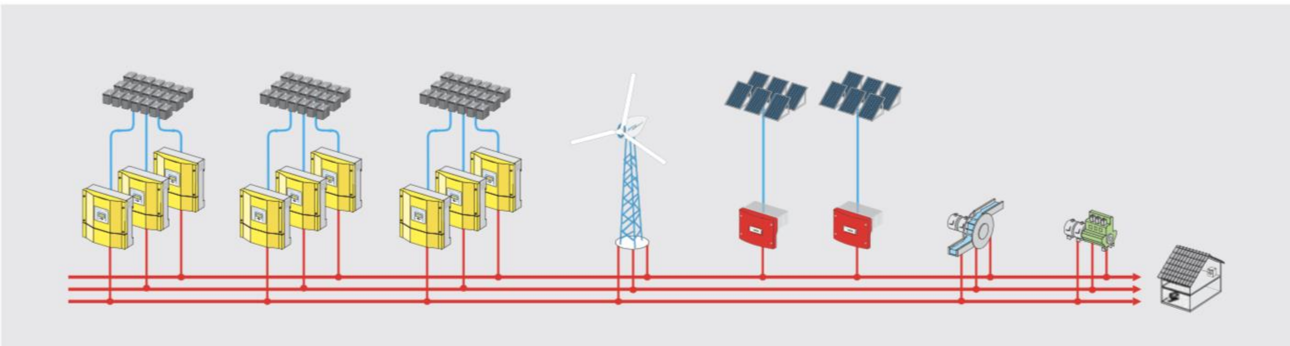


Figure 28. 3 Phase off grid multi-cluster system integrating wind, solar, hydro and generator.

Once the assessment of energy needs has been carried out, invertor suppliers can provide tools to assist in the selection of build of system components, such as invertors, and storage.

BOS Technologies

Examples of useful online sources when choosing BOS technologies are available in Table 13.

Table 13. Useful online tools for BOS Technologies.

Online source	**Web address**
Schneider Electric	https://www.schneider-electric.com/en/all-products#/2 https://www.schneider-electric.com/en/product-category/2100-human-machine-interfaces-%28hmi%29/?filter=business-1-industrial-automation-and-control

SMA	www.SMA.de/en
Siemens AG	https://w3.siemens.com/mcms/programmable-logic-controller/en/logic-module-logo/modular-basic-variants/pages/default.aspx
ABB	https://new.abb.com/power-converters-inverters/solar
KNX Association	https://www2.knx.org/ie/knx/association/introduction/index.php

Water Treatment

Several options exist for the containment, filtration and treatment of waste-water (Figure 29). These include large-scale plants, which will not be considered here. Of interest to Arctic Stations are the types of treatment possibilities that have been demonstrated to be successfully operated in extreme environments or other Arctic or Antarctic Stations. Water treatment Best Practice at Arctic Research Stations is not typically available from the INTERACT statistics, and so conclusions have been drawn from wider afield. Waste water treatment (WWT) possibilities can go as far as required, from the minimal to ensure safety of the surrounding ecosystem, to total purification for re-use as potable water, as is done in the International Space Station. Each step of additional purification will require energy and resources, so a balance has to be aimed at between targets and resources available.

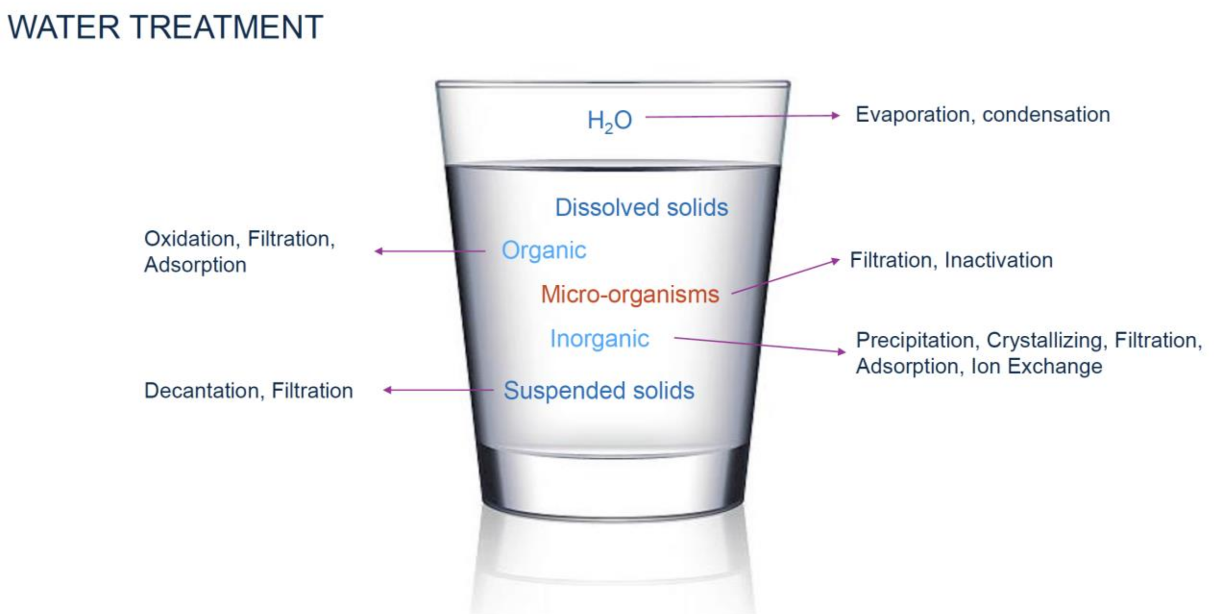


Figure 29. Several options exist for the containment, filtration and treatment of waste-water *© Dries Demey, Qinetiq*

Purification for re-use as potable water will aim to remove contaminants such as suspended solids, dissolved solids, organic, and inorganic contaminants, and micro-organisms. Each type of contaminant will be treated with a different technique, whether mechanical, biological or chemical, to obtain the final result.

Depending on the level of purification being sought, and regardless of the technology chosen, the removal of contaminants progresses through stages of elimination. The WHO Guidelines for Drinking Water Quality list[59] the processes by which reductions of contaminants can be achieved. These apply to water sources. For wastewater discharged into the environment, treatment is not required to be stringent unless the treated water is to be re-used, or discharge is into a sensitive ecosystem. The elimination processes by type are:

Pretreatment: Roughing filters, micro-straining, off-stream/ bankside storage, bankside infiltration

Coagulation/flocculation/sedimentation: Conventional clarification, high rate clarification, Dissolved air flotation, lime softening

Ion Exchange: Ineffective

Filtration: Granular high-rate filtration, slow sand filtration, pre-coat filtration, including diatomaceous earth etc., membrane filtration (micro, ultra, and nano), reverse osmosis – increased effectiveness

Disinfection: Chlorine, monochloramine, chlorine dioxide, ozone, and UV irradiation.

Primary treatment – Discharge

The simplest method of handling wastewater is to eject it directly into the environment, generally the surrounding land or a body of water. Sometimes the wastewater will pass through a mechanical process for breaking down larger material before discharge. Sometimes grey water is separated from black water. While discharge into the surroundings might appear, on the face of it, as the most practical and cost-effective solution, the long-term effects are more difficult to assess. In areas where the cumulative impact of discharge, associated with long-term human occupation, has been studied there are significant consequences linked to the survival of pathogenic bacterial and other faecal micro-organisms in the surrounding environment. A study carried out in Greenland assessed the impact of discharge to the sea. *"The Arctic nature is vulnerable to environmental contaminants because of low biological diversity, lack of nutrients and extreme seasonal variations in light. In Greenland neither industrial nor domestic wastewater is treated before it is discharged to the recipients, which in most cases is the sea. Wastewater contains a variety of substances, including anthropogenic pollutants, residues of pharmaceuticals and personal care products (PPCPs), pathogenic microorganisms and parasites as well as antibiotic resistant bacteria that can be harmful for the environment as well as human health. Due to the vulnerability of the Arctic nature, the direct release of untreated sewage may have severe consequences for the receiving aqueous environment".*

The Report also addresses the challenges facing any method of wastewater treatment in the region. *"With increasing populations in the Arctic communities and an increased demand to the level of comfort, it becomes even more vital to improve the status of wastewater treatment in these regions. However, designing, constructing and operating wastewater collection systems in the Arctic is challenging because of e.g. permafrost conditions, hard rock surfaces, freezing, limited quantity of water and high costs of electricity, fuel and transportation, as well as a settlement pattern with limited accessibility, particularly in*

[59] World Health Organization. Guidelines for drinking-water quality, 4th Edition- 2017 - ISBN 978-92-4-154995-0

the rural parts of the Arctic[60]*".* However, there are solutions available depending on the characteristics of the site and the resources available.

Natural filtration

The next level of WWT can be furnished through the use of sewage tanks in the earth, where the natural filtration capacity of the soil, and the breakdown of organic matter via methanogenic bacteria naturally present in soil, will provide a relatively tolerable level of treatment, as long as the carrying capacity of the soil biome is not exceeded.

Where the installation of sewage pits is in the permafrost, the rate of *breakdown* of organic matter by a variety of naturally occurring soil micro-organisms is markedly reduced by the low temperatures. The above-mentioned study assessed the impact of repeated cycles of freezing and drying, and concluded that while some pathogenic bacteria could be eradicated by this treatment, others such as *E. Coli,* might actually be enhanced. "*Laboratory experiments were conducted to test the effect of the selected processes on inoculated and indigenous microorganisms in blackwater. In the first laboratory experiments the effect of long-term freezing and repeated freezing and thawing on inoculated and indigenous microorganisms in dewatered blackwater was analyzed. The results indicated that freezing has a lethal effect on some microbial groups, such as coliforms, and sublethal on others, e.g. Salmonella. Other microorganisms, like faecal streptococci and coliphages, showed a limited reduction during the long-term freezing. Repeated freezing and thawing did, however, have an enhancing effect on both coliphages and amoxicillin resistant enteric bacteria*"[61].

This "freeze drying" was also found to be ineffective in the Antarctic, where studies show that bacterial spores of various strains were still present in the environment after several decades at sub-zero temperatures[62]. This single fact is sufficient in itself to provide the impetus to improve WWT practices. Using secondary and tertiary treatment capabilities is a requirement now in most parts of the EU, This has not always been extended to remote communities, but awareness of the issues is growing.

Secondary Treatment

As an intermediate step to discharge, different types of filtration will remove material of varying particulate size from the wastewater (Figure 30). The stages of mechanical removal progresses from largest particle size to smallest:

Macrofiltration : 1-10 **μ**m -will remove sand and large cells like yeast
Microfiltration : 0.1 - 1 **μ**m – will remove certain bacteria
Ultrafiltration : 0.01 -0.1 **μ**m – will remove some viruses, large molecular weight proteins and colloids
Nanofiltration : 1.001 -0.01 **μ**m – large molecules, pesticides, herbicides
Reverse osmosis: <0.001 **μ**m – will remove dissolved salts and metal ions

[60] Wastewater Treatment in Greenland - Ragnhildur Gunnarsdóttir - Department of Civil Engineering, 2012 - DTU Civil Engineering Report R-265 (UK) - May 2012

[61] Wastewater Treatment in Greenland - Ragnhildur Gunnarsdóttir - Department of Civil Engineering, 2012 - DTU Civil Engineering Report R-265 (UK) - May 2012

[62] Long-term survival of human faecal microorganisms on the Antarctic Peninsula - Kevin A. Hughes and Simon J. Nobbs - Antarctic Science 16 (3): 293–297 (2004) © Antarctic Science Ltd - DOI: 10.1017/S095410200400210X

Capital investment costs increase with each step of this stepped process. Reverse osmosis can be used where a high level of water purity is required, which is not likely to be necessary in a research station scenario, unless water is scarce.

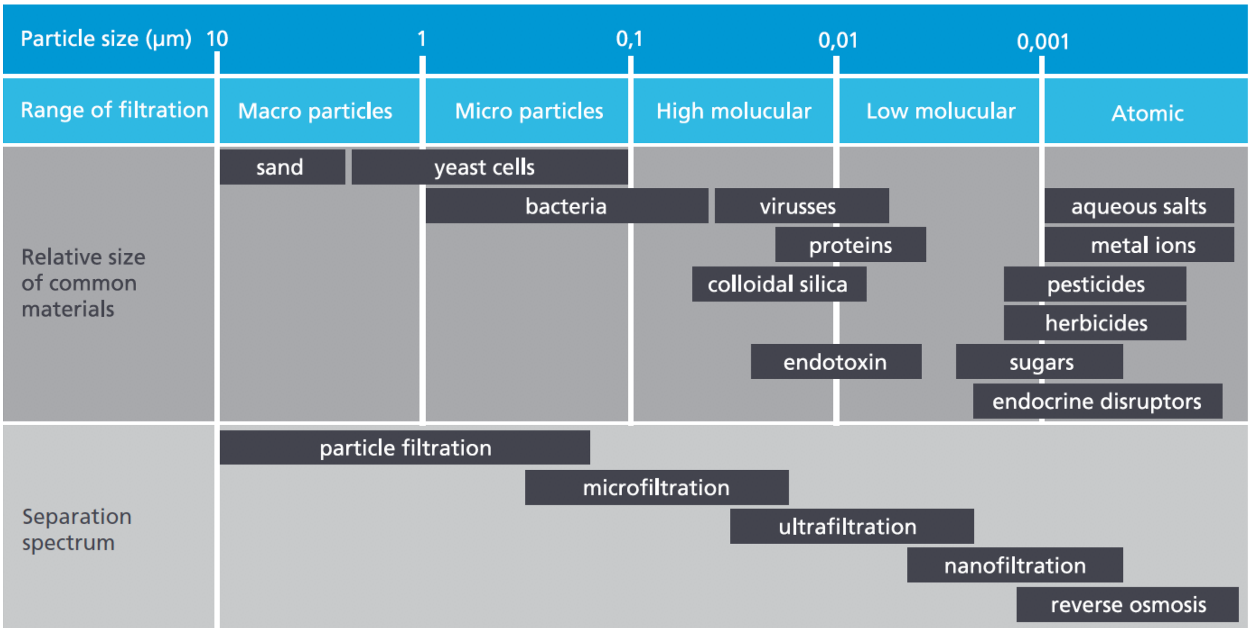


Figure 30. Different types of filtration will remove material of varying particulate size from the wastewater. © Waterleau

Membrane bioreactor

The Membrane bioreactor (MBR) uses a combination of biological digestion, and filtration to remove solids and dissolved matter, as well as pathogens from wastewater. Biological water-treatment in membrane bio-reactors provides a high level of purification. In combination with nano-filtration, the effluent can be recycled for use in less critical areas. When combined with UV disinfection, and addition of hypochlorite, the treated water can actually be considered potable. An MBR system can be automated to provide optimal performance, but since it is a biological system, the correct dimensioning of the digestion tanks will be important to handle the expected throughput.

Initially, a buffer tank is used to contain grey water and black water separately. These are then fed through different treatment loops depending on the design of the system. The waste-water is fed into a digestion tank, containing activated bacteria where organic matter is broken down, leaving behind a sludge. Bacteria in the aerobic digestion tank break down organic matter to produce methane and CO_2. Proteins are digested, and nitrogen from the protein molecules is converted into ammonium. Ammonium is then oxidised to produce nitrate in solution. The bacteria that drive this process are:

- *Nitrosomonas spp.* - transformation of ammonium to nitrite (NO_2)
- *Nitrobacter spp.* - transformation of nitrite to nitrate (NO_3^-)

$(NH_4^{\ +})+ 4(O^{2-})\text{-}> (NO_3^-)+ 2H^+ + H_2O$

Ammonium is converted into nitrates by bacterial “oxidation”. For this *aerobic stage* to be carried out efficiently, quantities of oxygen needs to be introduced into the digestion tanks, usually in the form of bubbles. The size of the bubbles will affect the rate of oxygenation of the mix. The effluent is then pumped into the anaerobic tank where in the next step, or the *anaerobic phase*, nitrates are stripped of oxygen by aerobic bacteria (this strain of bacteria will take molecular oxygen when there is no access to other sources). The resulting nitrogen gas, which is produced, is then vented. As the atmosphere consists of 78% nitrogen, this release of gas is not considered as being polluting. At the end of the process, a sludge remains consisting mainly of bacteria and water. Some of this active sludge remains in the tank, but excess has to be removed through ultrafiltration. After filtration, the treated water is clean enough to use for ordinary domestic purposes, such as toilets and laundry. Some disinfection will be required for all other use. Disinfection can be via the addition of chlorine or by using ozone or ultra-violet light. The quality of the water produced has to be tested on a regular basis to check for contamination by pathogens, and analysed for quality.

WHO Guidelines for Drinking Water Quality[63] (Table 14), sets parametric values which are globally followed by the values set in Annex I to Directive 98/83/EC. There are some differences, but the EU has begun to revise values[64] to come into line with the WHO Guidelines, except in some areas where EU criteria are stricter. The US EPA water quality standards[65] also follow WHO Guidelines, for heavy metals, and microbial contaminants.

Table 14. WHO Water quality standards.

	Cryptosporidium	***Campylobacter***	**Rotavirus**[a]
Organisms per litre in source water	10	100	10
Health outcome target	10^{-6} DALYs per person per year	10^{-6} DALYs per person per year	10^{-6} DALYs per person per year
Risk of diarrhoeal illness[b]	1 per 1600 per year	1 per 4000 per year	1 per 11 000 per year
Drinking-water quality	1 per 1600 litres	1 per 8000 litres	1 per 32 000 litres
Performance target[c]	4.2 $\log_{10}$ units	5.9 $\log_{10}$ units	5.5 $\log_{10}$ units

[a] Data from high-income regions. In low-income regions, severity is typically higher, but drinking-water transmission is unlikely to dominate.
[b] For the susceptible population.
[c] Performance target is a measure of log reduction of pathogens based on source water quality.

Water Treatment On-Line Resources
Water treatment online resources are listed in Table 15.

63 World Health Organization. Guidelines for drinking-water quality, 4th Edition- 2017 - ISBN 978-92-4-154995-0

64 COM(2017) 753 final Proposal for a Directive of the European Parliament and of the Council on the quality of water intended for human consumption.

65 2018 Edition of the Drinking Water Standards and Health Advisories - EPA 822-F-18-001 - Office of Water - U.S. Environmental Protection Agency, Washington, DC - March 2018

Table 15. Water treatment online resources

Country	Online source	Web address
Canada	Bipurewater	http://bipurewater.com/package-treatment-plants/
Denmark	BioKube	https://www.biokube.com/index.php/biokube-wastewater-treatment-plants-for-houses-resorts-villages
Finland	Cleantech Finland	http://www.cleantechfinland.com/clean-water
	Finnish Environment Institute (Suomen ympäristökeskus/ Finlands miljöcentral)	www.oulu.fi/water/
Germany	KLARO	https://en.klaro.eu/wastewater-treatment-plants/containerized-sewage-plant.html
	DELPHIN Water Systems GmbH & Co	https://www.delphin-ws.de/en/products/small-plants/
Greenland	Pure Aqua	https://www.pureaqua.com/reverse-osmosis-water-treatment-in-greenland/
	Greenland: Wastewater Treatment (Pernille Erland Jensen)	https://www.coursera.org/lecture/global-environmental-management/greenland-wastewater-treatment-pernille-erland-jensen-CmoKC
Russia	Wastewater Treatment Companies (Water and Wastewater) in Russia	https://www.environmental-expert.com/water-wastewater/wastewater-treatment/companies/location-russia
Sweden	Ecofiltration	http://www.ecofiltration.se
United Kingdom	Vortex	www.wte-ltd.co.uk
	Biorock	Biorock.co.uk

Conclusion

The environmental impact reduction strategies to be applied to the management of INTERACT Research Stations in the Arctic cannot be easily summarised to a few options. The climate, topography, surrounding habitats, and geological conditions at each site vary enormously, as do the logistics for reaching them. In addition, the number of occupants, the types of activities, age of infrastructure and the connection to utilities make each Station unique.

In order to approach the task of across-the-board impact reductions would require that each Station be studied on a case-by-case basis, and be audited for energy use, and water use and water discharge. These are the most important impacts associated with Station operations and addressing these aspects would give rapid and measureable returns. To be able to suggest customized solutions would also require that the unique character of each site be studied for the wind and solar potential. Not all sites will be able to benefit from using wind energy, while solar panels will only work in the summer months at high latitudes. Partnering with University engineering departments would be a very useful initiative to take, as the interest in low wind wind-turbines grows. Partnering with engineers will facilitate the process of finding technological solutions, freeing up research scientists and managers to carry on with their normal activities. Past experience with low wind speed vertical axis turbines may have been discouraging for those who have tried them previously, but the technology is evolving and solutions may be around the corner.

Where renewable energy will not provide a zero emissions solution, because of low wind, or other issues, a new generation of diesel generator, which is cleaner and more efficient would also bring about impact reductions. For Stations that benefit from hydro-electric and geothermal power, there is little incentive to use renewable energies to reduce environmental impact. For these Stations, other aspects can be studied, in particular energy efficiency strategies, whether through building materials to reduce energy loss, or automation and building management using smart technologies to reduce energy use. Re-examining activities will help to identify other areas where energy can be saved, or converted to less polluting methods of generation. New technologies are providing an ever-greater array of possibilities for impact reduction through the use of connected devices. Using autonomous observation stations will allow Station personnel and researchers to significantly reduce travel times dedicated to collecting data from observation stations. If remote instruments and devices can be connected using long-range RF communications, by terrestrial networks, this can reduce costs and energy use.

The next step should be to set up an on-line platform for the Research Stations to share experiences with different technologies, and services, so that the search for the ideal configuration will be less arduous, and the risk of costly mistakes would be reduced. Potential funding sources could also be covered, to help the Stations to access funds that are becoming available, but may require significant resources to identify and obtain.