

The Eco-efficient design of Small Hydropower Stations - A handbook of Life Cycle Design guidelines for Small Hydropower Stations



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ABSTRACT

English

Small-Hydropower stations (SHPS) are hydroelectric systems that use the runoff of a river to produce energy with an output of less than 10MW. They are usually located in the mountain areas of a catchment basin where steep slopes facilitate the water delivery to the turbines or waterwheels at high speeds. It is generally thought that distributed energy technologies such as small hydropower systems have a low impact on the environment surrounding them. However, in the case of small hydropower systems, it is important to assess all aspects of its life cycle stages (LCA) to truly understand the overall possible adverse effect it has on the environment. This assessment should result in identifying areas of priority when designing future, eco-efficient small hydropower systems. The life cycle stages of a small hydropower system includes production, transportation, usage and disposal at the end of its lifespan. Therefore, an environmental assessment of all the life cycle stages (LCA) is worth doing to identify the phases and processes with the highest environmental impacts.

This thesis performs a Life Cycle Assessment (LCA) on a typical small hydropower system, and identifies environmental priorities over the Life Cycle Design (LCD) strategies and guidelines. In other words this thesis moves from general to product specific LCD guidelines and a checklist. All of this will result in the form of a handbook for designer free of charge and in copy left.

ABSTRACT

Italian

Il cosiddetto piccolo idroelettrico è una particolare centrale idroelettrica con una ridotta capacità di produzione di energia (inferiore ai 10 MW). Solitamente sono situate nelle aree montane dove l'acqua di un fiume grazie alla naturale pendenza, viene condotta da un bacino, attraverso un canale, a una turbina. L'azione del flusso dell'acqua sulle pale della turbina permette la rotazione dell'albero di un generatore, che converte il movimento dell'asse in energia elettrica.

È pensiero comune il fatto che questo genere di tecnologia sia considerata a basso impatto ambientale. Rimane a ogni modo importante, nel caso di questo particolare tipo di centrale idroelettrica, valutare tutti gli aspetti del suo ciclo di vita per comprenderne appieno l'impatto ambientale. La valutazione che ne risulta aiuta a individuare le priorità ambientali nella progettazione futura di piccoli impianti idroelettrici eco-efficienti.

La valutazione ambientale di tutte le fasi del ciclo di vita è importante per identificare le fasi ed i processi a maggior impatto sull'ambiente. Le singole fasi del ciclo di vita comprendono: pre-produzione, produzione, trasporto, uso e dismissione. Questa tesi sviluppa il Life Cycle Assessment di un piccolo idroelettrico, e ne identifica le priorità strategiche ambientali. In seconda battuta sviluppa delle linee guida di Life Cycle Design specifiche per il tipo di prodotto e indicatori di priorità strategiche ambientali.

Il risultato del lavoro di ricerca progettuale è poi riportato nella forma di una Manuale di linee guida per la progettazione di piccoli sistemi idroelettrici. Il manuale sarà disponibile in licenza creative commons e disponibile gratuitamente nella versione digitale.

INDEX

PART I: BACKGROUND

1.	Introduction	13
1.1.	Who can benefit from Life Cycle Design guidelines supported by a Life Cycle Assessment ?	15
1.2.	Life cycle design of product and product specific guidelines and priorities indicators	15
1.3.	Why a Product Service System approach to SHPS design?	16
2.	Sustainable Energy for Sustainable development	
2.1.	Sustainable Energy for All	18
2.2.	The context of Hydro energy in Europe	19
2.3.	LeNS.es - The Learning Network on Sustainable energy system EU project	21

PART II: THE DESIGN RESEARCH APPROACH

3.	Product design for environmental sustainability	
3.1.	Introduction	24
3.2.	Product Life Cycle Design (LCD)	24
3.3.	Functional unit	26
3.4.	Life cycle Phases	27
3.5.	Life cycle design (LCD) guidelines	30
3.6.	Definition of Specific Design Guidelines and priorities	31

PART III: THE STUDIED SMALL HYDROPOWER STATION

4.	Location of the studied SHPS	34
4.1.	The context of Hydro energy in Romania	34
5.	The Small Hydropower Station Design	
5.1.	Descriptions of small hydropower energy generation stations	38
5.2.	How are they built?	40
5.3.	The Hălmagel SHPS Specification	41
5.3.1.	The Intake	42
5.3.2.	The Sluice Gates	42

5.3.3.	The Silt Basin	42
5.3.4.	The Forebay tank	44
5.3.5.	The Rapid Pipeline	44
5.3.6.	The Powerhouse	44
5.3.7.	The Tailrace	46
5.3.8.	The electromechanical equipment.....	46
5.4.	Incentives from the state	49
5.5.	Payback time	49

PART IV: THE LIFE CYCLE ASSESSMENT OF SMALL HYDROPOWER STATIONS

6.	The method of quantifying analyzing and estimating the environmental impact of Small Hydropower Stations	54
6.1	Life Cycle Assessment (LCA)	55
6.2.	The SimaPro software	59
7.	The life cycle assessment of Hålmagel Small Hydropower Station	
7.1.	I phase: The Goal and Scope Definition	60
7.1.1.	The system under study	60
7.1.2.	Data collection and quality	61
7.1.3.	The life cycle model - The system boundaries	62
7.2.	II phase: Life Cycle Inventory (LCI)	
7.2.1.	The Functional Unit for Hålmagel SHPS	63
7.2.2.	Intake inventory	64
7.2.3.	Rapid Pipeline inventory	66
7.2.4.	Powerhouse inventory	68
7.2.5.	Equipment inventory	70
7.3.	III phase: Life Cycle Impact Assessment (LCIA) results	72
7.4.	IV phase: Interpretation	74

PART V: SMALL HYDROPOWER SPECIFIC LIFE CYCLE GUIDELINES AND PRIORITIES

8.	Introduction	78
8.1.	Minimizing Material Consumption	82
	8.1.1. Equipment	84
	8.1.2. Pipeline	87
	8.1.3. Powerhouse	89
	8.1.4. Intake	92
8.2.	Optimization of Product Lifetime	96
	8.2.1. Equipment	98
	8.2.2. Pipeline	102
	8.2.3. Powerhouse	105
	8.2.4. Intake	108
8.3.	Minimizing Toxicity	111
	8.3.1. Equipment	112
8.4.	Optimization of Material Lifetime	114
	8.4.1. Equipment	116
	8.4.2. Pipeline	120
	8.4.3. Powerhouse	123
	8.4.4. Intake	127
8.5.	Renewable and Bio-Compatible Resources	131
	8.5.1. Equipment	133
	8.5.2. Pipeline	135
	8.5.3. Powerhouse	137
	8.5.4. Intake	139
8.6.	Minimizing Energy Consumption	141
	8.6.1. Equipment	142

8.7. Design for Disassembly, design with the purpose of separating the parts of materials	146
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PART VI: CHECKLIST	151
---------------------------	------------

PART VII: FINAL REMARKS AND FURTHER STEPS	
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9. Future steps	241
10. Final remarks	242

Bibliography	246
Sitography	248
Image Sources	249

PART VIII - Annexes	103
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part 1: background

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PART I: BACKGROUND

1. Introduction

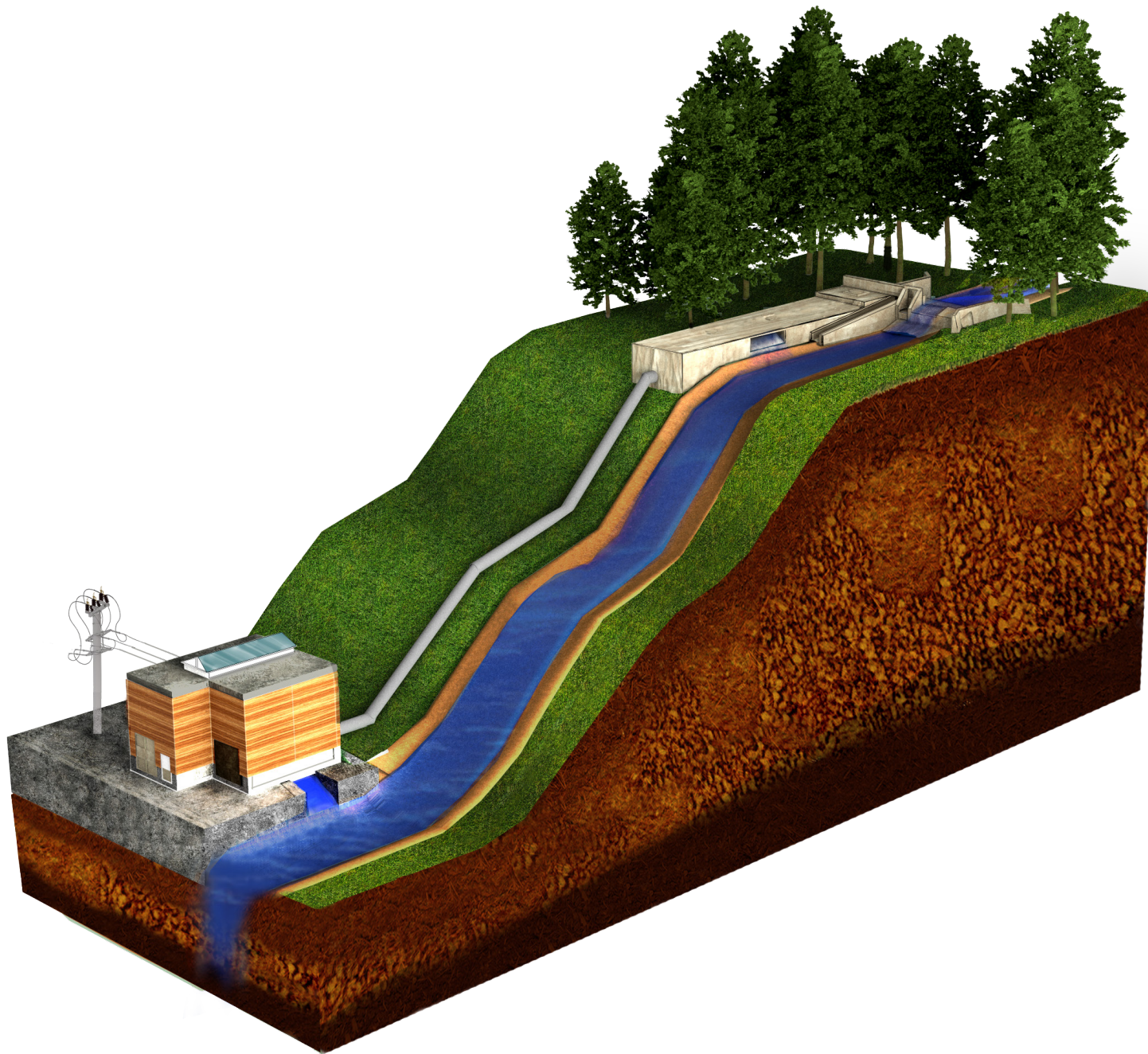
Small Hydropower stations (SHPS) are hydroelectric systems that use the runoff of a river to produce energy with an output of less than 10MW. They are usually located in the mountain areas of a catchment basin where steep slopes facilitate the water delivery to the turbines or waterwheels at high speeds. (SHERPA, 2006)

Hydropower generation is considered a renewable energy source because it does not consume exhaustible materials or fuel during energy production. Actually after the construction phase it uses almost no materials during energy generation, and the resources used, the water, is returned to the environment with minimal loss.

Small hydropower stations can be built in isolated areas where it would be uneconomic to serve from a network, or in areas where there is no national electrical distribution network. Since small hydro projects usually have minimal reservoirs and civil construction work, they are seen as having a relatively low environmental impact compared to large hydropower plant. The hydro system designer and site developer must strike a balance to maintain both the health of the stream and the economic gains.

The European Directive regarding renewable energy imposed that a specific proportion of energy be produced from renewable sources to all the member states. This consequentially has increased the investment in the renewable sectors making sustainable energy resources a priority. Apart from the need to generate energy from renewable sources as opposed to bigger polluting alternatives using fossil fuels, energy generation and usage need to also become more efficient.

As is the opinion of some NGOs, just because hydropower generation does not create CO₂ emissions does not necessary mean they produce green energy. (World Wide Foundation, 2013) Actually if by green energy we understand 0 emission outputs, no product, be it a small hydropower or a solar panel or a wind turbine is 100% emission free. This is due to the fact that in order to produce any product an exchange of substances need to happen between the biosphere, the geosphere and the techno-sphere. This means that any product has an environmental impact that can be measured, due to the fact that it needs to be pre-produced, produced, transported, used and disposed of at the end of its lifespan.



1.1. Who can benefit from Life Cycle Design guidelines supported by a Life Cycle Assessment ?

The design criteria and generation guidelines is meant to help designers introduce product environmental requirement as early as the development stages of a hydropower station project, in order to achieve energy and environmental eco-efficiency through assessments and environmental reduction guidelines. Small hydro stations are generally designed by specialized companies with design teams usually consisting of hydro-technic engineers. The investor or the beneficiary employs this company to create the project. In some instances the projecting company might not have a construction team, meaning one needs to be commissioned in order to construct the parts on site. (Civil construction works).

An interesting scenario rises when the investor is a public institution, because apart from reducing the environmental impact of the SHPS, the state should be also interested in protecting the quality of the rivers and streams and at the same time have renewable energy sources.

Many environmental activists have argued that SHPS have a big ecologic impact on the ecosystem they are built in. This makes LC design strategies more and more mandatory stages during hydropower stations design. Not doing so means having to rectify the damage done to the environment and the ecosystems, which can be an expensive and time consuming process, and sometimes impossible.

1.2. Life cycle design of product and product specific guidelines and priorities indicators

The first criteria of Life Cycle Design (LCD) is to shift the focus from classic physical product design to designing stages of the product life cycle. All activities related to the product, from the production of materials to its distribution, its use and finally its disposal, are considered as a single unit.

The second criteria of LCD is to design with regard to the function delivered by the product. In fact, it is in relation to this function (functional unit) that it is possible with Life Cycle Assessment (LCA) to assess whether the environmental impact has been reduced and how.

A life cycle model that comprises all the life cycle stages of the product is made, starting from extraction of material until their disposal. The functional unit is considered to be the availability of the SHPS to create renewable energy for a period of 70 years.

Further an environmental assessment is made on this model, in order to understand the environmental impact of each of the life cycle stages, for the four main components of the station.

Next, the priority indicators for product specific guidelines are calculated using IPSA (Strategic Design Priorities Identification) method. The result is a rank list of seven most important LCD strategies. The rank and the guidelines are as follows:

- 1) Minimizing Material Consumption
- 2) Optimization of Product Lifetime, design durable and intensely usable products
- 3) Minimizing Toxicity
- 4) Optimization of Materials Lifespan, design with the purpose of increasing the value of disposed materials via recycling, composting or incineration.
- 5) Renewable and Bio-Compatible Resources, select more eco-compatible materials, processes and energy sources
- 6) Minimizing Energy Consumption
- 7) Design for Disassembly, design with the purpose of separating the parts of materials.

1.3. Why a Product Service System approach to SHPS design?

(Mont, 2001) Defines PSS as “a system of products, services, supporting networks, and infrastructure that is designed to be competitive, satisfy customers’ needs, and have a lower environmental impact than traditional business models”. Mont elaborates her definition as follows: A PSS is pre-designed system of products, service, supporting infrastructures, and necessary networks that is a so-called dematerialized solution to consumer preferences and needs.

The Life Cycle design approach has similar fundamental levels of PSS .These levels are:

- Environmental redesigning of existing systems – choosing low impact materials and energy.
- Designing new products as services – substituting old systems with more environmentally sustainable ones.
- Designing new production-consumption systems – offering intrinsically sustainable satisfaction of needs and desires.
- Creating new scenarios for sustainable life cycles.

A systemic approach to SHPS design is needed in order to meet environmental requirements demands. This means that, in order to meet these demands a designer needs to understand the whole system and all its stakeholders, understand how the system works, and how the stakeholders interact within it. In fact, a systemic approach is helpful for creating an accurate life cycle model, which together with following sustainable design methodologies and assessments, leads to an understanding of the opportunities to increase the efficiency of the system.

The first stage requires the creation of a life cycle model. This needs to start with a clear evaluation of the initial conditions of the system. However, as some of the processes involved in product life cycle are hard to pinpoint, data availability becomes extremely crucial. A good practice is to predict and choose to employ low impact materials and energy in every stage of the product life cycle.

The second stage predicts the alteration of the system and suggest a dematerialized approach, namely products as services. At this point it becomes smart to choose a function satisfaction model in contrast to physical design. Operating at this level of technical-productive innovation can be radically favorable to the environment.

The LC approach needs to be aimed also at creating a new blend of products, goods and services that are socially appreciated and can overcome the cultural and behavioral inertia of consumers, as well as also being recognized as valid and socially acceptable.

2. Sustainable Energy for Sustainable development

2.1. Sustainable Energy for All

¹ *World Energy Outlook 2013*

Energy surrounds us, it is fundamental to answer to basic human necessities, like cooking, heating, illumination for instances. Energy is also necessary to sustain economic activities like agriculture, industry, transportation and service. Having energy is in fact a necessity to promote growth and economic well being; this is why energy has become a major geopolitical and socio-economic issues. Moreover the energy sector has a great environmental impact on the planet, of course there are some energy sources have a greater impact than others. The world population will continue to grow, at least for some few more decades, this means that also the energy requirement is going to increase. The key-point is how the reliable source of electricity is going to be produced. Nowadays, worldwide, 68% comes from fossil fuels (41% coal, 21% gas, 5,5% oil), 13,4% from nuclear fission and 19% from hydro and other renewable resources.¹

All energy sources have initial financial and environmental costs, but fossil energy is by far the most used source of energy worldwide and the resources are limited, as this resources become less abundant, the price will increase. Moreover fossil energy use is associated with a number of negative environmental effects is likely to contribute to global climate change, but also gives rise to other negative impacts.

To provide well being and meet energy security, there is the need to reduce the use of fossil energy resources; instead low-polluting, renewable and clean energy should be enhanced.

2.2. The context of clean energy in Europe

National energetic policy needs to be correlated with European policy in the European Community, which presumes respecting the 2009/28 /EC Directive, by all member states. Romania is a member of the European Union (EU) and it is the location of the station studied in this thesis.

Often ranking among the last in EU on various indicators, Romania has a leading position in the production of renewable energy, according to a report of the European Commission (EC) in a document, published in June 2015.

Reaching a level of 23.9% since 2013, Romania has far exceeded the target for 2013-2014 (19.7%) and is very close to fulfilling the mandatory target by the end of the decade. Romania is the eighth EU country in terms of share of renewable energy and has been well above the European average of 2013 (15.3%). (Infomediu Europa, 2015)

According to the Directorate-General for Energy of the European Commission, energy is an essential element of sustainability. Utilizing the hydro-energetic potential of the interior rivers represents the most ecofriendly way of obtaining energy. The world scenarios for growth positions hydro power on the first place for sustainable power generation.

Developing hydropower plants in areas with local natural and cultural values, but under natural vulnerability, can constitute the element that will ambition the community in growing its independence on the natural available depleting resources, contributing in this way as a key element at a modern conception of critical infrastructure (Directorate-General for Energy, n.d.)

When considering the security of energy supply, the EC expects that the dependence on natural gas will rise from 57% to 84% worldwide by 2030, and for petrol from 82% to 93% in the same period. And when considering sustainability, it needs to be acknowledged that the energy sector is at the European Community level, one of the main producer of greenhouse emissions. Unless measures are taken, at the recent rate of energy consumption, the greenhouse emissions in the EC will grow by 5% and by 55% at world level by 2030.

A solution to this would be the use of energy from nuclear power as this is considered a carbon-neutral

source of energy. Moreover, the EC report indicates that in 2007 nuclear power was ensuring a third of the annual electricity production in the EU. However there are considerable risks and important costs for the security of co-product in the long term.

Regarding competitiveness, EU's internal market insures the stability of correct pricing for energy. The consequence of the fact that the fuel reserve gets to be controlled by a small number of shareholders can have considerable effects. As an example, if the price of petrol increases to 100USD/barrel in the year 2030, the EU cost of energy import would be around 170 mil EUR per year, which means a value of 350 EUR/year for each European citizen.

The EC proposes the following objectives in its New Energy Policy of the EU:

- Reduction of greenhouse emissions with 20% until 2020 compared with 1990 levels.
- The rise of renewable energy resources from the total of energy mix to 20%, from 7% in 2006 by 2020.
- The rise of biofuel to 10% from the total fuel used in transport by 2020.
- The overall reduction of primary energy with 20% by 2020.

On 19 October 2006, the EC has adopted the Action Plan which regards the energetic efficiency of the final consumer and energetic services, and contain measures through which the EU can make visible progress in fulfilling its main objective: the 20% reduction of primary energy by 2020.

It is estimated that approximately a quarter of the global primary energy sources will be fulfilled by coal in the future. Concomitant with the growth of energy consumption the coal consumption will grow too. The data centralized by the World Energy Council, show a growth of up to 50% of coal extraction at a world level in the year 2005 from the year 1980.

The growth of energy demand, combined with geo-political factors such as the situation in the Middle East have determined the growth of oil price in the first decade of the XXth century, and this also induced a growth of natural gas prices. Another factor that determined the growth of oil price at a world

level was the lack of refinery capacity, a problem that needs a long term solutions. Adding to this was also the tendency of some states to supplement stocks for facing crisis situations. The above mentioned elements are at the base of the energy policy of the countries that are big energy importers. This leads to a growing attention given to renewable energy resources and the improvement of energetic efficiency. (Botoc, Cret, Roman, & Floarea, 2012)

2.3. LeNS.es - The Learning Network on Sustainable energy system EU project

The acronym stands for the Learning Network for Sustainable energy systems. LeNS.es is a multi-polar and open network for curricula and lifelong learning capacity development focused on locally-based Sustainable Energy System Design & Engineering (SES.DE).

It is a 3 year project (Oct 2013 - Oct 2016) funded by the European Commission (ACP-EU Edulink II), involving 3 design schools in Europe and 4 in Africa. LeNSes is an action of human resources and curriculum development, aiming at the promotion of a new generation of designers (and design educators) capable to effectively contribute to the transition towards a sustainable energy for all society. LeNSes ambitions to promote a new shared and articulated disciplinary ground on System Design for Sustainable Energy for all focused on Sustainable Product-Service System (S.PSS) and Distributed Renewable Energy (DRE) models, through a series of exchange activities and pilot courses at the partner institutions.

LeNSes will produce an open learning e-package, a modular package of teaching materials (texts, slide shows, audio, video, etc.) and tools for designers that design educators worldwide will be able to download (free of charge), modify/remix and reuse (copy left). LeNSes will also promote a series of diffusion activities targeting the design community worldwide.

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part 2 the design approach

3. PRODUCT DESIGN FOR ENVIRONMENTAL SUSTAINABILITY

3.1. Introduction

Assessing environmental requirement for industrial products became available as a discipline in the second half of 1990s and was able to deal with the complexity of the subject. This discipline was able to evaluate the environmental impact of the input – output between the technosphere of a product and the geosphere and the biosphere.

In more general terms is the exchange of substances between the nature and the production-consumption system:

As inputs: extracting substances from the environment (extracting resources, alteration of ecosystem's balance)

As outputs: emitting substances into the environment (extraction processes)

There are two approaches, which have great enough repercussion on design approaches that aim to integrate environmental requirement into industrial products.

Those are: Product life cycle, and Functional unit.

3.2. Product life cycle

Product life cycle refers to a holistic approach on all the stages of the life of the product, starting with the mining for necessary resources and manufacturing its components to energy and resources and emissions flows during the use, to the end-of-life treatments.

The entire life of a product can be described as a set of activities and processes, while every one of them consume a certain amount of resources and energy goes through a series of transformations and triggers emissions of various kinds.

To help trace the life cycle of a product the processes are divided into the following phases:

1. Pre-production
 - Acquisition of resources
 - Their delivery to the production area

- Their transformation into raw materials or energy

Raw materials and energy are produced from

- Primary or virgin resources
- Secondary or recycled resources

Primary resources come straight from the geosphere and can be classified as

- Renewable primary resources
- Non- renewable primary resources

2. Production

- Processing of materials
- Assembly
- Completion

3. Distribution

- Packaging
- Transportation
- Storing

4. Use

- Utilization or consumption
- Service

5. Disposal

Options:

- It is possible to restore the functionality of the product or its parts (reusing or re-manufacturing)
- It is possible to recover the component materials and energy of the disposed product (recycling, composting, incineration)
- Open loop recycling

- Closed loop recycling (inside the same production system)
- In any of these cases recycling implies a series of processes and stages:
- Recollection
 - Transportation
 - Pre-production of secondary raw materials / incineration
-
- After all this, is possible to regain nothing (landfilling)

3.3 Functional unit

The functional unit is the impact of a sum of cumulated processes employed to satisfy a certain function, and not the independent product impact on the environment.

In the case of this thesis, the functional unit is to satisfy the need of electricity of a remote settlement and not the physical characteristics of the construction. In other words, the functional unit is a performance of the assessed SHPS; therefore the function and the service supplied by the product has to be studied, not just the physical product itself.

The functional unit starts to be important when we need to match equivalent products, services or processes, therefore it becomes the measure for comparison amount products with a similar function. A comparison example would be: Which means of generating energy brings less impact on the environment?

Consequently the second fundamental criterion is therefore based on designing the function that the product has to supply rather than the product.

3.4. Life cycle design (LCD)

Life cycle design is also called: eco-design or design for the environment.

Life cycle design is characterized by:

- A greater design horizon: from product design to LCD, designing stages of the life cycle

Within this framework products have to be designed considering all phases of the life cycle. All activities related to the product, from the production of materials to its distribution, to its use and finally its disposal, are considered as a single unit.

- From product design to design of the function, designing the satisfaction of the product.

The second criteria of LCD is to design with regard to the product function delivered by the product, more than from the physical product itself. In fact, it is in relation to this function (functional unit) that it is possible (e.g. with LCA) to assess whether the environmental impact has been reduced and how. Function, a fundamental and historic theme in the culture and practice of design, acquires, in this context, a new meaning and a new vitality.

This approach goes from product design to product system design (PSD) – designing all the life stages, all the events that determine and accompany a product during its lifespan. This approach allows for a more holistic identification of all the consequences of the designed product, including phases that are not traditionally included.

The disadvantages are regarding the complex process. The first reason for the complexity is the required amount of information about the input-output processes and their impact on nature. The second reason, regarding the disposal, is the unpredictable techno-economical evolution. Not everything is known

during the design process. Those processes are in continuous evolution and hard to predict with any certainty. In ten years time, the disposal scenario that we had assumed, has evolved or might not be adequate for our product or its materials. Therefore a designer cannot be the sole responsible of the entire product system, other participants need to take over or control the stages of the life cycle as: raw materials suppliers, manufacturers, distributors, users, companies, and organization dealing with disposal.

The LCD should try to minimize the environmental impact at all stages, even though the production system is totally or partially controlled by the producer or designer from inside a company.

In the case of a SHPS design, the designer willing to reduce the environmental impact has a limited control over all the life cycle phases.

Usually small hydro stations are designed by specialized companies and the design team consist of hydro-technic engineers. The investor or the beneficiary employs this company to create the project.

Areas where a LCD designer has good control:

Pre-production phases:

- acquiring materials with a lower environmental impact
- choose raw materials that use renewable sources for exploitation or pre-production
- choose secondary or recycled materials

Production phases:

- choose raw materials that do not need a lot of processing
- employ procedures with low impact for construction and assembly of the station, on site and before

Distribution:

- choose nearby suppliers
- choose transportation with low environmental impact

- choose materials that are not packed

Use:

- choose renewable energy sources

Disposal:

- choose easily recyclable materials with accurate lifespan.

Areas where a LCD designer has partial control:

Pre-production

- controlling the processes or energy sources used during exploitation of raw materials
- transportation of raw materials from the geosphere to raw manufacturing factories
- controlling the processes or energy sources used during pre-production of raw materials
- finding information about processes of secondary raw material
- exact emissions and energy used for pre-production
- finding information about the chain of delivery from exploitation to acquisition company

Production

- exact emissions and energy used for production
- environmental impact on site of the construction

Distribution:

- finding suppliers that use local materials

Use:

- efficiency of energy distribution lines
- efficiency of maintenance works

Disposal

- disassembly procedures
- disposal transport
- amount of recycled materials
- amount of materials to landfill
- environmental impact of disposed materials

3.5. Life cycle design (LCD) guidelines

Generally speaking, the term guideline is used to indicate a set of procedures and tools to orient a decision making process towards given objectives.

The concern is put on designing products for environmental sustainability:

- the decision making process is intended as the design activity, from the briefing, to the conceptualization, to the product development;
- the objective of concern is the minimization of the environmental impact.

Using the above classification of tools, the guidelines for LCD can be defined as support tools for the design process of product conceptualization and development.

The guidelines should inspire and indicate those design decisions/solutions that have the major potential to be environmentally sustainable. They should also give a promising direction to achieve environmental gains in the product that has to be designed. This does not always happen. Even though guidelines are based on a matured experience and knowledge on sustainable assessment, sometimes guidelines can be misleading. This has to be evaluated casebycase. Furthermore, it should be kept in mind that guidelines are not fixed, but can and should evolve in time with the knowledge updating; particularly important for the less consolidated knowledge, such as those connected with the assessment of sustainability.

The term environmental design criteria, as a concept for guidelines management and aggregation.

- should represent a clearly separated area of concern of environmental sustainability in a form that is understandable by a designer;
- should allow some kind of environmental assessments, in terms of relative environmental priority setting (among the various criteria);
- should allow the clustering of guidelines, i.e. the criteria are the headers of various sets of design guidelines.

3.6. Definition of Specific Design Guidelines and priorities

To be effective, guidelines should inspire and indicate, as precisely as possible, those design decisions and solutions that have the major potential to be sustainable; they should “provide specific advice and strategies on how to reduce [...] impacts” (Dahlstrom H)¹.

The specificity of guidelines refers to the quality of the decision making process and the product typology. With the quality of the decision making process is intended that for any decision making process, there should be a specific set of guidelines considering what has to be decided and by whom. In this framework, what is the product conceptualization and development and who is the designer. Guidelines’ specificity per product typology refers, on the one hand to its general requirements, characteristics and functionality and on the other hand to its typical environmental impact.

This last point shows that, given the variability of the environmental impacts for the various product typologies, guidelines/criteria may have an environmental weight (in general and among them): some guidelines/criteria would be more relevant than others to achieve environmental impact reduction for a given product.

In this perspective it is important to establish guideline priorities per any product typology; they should be defined on the basis of a more critical environmental impact for the product typology according to the potentials of environmental impact reduction for a series of determined criteria.

Besides the elaboration of specific guidelines, it is important to define an effective process aiming at their integration into company realities. Then the issue of the usability of the guidelines acquires two main purposes: the first one is referred to the integration in the company’s existing procedures; the second one is related to the staff which makes use of them: human beings with their own habits and expectations. This is a requirement which is usually less considered, but has proven to be a crucial aspect.²

¹ Dahlstrom H. (1999) *Company-specific guidelines*. J. Sustain Prod Design

² Vezzoli, C., & Sciama, D. (2006). *Life Cycle Design: from general methods to product type specific guidelines and checklists: a method adopted to develop a set of guidelines/ checklist handbook for the eco-efficient design of NECTA vending machines*. Journal of Cleaner Production.

ECO-EFFICIENT DESIGN OF

SHPS

3

part 3 the studied SHPS

PART III: THE STUDIED SHPS

4. Location of the studied SHPS

Romania has been chosen as a location due to a wide availability of data. And because the small hydro station sector has boomed in the past years, due to incentives from the state. It is expected that in 15 years, (from 2005 until 2020) Romania would have built an average of 11 SHPS every year.

The effects of the SHPS on the environment has been a media subject and nonetheless a controversial one, some voices clamming that the environmental effect does not justify the energy return, and some clamming that the SHPS are built for immediate profit and not for enlarging the renewable portfolio of Romania. Another factor raising questions is that Romania has the largest hydropower station on the Danube and a nuclear power plant, which capacity is going to be increase in the following years. So many voices question the need of interfering in the well-functioning of stream systems to build SHPS.

4.1 The context of Hydro energy in Romania

A study regarding the hydro energetic potential of small hydropower stations as sources of renewable energy, with the scope of identification the optimal sites of such station in Romania, was conducted in 2005 by the Center of Energy Research and Environment Protection within the Polytechnic University of Bucharest and the Institute for Hydro-technic Study and Design. As a result of this, they inventoried all the locations for SHPS and set the hydro energetic potential of the country at 38 000 GWh per year for small station generation. (Nisteanu, Popa, Paraschivescu, n.a., 2005)

The study showed that among the sources of renewable energy specific for the climate and geography of Romania: solar energy, wind energy, hydro energy, bio-waste energy and geothermal energy, the hydro power has the biggest share.

The potential of small and micro hydropower stations is part of the total energetic potential of Romania. In the past, especially during the XX century, this was focused on the construction of hydroelectric power station with power above 10 MW. However nowadays, the country makes steps for further capitalization of the micro potential to answer the request of the Energy Directive of the European Union regarding the renewable energy sources.

The biggest hydropower plant of Romania and Serbia is the Iron Gates I on the Danube. Is the biggest dam constructed on the Danube River and the biggest run-of-river hydropower constructed in this part of Europe. After the renewing of its turbines in 2007, it reached an installed power of 2.254,8 Megawatt, it produces in average 5.4 terawatt hour in one year, only on the Romanian side and 5.65 terawatt hour per year on the Serbian side. Depending on the water debits reports shows a top of 7.7 terawatt hour of energy produced in 2010. With an average of 0.001 Gwh/year the consumption of one person, 5400 Gwh/ year of power will be enough for 5.4 million people for one year.

According to the conductors of the research mentioned above, if all the potential of small hydropower generation in Romania is used by stations with installed capacity under 10 megawatts, this will be equivalent with up to 70% of the energy produced by Iron Gates I in one year. The difference is that SHPS can be distributed equally across almost all the country and their construction would presumably bring economic growth in all the areas of the country where they are built.

The number of small and micro hydropower station built until 01. 01. 2005 (the date of the inventory) is 380 small and micro stations with a total installed power of 500 MW and an average of energy per project of 1508 Gwh/year. It is believed that the number of small hydropower station will reach 550 by 2020. According to the European Small Hydropower Association 1 Gigawatt generated by small hydropower stations (SHPS) means a reduction of 480 tons of carbon dioxide. Therefore, an average for the year 2005 can be around 723.840 ton of carbon dioxide reduction in Romania.

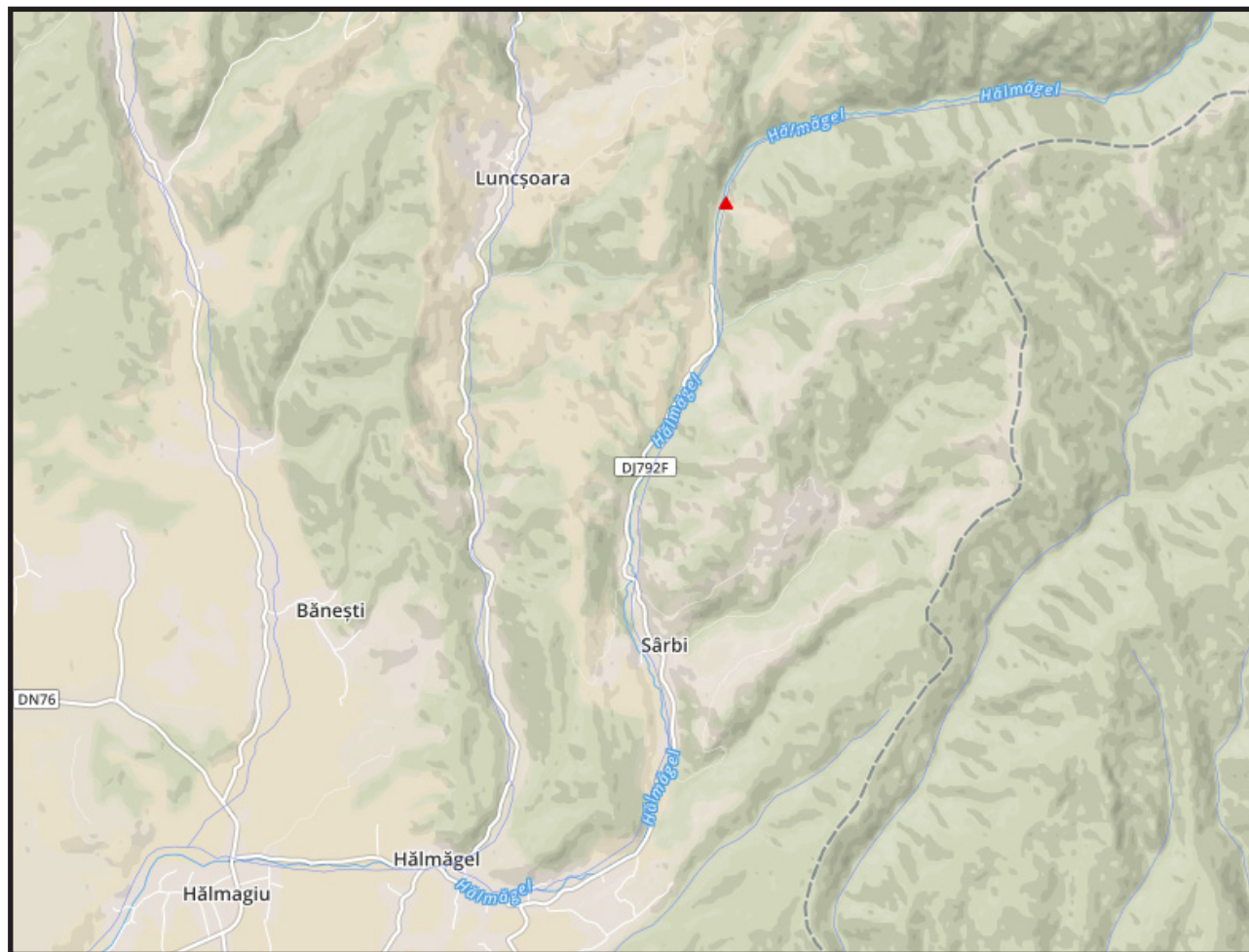


fig.2 - Location of the studied Small hydropower station (on the valley of Hălmăgel river close to Sarbi and Hălmăgel village in the county of Arad)

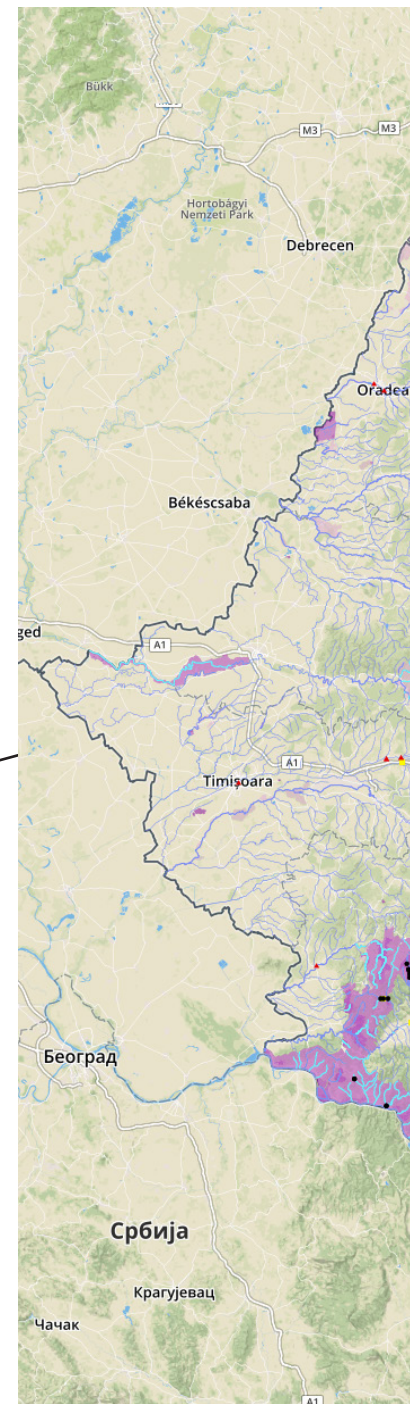
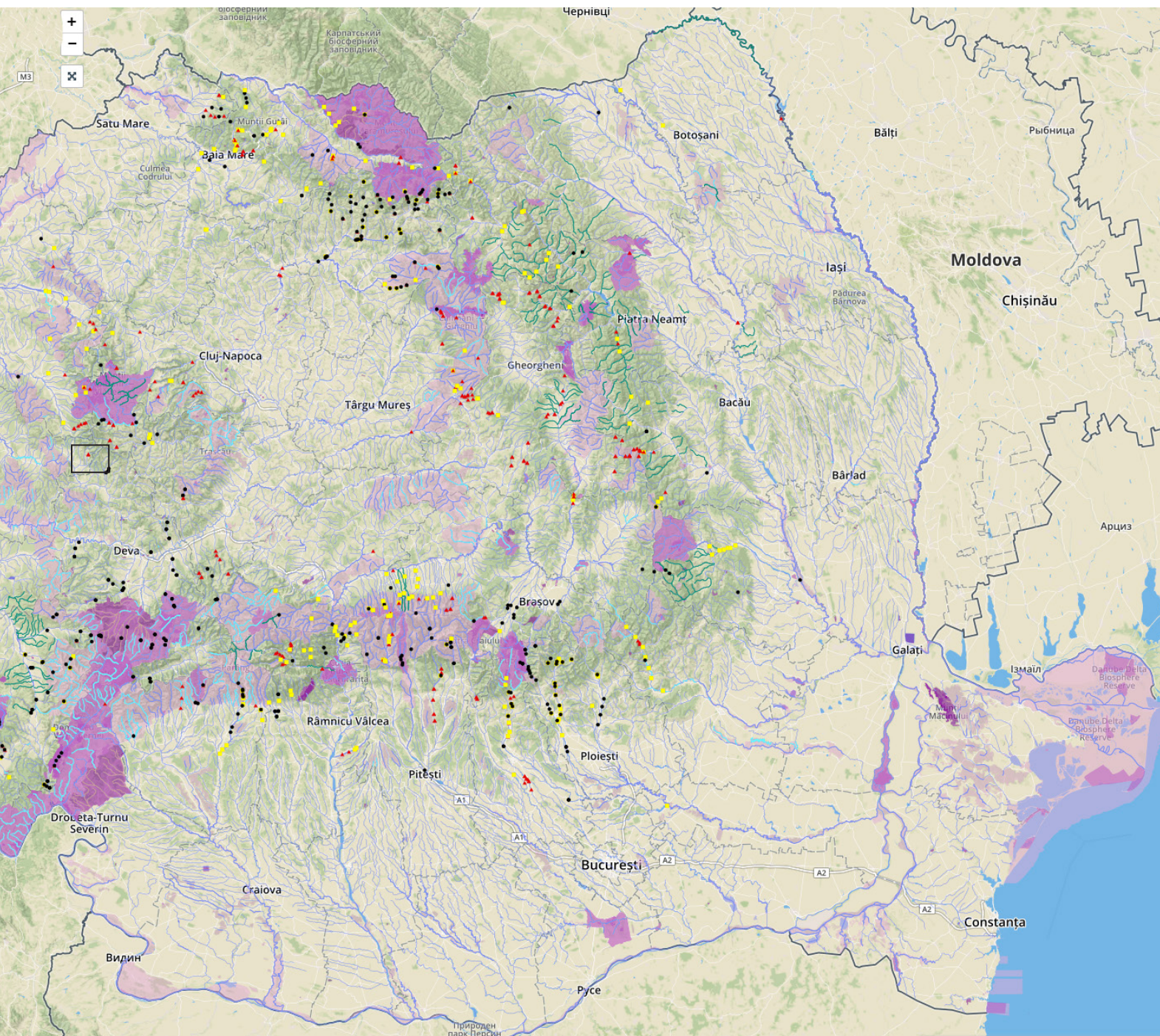


fig. 1



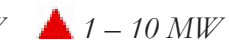
LEGEND

I. INFRASTRUCTURE

Hydropower facilities that are in the licensing process, under construction or operating (of maximum 10 MW)



Capacity Unknown



II. HYDROGRAPHIC ELEMENTS:

Extremely rare water bodies with a very good ecological status (<3% of all the rivers of Romania)

Water bodies having a good ecological status and a very good condition of the river bed (hydro morphology)

Hydrographic Network

III. PROTECTED AREAS:

Protected areas of national interest (scientific reserves, national parks, natural monuments, nature reserves, natural parks) and of international interest (Geoparks).

Sites of community interest (SCI) designated for the protection of species of fish, otter and crayfish and for the habitats of these species (according to the Environmental permit no.10938/2012 for the Energy Strategy of Romania) as well as for the alder galleries forests.

5. THE SHPS DESIGN

5.1. Descriptions of small-hydropower energy generation stations

Small-hydropower installations have the potential to provide a renewable supply of energy to people in remote, hilly communities, far from the national grid.

SHPS are hydroelectric systems that use the runoff of a river to produce energy with an output of less than 10MW. They are usually located in the mountain areas of a catchment basin where steep slopes facilitate the water delivery to the turbines or waterwheels at high speeds. (SHERPA, 2006)

The term “small-scale” applies to developments of less (generally much less) than 5 Megawatts generating capacity. Small-scale hydropower plants include both low head and high head schemes. The former typically comprise lowland sites where a large volume of flow is diverted at an existing weir and through a turbine. High head schemes, by contrast, utilize smaller flows (but often a substantial proportion of the available river flow) at upland sites, diverting water typically over perhaps several hundred meters or more and taking advantage of the difference in height over that distance. Turbines may also be installed in water supply reservoirs to take advantage of compensation water or other releases.

In large hydroelectric plants, the reservoir is an important component for regulating the use of water throughout the year. In small hydroelectric plants, this component is not used, other than in exceptional cases when the cost of this structure justifies the investment.

The main components of small hydropower stations are as follows:

1. Intake weir
2. Headrace channel
3. Coarse settling basin
4. Conveyance channel
5. Silt basin
6. Forebay tank
7. Penstock or Rapid Pipeline
8. Powerhouse
9. Turbine

10. Generator
11. Controller
12. Tailrace
13. Electricity grids*
14. Transmission grids
15. Distribution grids

*The electricity grids correspond to conventional electrical engineering works.

Furthermore, it is customary to analyze a hydroelectric power plant in accordance with the following components: civil works, electromechanical equipment, electricity grids and management of the system in operation. (Rodriguez & Sanchez, 2011)

5.2. How are they built?

SHPS are constructions of national interest and they require a set of documents and authorization before the implementation stages, both for the permission to build on a river that is considered the property of the state and for being entitled to incentives.

Technically speaking, designing a SHP station involves a group of documents that contain processed calculations, a detailed description of the calculation results, including explanatory tables and other elements to verify the accuracy of the data and methods used. The documents needed are listed below:

1. Electricity market surveys
2. Hydrological study
3. Type and design of the station
4. Civil works: scaling of the civil works and detailed calculations of the physical dimensions of each of the components mentioned above, as well as complementary works such as the access road, camp, etc.
5. Electromechanical equipment (including the technical characteristics of each of the machines and auxiliary equipment)
6. Transmissions lines
7. Distribution grids
8. Geological studies

All these need to be authorized by competent agencies such as the Ministry of Environment, Waters and Forests and the National Authority for Energy Regulation.

After the studies and the documentation of the site and the design of the SHP station receives all the agreements from the authorized agencies, the construction can begin.

5.3. The Halmagel SHPS Specification (Botoc, Cret, Roman, & Floarea, 2012)

The construction site is located at and at 8 km from Halmagel village and 126 km from Arad the region's residence city.

The specifications:

- A run of river independent station located on Halmagel river, in Apuseni mountain region
- A Pelton turbine with an installed power of 3,2 mW in the powerhouse
- An annual production of: 1253 mWh/year
- An intake situated at 602,50 m altitude with a medium flow of $Q_m = 0,351 \text{ m}^3/\text{s}$
- A Ø 600 mm diameter glass fiber reinforced plastic pipe with a length of 1870 meters
- A powerhouse with an average of 70 m² located at 514,60 m altitude.

The construction duration was around 8 months in 2012 and was carried out by 18 people:

- one engineer – the site master
- one topographer
- two concreters
- two blacksmiths
- two carpenters
- two drivers for machinery and transport
- eight laborers

In the project studied the Coarse Setting basin is missing and the Conveyance Channel is replaced with a plastic pipeline. After the Headrace channel the water goes into the Silt Basin where it decants and after into the charging room, called forebay tank, then goes into the pipeline that is connected to the electro-mechanical equipment inside the powerhouse.

5.3.1. The Intake

The construction of hydroelectric projects starts with the Intake, upstream, and this takes on average 2 months to complete. It requires building a small barrage blocking the passage of the river and constructing an intake that allows part of the water to pass normally and part of it, usually a small percentage from 1% to 5% to be captured. The intake is a tyrolean type, meaning that the water is caught gravitationally, through an aperture covered with a screen. After the site is dug up, formworks are used to create the outlay and the shapes of the components. The walls of the small basin that will be created by blocking the river, the small water bridge, the connecting channel. Those components are made entirely from reinforced concrete and specific construction machinery are used.

5.3.2. The Sluice Gates (or flood gates)

The Halmagel station has two sluice gates. The first is actioned automatically by an engine in case of overflow and is located after the Intake aperture. The second at the entrance to the silt basin and can be closed to stop the overall entrance of water in the system. They are made entirely from steel. One has around two meters height and one meter width.

5.3.3. The Silt Basin

The silt basin is the first chamber of the system where the water flow arrives and is decanted, meaning that the sand or small rocks that were not stopped by the intake's screen can settle on the bottom of the basin. That is why it has a descending ramp towards the exit of the tank, and it is closed. This is a measure meant to protect the turbine's buckets from damage. Usually the basin is placed somewhat parallel to the river and on the river side, exists a spillway gate preventing too much water from arriving into the charging room. It is built with concrete forms and it is made from reinforced concrete.



fig. 3 - View of the Hålmätgel tyrolean type intake with sluice gate, fish ladder and covered silt basin.



fig. 4 - View of the Hålmätgel small accumulation basin surrounded by artificial reinforced concrete walls and stone walls, and upstream control house.

5.3.4. The Forebay tank

It is a large cubic chamber of big volume, about 53.5 m³. Is also called the charging room, because is where the water is charged into the rapid pipeline and starts going downstream to the powerhouse. It is made out of reinforced concrete and concrete forms are used to create the outline and pour the concrete. It is also closed with a concrete platform.

5.3.5. The Rapid Pipeline

The pipeline has 1870 meters and the producer is Hobas US. The material is glass-fiber reinforced with polyester resin, 632 pieces of 6 meters were used. The construction of this stage took the longest amount of time, 6 months and it involved digging up to 2 meters in the ground to create the channel where the pipe is placed. In order to fix the pipeline in the ground, concrete anchor blocks were built. It also requires different large construction machinery.

5.3.6. The Powerhouse

The powerhouse is a diaphragm concrete construction with one level, lower downhill from the Intake, in the proximity of the same river. It has a strong foundation in order to sustain the electromechanical equipment that weights up to a ton. It requires good phonic isolation, because at high flows the generation process is noisy. This construction is made using forms and reinforced concrete, large concrete forms are used to create the walls and the floors and it has an outside phonic wood isolation cover. The construction time lasted for 5 months, and was started one month after the one of the rapid pipeline.

The powerhouse is placed on a concrete platform and it is surrounded by a metal fence. Good lightning is present for night illumination.



fig. 5 - View of the Rapid Pipeline before covering



fig. 6 - View of the Hălmăgel Powerhouse



fig. 7 - View of the Hălmăgel Powerhouse and the tailrace, with the water that was turbined, flowing back to the Hălmăgel river.

5.3.7. The Tailrace

The Tailrace is a component of the powerhouse. Is an exhaustion channel of 5 meters, going from under the turbine to the river and it carries the high speed water that has passed through the turbine.

5.3.8. The electromechanical equipment

The Turbine and Generator are custom made to fit the specific flow, drop and speed of the water present in the system. After the mountain site is found and the river's characteristics are measured the turbine size is calculate to obtain the best efficiency. The Pelton turbine has a high efficiency up to 90% that is why it is the preferred choice for small hydropower stations with low flows. The electromechanical equipment is delivered to site and installed in the powerhouse by technicians and connected to the electric grid. In the case of Halmagel SHPS an electric grid was already presen

For in depth technical design refer to the annexes.

fig. 8



fig. 9



fig. 10



fig. 8 - Medium tensions cells

fig. 9 - Nozzle and turbine wheel inside the casing

fig. 10 - Pelton wheel

fig. 11/12 - Turbine (blue) and Generator (red) inside Hålmägel Powerhouse



fig. 11



fig. 12

5.4. Incentives from the state

The small and micro power stations are considered renewable energy sources and receive incentives from the state also called green certificates in Romania. An average small station can receive up to 2.3 green certificate per Megawatt hour produced, but this changes every year. In 2016 in Romania a green certificate was calculated as low as 0.317 per 1 Megawatt hour (0.317GC/Mwh). The price for a green certificate varies from 27 to 57 euro according to the inflation of the European Market. This price was in November 2014 – 29,28 euro in Romania (Focus Energetic.ro, 2014). But this low prices influences negatively the renewable energy producers and some declare it can also bring them to bankruptcy.

5.5. Payback Time

The green certificates become extremely important in the context of payback time of the investment for a beneficiary of a small hydropower station. Unfortunately for the station assessed in this thesis (Halmagel station), the overall investment was not made public. But compared to other station built in the same period and with similar techniques and materials we can approximate an average from 0,8 to 2 million euro cost of investment.

(Riscograma.ro, 2013), a business and economy website, made a calculation of the average cost for one kilowatt hour installed power needed for the construction of different renewable power generation sources. They presented the following results:

- Photovoltaics around 3000 euro
- Wind turbine around 1000 euro
- Bio gas around 2000 euro
- Small hydropower 4000 euro

The author of the article mentions that each technology has its costs reported to the installed power and a capacity factor (the maximum hours of functioning reported to the total hours of functioning) from which the net ratability is calculated. This excluding the cost of insurances, taxes and the work value calculations. The numbers are approximated and rounded and serve to compare the investment among this

sources, specific investment calculation should be made for better evaluation of the investment.

If we take as valid the approximation from the aforementioned website and make a simple calculation, the costs of the SHPS from Halmagel, Romania reaches a construction cost of 1.280.000 euro. The power of the turbine, the capacity factor, the annual production were taken from the Explanatory report. The price the green certificate from focus-energetic.ro

With an installed power of 320 kilowatt, this station's construction cost is 1.280.000 euro.

Cost for kW installed: 4000 euro

Capacity factor: 44,7%

Annual Production: 1253 MWh

Green Certificate/MWh: 2.3 (value for 2013 when the investment was made)

Green Certificate prices: 29 euro

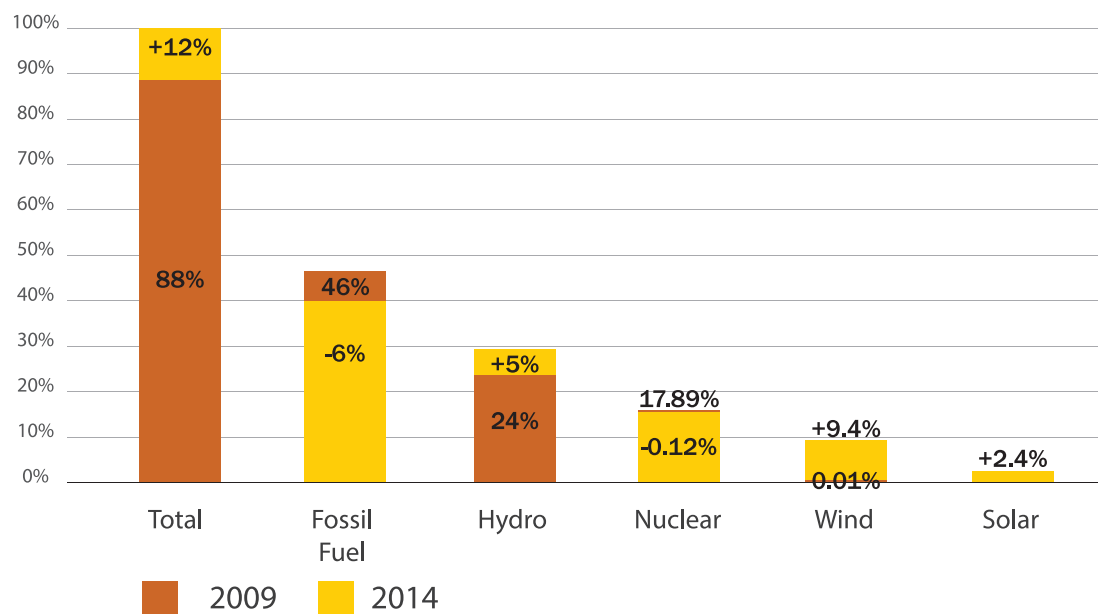
Electricity price: 50 euro MWh

Payback time with no incentives: 62.650 euro/year, so a return of 4.89 % and amortization in 20 years.

Minimum influx with incentives: 71.007,51 euro/year so a return of 5.54 % and amortization 18 years

Maximum influx with incentives: 146.225,1 euro/year, so a return of 11.42 % and amortization 8.7 years.

However recent development in the energy field might make payback time hard to estimate because of two reasons: first of all, the number of green certificates given per megawatt generated from renewable energy sources varies from one year to the next and, in the case of SHPS in only three years it dropped from 2.3 Green Certificates per megawatt to 0,3 Green Certificates per megawatt. Subsequently, the value of the green certificates is fluctuating as well around 29 euro. Some say that their prices will drop altogether to the European level to 15 euro (Focus Energetic.ro, 2014). The second reason is that Romania is considering eliminating the green certificate altogether and adopt a feed-in tariff system like most of the European countries.



Comparison between 2009 – year when the new EU Directive was adopted and 2014 - last available data. We can see a growth in renewable energy and a drop in fossil fuel, but also an overall growth in generated energy.

	Energy produced 2009	Energy produced 2014
Total	58.016 million kW/h	65.675 million kW/h
Fossil Fuel	30.448 million kW/h	26.903 million kW/h
Hydro	15.807 million kW/h	19.279 million kW/h
Nuclear	11.752 million kW/h	11676 million kW/h
Wind	9 million kW/h	6.201 million kW/h
Solar	-	1616 million kW/h



ECO-EFFICIENT DESIGN OF



4

part 4 the Life Cycle Assessment of a Small Hydropower Station

PART IV: THE LCA OF SHPS

6. The method of quantifying analyzing and estimating the environmental impact of Small Hydropower stations

In this thesis the method of quantifying and estimating the environmental impact – the life cycle assessment - was made with the use of the SimaPro software and is detailed at length in the following chapters. A life cycle assessment is considered the most established methodology and the best established finding official recognition in the ISO standards.

However, to estimate and interpret relations between the product and the environment can be rather complex, and here are some reasons why:

- The sum of processes that go into the life cycle of the product can be hard to pin point in great detail, which is why a life cycle model is necessary, from the extraction of raw materials to the disposal processes. However this model can rise considerable uncertainties.
- Even when the entire life cycle is mapped, despite of great progress, many impacts of processes remain doubtful due to lack of considerable data.
- And also after we managed to reach a great understanding of the nature surrounding us, it is still a very complex model, and cause-effect relationships are hard to isolate.

Setting a clear goal and scope definition of the assessment is mandatory and when comparing similar projects all the data of the inventory need comparing following the same functional unit.

As for the results, the actual value of the numbers are only worth comparing to a before-and-after model that seeks to reduce environmental impacts.

Therefore the criticism that are brought to this kind of model, and the reason why a close attention need to be put on consistent data is that: the methods are too complex and expensive, time consuming and not usable in industry; and that the model simplifies the reality too much and becomes unreliable from a scientific perspective.

In meeting these concerns the following considerations need to be made.

In the case of this thesis, the depth to which the life cycle model goes is the procurement of raw materials. Some preliminary data are contained in the raw material model inside the software SimaPro, those takes into consideration the average transformation of raw materials at an average level.

Another lack of data can be identified in the end-of-life treatments. There is actually no data about what happens with the built parts of the station after the end of its lifespan. However a best case scenario for recycling and end of life processes were assumed, meaning that in the search of the highest impacting components the actual result can be smaller than the reality.

Another noteworthy point is that the result of the life cycle assessment were used to prioritize among seven environmental reduction strategies and to create design guidelines.

6.1. The Life Cycle Assessment (LCA)

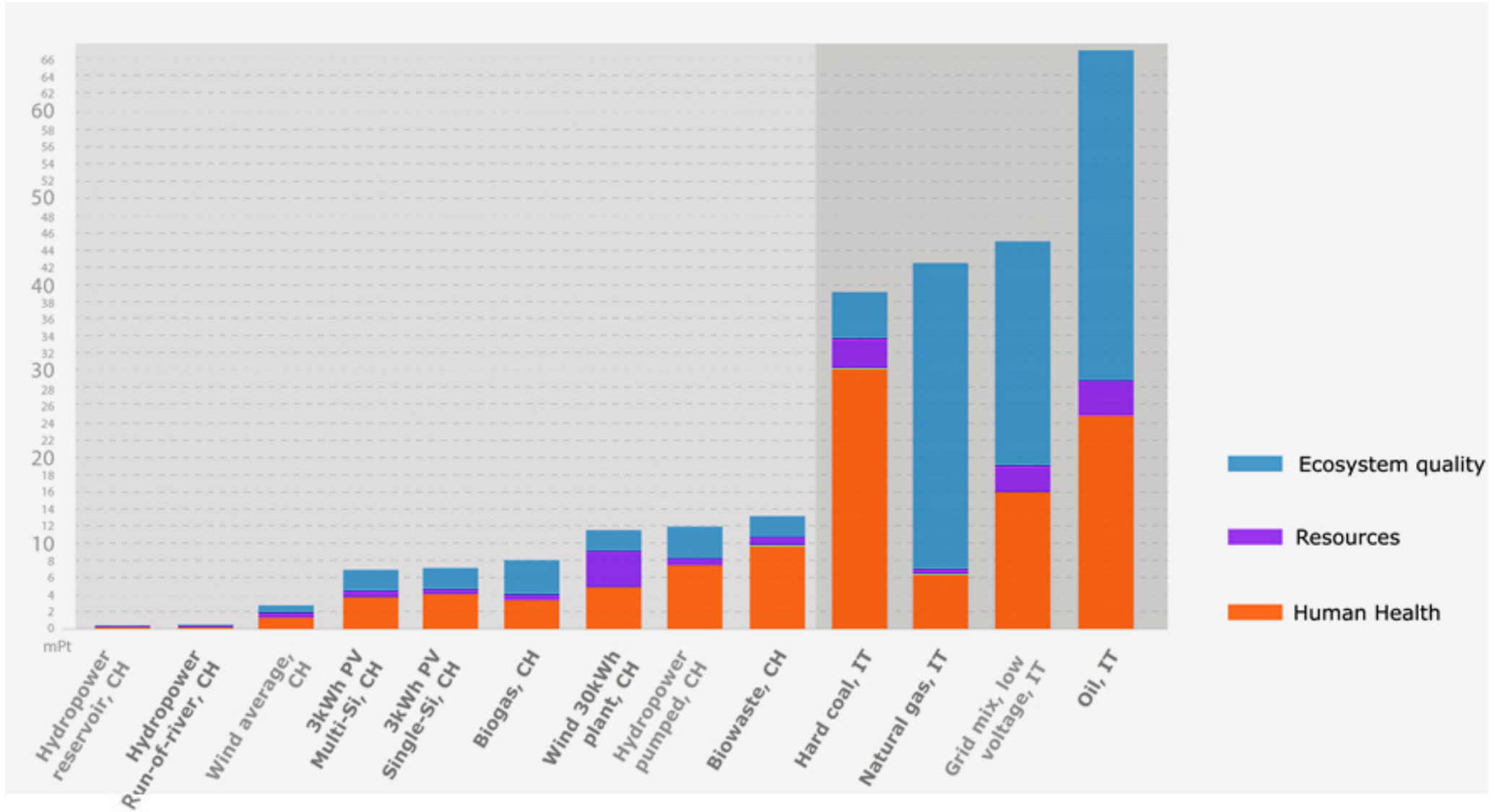
The product life cycle assessment found official recognition in international standards as it was introduced to the ISO (International Standard Organization) normative as ISO 14040.

According to the ISO 14040 definition, the LCA technique addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal, namely:

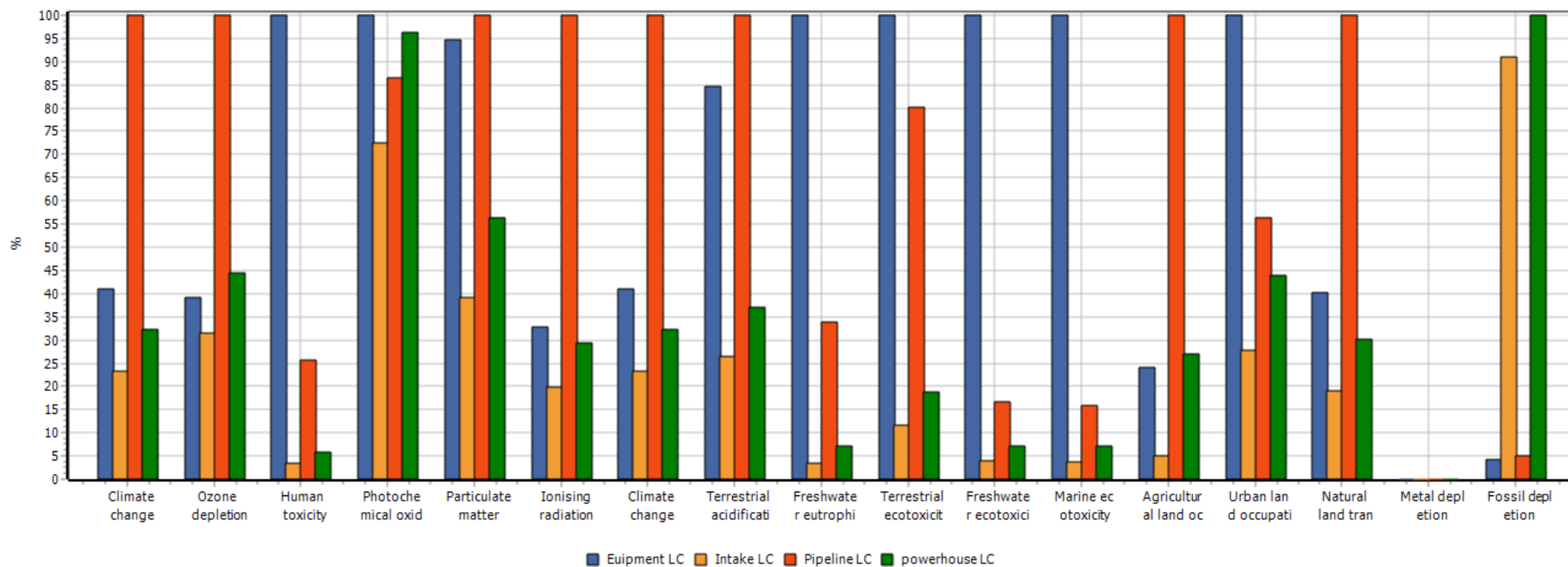
Compiling and inventorying the implications of the system's inputs and outputs.

Evaluation of potential impacts regarding these inputs and outputs

Interpreting the results of the inventory and evaluation phases according to given scope and objectives.



Method: Eco-indicator 99 (H) V2.07 / Europe EI 99 H/A / Single score



Confronto di 1 p 'Equipment LC', 1 p 'Intake LC', 1 p 'Pipeline LC' e 1 p 'powerhouse LC'; Metodo: ReCiPe Endpoint (H) V1.12 / Europe ReCiPe H/A / Caratterizzazione

Method: Eco-indicator 99 (H) V2.07 / Europe EI 99 H/A / for the four main components of the system.

There are four phases in an LCA study:

1. the goal and scope definition phase,
2. the inventory analysis phase,
3. the impact assessment phase,
4. the interpretation phase.

1) The scope, including the system boundary and level of detail, of an LCA depends on the subject and the intended use of the study.

2) The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study.

3) The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance.

4) Life cycle interpretation is the final phase of the LCA procedure, in which the results of a life cycle inventory (LCI) or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

There are cases where the goal of an LCA can be satisfied by performing only an inventory analysis and an interpretation. This is usually referred to as an LCI study.

Generally, the information developed in an LCA or LCI study can be used as part of a much more comprehensive decision process. Comparing the results of different LCA or LCI studies is only possible if the assumptions and context of each study are equivalent.

LCA is one of several environmental management techniques (e.g. risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) and might not be

the most appropriate technique to use in all situations. LCA typically does not address the economic or social aspects of a product, but the life cycle approach and methodologies can be applied to these other aspects. (ISO, n.d.)

6.2. The SimaPro software

SimaPro1 was developed in the nineties to facilitate the quantification of the environmental impact of a product's life-cycle. Since then, it has been used by many companies worldwide. SimaPro was primarily developed to process LCA only. However, IO (input output) tables were incorporated in the program about a decade ago, enabling input-output analysis (IOA) as well as a hybrid analysis (the mix of the two). LCA is a tool for quantifying the environmental performance of products taking into account the complete life cycle, starting from the production of raw materials to the final disposal of the products, including material recycling if needed.

When using SimaPro an LCA model of a product, service, or system life cycle is created. What is important to realize is that a model is a simplification of a complex reality and as with all simplifications this means that the reality will be distorted in some way. The challenge for an LCA practitioner is to develop the model in such a way that the simplifications and distortions do not influence the results too much. The best way to deal with this problem is to carefully define the goal and scope of the LCA study. (SimaPro manual).

Data related to all the life cycles phases are needed in order to create a faithful depiction of the environmental impacts.

SimaPro is using the Eco-indicator point as a measuring unit. The value of one 1 Pt is representative of one thousands of the yearly environmental load of one average European inhabitant. The absolute value of the points is not very relevant as the main point is to compare relative differences in the components. (Eco-indicator 99 Manual for Designers, 2000)

7. THE LIFE CYCLE ASSESSMENT OF HALMAGEL SHPS

7.1. Phase One: The Goal and Scope Definition

The assessment of the system using SimaPro will generate Eco-indicator points that are used to calculate the environmental priorities. They are composed of six strategies that will help in generating precise and direct eco-efficient design guidelines for designing SHPS with a lower environmental impact. The goal of the study is to create a handbook of guidelines and a checklist that will support and orientate the sustainable design based on these strategies:

- Minimizing Material Consumption
- Optimization of Product Lifetime
- Minimizing Toxicity
- Optimization of Materials Lifespan
- Renewable and Bio-Compatible Resources
- Minimizing Energy Consumption

The intended audiences for this guideline are engineers and designers of sustainability, the design guideline handbook will be free of charge and in copy left.

Defining the Scope

The scope of the study describes the most important methodological choices, assumptions, and limitations as described in the sections below.

7.1.1. The system under study

A SHPS is an independent means of generating energy harnessing the power of water. The system under consideration is located in the mountain region of Apuseni in Romania on the river Halmagel. It is a gravitational flow system composed of three main components and the energy generating equipment: the intake, the pipeline and the powerhouse.

The Intake is located upstream, on the mountain, where it gathers the required flow, the drop difference is 88 meters spreading on 1870 meters from upstream to downstream and is made up of a Rapid Pipeline. The flow gathers speed downstream where it enters the Powerhouse and goes through the energy gene-

ration process. The station has installed a 3.2 MW power Pelton Turbine with a vertical shaft and three jets, together with a three-phase asynchronous generator, self-exciting, 220 V 60Hz, 1800RPM 50kW, two 2500kVA 20/0,4kV transformer cells and two medium tension cells 24kV 630A 16kA.

The energy generated is used to power the nearest village of Hălmagel through a LEA 20 kV existing line infrastructure.

7.1.2. Data collection and quality

The data was acquired from a public document called: “Explanatory report for acquiring the Environmental agreement license for Hămlagel Hydro-energetic development in the county of Arad” (Botoc, Cret, Roman, & Floarea, 2012) found on the Environmental Ministry of Romania’s website.

For the in depth calculation a detailed project was made using the above mentioned document and expertise literature “Designing and Building Mini and Micro Hydropower Schemes, A Practical Guide” (Rodriguez & Sanchez, 2011).

For the LCA the four components were analyzed independently in order to highlight the one with the highest environmental impact.

Exact data:

Some of the data was exact, such as: the gross size of the powerhouse construction and the materials used, the pipeline dimensions and the materials, the flow of the river and the flow required for power generation, the power of the equipment and the typology, additional power generation equipment and typology, illumination, safety, time required for each of the parts construction and also pictures were available.

Assumed data:

For the rest of the project design, following the available data and literature, the sizes of the intake were inferred, and also different details about the powerhouse were assumed. Thus the decision to create a technical project was made, together with technical drawings. The materials calculations were made on the resulting volume and information about materials used and typologies were accrued from the practical

guide¹, some of the assumption are detailed in the inventory of each component. To be mentioned that some of the technical designs were overseen by an engineer.

7.1.3. The life cycle model - The system boundaries

Pre-production:

Following the volumetric design and the details found in the expertise literature¹ about materials used in this kind of construction (weights, density etc.) a bill of quantities was made and the materials inventoried were added as pre-production in the life cycle phase of each of the components. Those are considerable raw and at plant.

Production:

The materials processed were calculated considering the quantities resulted in the pre-production phases. For the construction on site, construction machinery's fuel consumption was calculated on available data (Oprea, 2012). The machinery used in this construction are assumed to be: one tractor, one dozer, one excavator, one pipe-layer, three trucks, and one mechanical pump).

The average was calculated for each component of the station, taking into consideration that the overall construction time was 8 months, as said in the explanatory report. The construction started upstream with the intake – about 2 months, after the completion, the pipeline was started – about 6 months. After one month, the construction of the powerhouse started, so that the system can be finished at the same time – construction time 5 months.

The results were added as production phases in the inventory of the life cycle of each component.

Distribution:

Distribution was considerable for readymade materials traveling from a distance of 126 km, from the biggest city, Arad, with a 16 ton truck. For the machinery transportation to site was taken into account the use of one 32 ton truck, operating on the same distance.

Use:

For the use phase of the life cycle inventory, the lighting system (3 safety lights 8W, 3 - 150W lights, 3 – 58W lights, 2 – 36W lights) and other automatization devices (one command panel – estimating 10Kwh and two motors of 4 kWh) and also the turbine power efficiency loss (10% of the overall power generated) were considerate as specified in the explanatory report.

Disposal:

The disposal was assumed on average, about 70% recycled and 30% landfilled. Detail information is found in the in depth description of each component.

The appointed software and LC model design was made using SimaPro. In order to highlight the component of the SHPS that has the biggest environmental impact, the model was split in four components: the Intake, the Rapid Pipeline, the Powerhouse and the Equipment.

The assembly of this components contained the materials and processes for pre-production and production.

In the life cycle, the assembly was added together with independently calculated quantity for transport. The equipment has an extra energy use and an additional life cycle – the mineral oil that was created as an individual assembly and added.

An overall disposal scenario was created assuming common materials are recycled and average recycling percentages.

The calculation was made comparative and on singular components.

7.2. Phase two: Life Cycle Inventory (LCI)

7.2.1. The Functional Unit for Halmagel SHPS

In a LCA, each quantity of materials or processes is calculated according to the system's referral functional unit. It is the base of comparisons among product performances. In this case the Functional unit is: the availability of the 3.2 MWpower Small Hydropower station to produce (renewable) electricity for

70 years of operative lifetime. The energy produced per year = 1253 MWh, about 87.71 GWh/70years.

In order to understand the environmental impact of the materials and processes, distribution and energy used, the resulting quantities are divided by the functional unit. In this case the GWh was used due to rounding figures. Consequentially all the quantities in the Inventory are divided by 87,71.

7.2.2. Intake Inventory

For the Intake knowing the flow, the gross volume could be inferred following the practical guide descriptions. The report mentions that the construction is made of reinforced concrete.

The materials considered in the Pre-production phase are: cement, gravel, and sand, water, reinforcing steel for the constructed parts: tyrolean intake, walls, headrace channel, and silt basin and forebay tank.

The concrete calculation percentages are as follows: 11,1% Portland cement, 41,5% gravel, 40,1% sand, 6,8% water, 0,03% water loss. Resulting in 55400kg cement, 201850 kg gravel, 195040 kg sand, 33000 kg water, and 140 kg water loss per construction. The quantity related to the entire lifespan divided by the Gigawatt for a lifespan of 70 years (the functional unit) is the amount $x/87.71$ (GWh in 70years) resulting in 631,6 kg/GWh cement; 2301,3 kg/GWh gravel; 2223,7 kg/GWh sand; 376,2 kg/GWh water; 1,6 kg/GWh water loss.

Reinforcing steel 43780kg, 499,1kg/GWh. A percentage of 2% or 3% of reinforcing on the volume was assumed.

Chromium steel for the two sluice gates and filtering grills 3824,8 kg; 43,6kg/GWh. Quantities and sizes were calculated on literature and it was assumed they were replaced once.

The production phase: the material's processes were calculated considering the quantities resulted in the pre-production. Plaster or concrete mixing for 486.400 kg and for 5545,88kg/GWh; Metal product manufacturing, average metal working for 3823.2kg and for 43.59kg/GWh; Diesel burnt in construction machines 258.74MWh (2months), 2.95MWh/GWh.

On the use phase no consumption was considerate.

Distribution of 533034 kg and 765.734kgkm/GWh (for 126 km).

Disposal estimations - Recycled: 60%, Landfill: 40% .

INVENTORY OF MATERIALS AND PROCESS

Abbreviation of name of LCA:

PP = Pre-production , P = Production, DT = Distribution, U = Use, DM = Dismantail, FU= Functional Unit SHP = Small hydropower

	Parts	Quantity one module	Quantity/ SHP	Unit	N. Module per F.U.	Lifespan (years)	N° parts / lifespan	Quantity per F.U. (kg/GWh)	Calculation	Material	In SimaPro	Comment
PP	Macro-component : tyrolian intake,walls, headrace channel, silt basin, forbey tank,											
	Concrete ingredients	55,44	55400	kg	1	70	1	631.6269525	55400*1*1/87.71 = 631.62 kg/GWh	cement	Portland cement, at plant	11,1%
		201,85	201850	kg	1	70	1	2301.333941	kg/GWh	gravel	Gravel I	41,5%
		195,04	195040	kg	1	70	1	2223.691711	kg/GWh	sand	Sand CH	40,1%
		33,00	33000	kg	1	70	1	376.2398814	kg/GWh	water	Tap water CH	6,8%
		0,14	140	kg	1	70	1	1.596169194	kg/GWh	water loss	Tap water CH	0,03%
	Total concrete	200m³*2432 kg/m3 = 486,4ton	485430	kg	1	70	1	5534.488656	kg/GWh	concrete		2432kg/m³(cement:279kg, gravel:1010kg ,sand:976kg, water:166kg, water loss: 0,9kg)
	Reinforced steel	43,78	43780	kg	1	70	1	499.1449094	kg/GWh	reinforced steel	Steel rebar, blast furnace	Process inside material
	Sluice gates	230	460	kg	2	35	2	10.48911185	kg/GWh	stainless steel	Chromium steel 18/8	
Grates	726.2	1452.4	kg	2	35	2	33.11823053	kg/GWh	stainelss steel	Chromium steel 18/8		
P	Parts	Total quantity						Quantity per F.U.		Processing	In SimaPro	
	Total concrete	486400	kg				5545.88		Mixing	Plaster mixing (CH) processing		
	Sluice gate	3.2	m				0.072967735		Metal Working	Welding, gas, steel (RER)		
		920	kg				10.48911185		Metal Working	Metal product manufacturing, average metal working/RER S		
	Grate	4.7	m				0.10717136		Welding	Welding, gas, steel (RER)		
		2904.8	kg				33.11823053		Metal Working	Metal product manufacturing, average metal working/RER S		
	Dozer, Tractor, Power pump, Truck*2 Excavator	26688.5l*0.835kg/m3= 22284.8975 kg				259.17	Mwh	2.954851214		Construction operations	Diesel Burnt in construction machine - 2 months	
DT	Means	Transported quantity			Distance			KgKm		KgKm/FU	In SimaPro	Comment
	Transport in construction faze											
	Truck-Intake	533,033.800	kg		126 km truck full + 126km truck empty			67,162,385		765732.3543	Transport, lorry 16t, EURO4	Intake / lifespan
	Truck	1912.4	kg		126 km truck full + 126km truck full			241088.4		2748.699122	Transport, lorry 16-32t, EURO4	Intake - 35 yeas lifespan
U	Activity	Processes and Materials						Quantity per U.F. (kWh)			In SimaPro	
	No consumption											
DM	Destinazione/Trattamenti										In SimaPro	
	Considerated on average: Recycled: 60%, Landfill: 40% .											

7.2.3. Rapid Pipeline

For the Rapid Pipeline, the explanatory report describes all the sizes and the company producing it, Hobas US. Details about the material density and composition are available on the Hobas website. The material is glass-fiber reinforced polyester resin. About 622 pieces of - SN 5000 N/m² pipeline typology, each of 6 meters with a weight of 45kg/meter are quantified in the inventory and an additional 10 pieces of - SN 10.000 N/m² pieces of 6 meters and 56kg/meter result in an average of 85650 kg per construction and 171300 kg per the entire lifespan. As expressed on the data sheet of the product, the lifespan of the pipe is 50 years. In the inventory it was assumed all the pipeline is replaced once for reaching the lifespan of 70 years.

The quantity related to the entire lifespan divided by the Gigawatt hour for a lifespan of 70 years (the functional unit) is the amount $x/87.71$ (GWh in 70 years) reaching a total of 1953 kg/GWh of glass-fiber reinforced polyethylene for a station. This is the only material considerate in the pre-production phase for the rapid pipeline.

In production phase: Extrusion of plastic pipes was added as a process for the above mentioned quantities 171.300 kg for the entire lifespan reaching a total of 1953 kg/GWh. Fuel use by construction machinery on site: 462.92 MWh for 6 months – and 5.277 MWh/GWh (one tractor, one excavator, one pipe layer, two trucks).

On the use phase no consumption was considerate.

Distribution: for 171.300 kg and 246.083 kgkm/GWh. (126km)

Disposal: Recycled - 80%, Landfill – 20%.

INVENTORY OF MATERIALS AND PROCESS

Abbreviation of name of LCA:

PP = Pre-production , P = Production, DT = Distribution, U = Use, DM = Dismantail, FU= Functional Unit SHP = Small hydropower

	Parts	Quantity one module	Quantity/ SHP	Unit	N. Module per F.U.	Lifespan (years)	N° parts / lifespan	Quantity per F.U. (kg/GWh)	Calculation	Material	In SimaPro	Comment
	Macro-component : Powerhouse											
	Pipe and fittings	270 kg	83970	kg	311	50	2	1914.71896	kg/GWh	glass-fiber-reinforced	Glass-fiber-reinforced plastic	
	Pipe and fittings	336 kg	1680	kg	5	50	2	38.30806065	kg/GWh	glass-fiber-reinforced	Glass-fiber-reinforced plastic	
P	Parts	Total quantity						Quantity per F.U.		Processing	In SimaPro	
	Glass-fiber-reinforced plastic		171300	kg				1953.027021	kg/GWh	Extrusion plastic pipes	Extrusion plastic pipes RER/U	
	Dozer, Tractor, Power pump, Truck*2 Excavator		47670 l*0.835kg/m3= 39804.45 kg			462.92	Mwh	5.277847452	MWh/ Fu	Construction operations	Diesel Burnt in construction machine - 6 months	
DT	Means	Transported quantity				Distance		KgKm		KgKm/FU	In SimaPro	Comment
	Transfort in construction faze											
	Truck	171,300.000		kg		126 km truck full + 126km truck empty		21,583,926	kgkm	246082.8412	Transport, lorry 16t, EURO4	Rapid Pipeline/ lifespan
	Truck	5635.2		kg		126 km truck full - 126km truck full		710161.2	kgkm	8096.69593	Transport, lorry 16-32t, EURO4	Powehouse - 35 years lifespan
U	Activity	Processes and Materials						Quantity per U.F. (kWh)			In SimaPro	
	No consumption											
DM	Destination/Treatments										In SimaPro	
	Considerated on average: Recycled - 80%, Landfill – 20%.											

7.2.4. Powerhouse

The powerhouse's gross dimensions can be found in the explanatory report and are as follows: machine room: height = 6,3 meters, length = 9 meters, width = 7,65 meters; canal connecting river bed: height = 1,5 meters, length = 5 meters, width = 2,8 meters. The report mentions that the construction is made of reinforced concrete.

In the pre-production the material inventoried are: concrete with the following percentages: 11,1% Portland cement, 41,5% gravel, 40,1% sand, 6,8% water, 0,03% water loss. The quantity related to the entire lifespan divided by the Gigawatt hour for a lifespan of 70 years (the functional unit) is the amount $x/87.71$ (GWh in 70 years). Resulting in 69590 kg/lifespan and 793,4kg/GWh cement; 253350kg/lifespan and 2888,5 kg/GWh gravel; 244810kg/lifespan and 2791kg/GWh sand, 41510kg/lifespan and 473,2kg/GWh water; 180kg/lifespan and 2.05kg/GWh water loss.

Reinforcing steel on a percentage of 2% or 3% per volume resulting in 47730kg/lifespan and 544.17kg/GWh.

Silver fir wood for exterior insulation 3657.6kg/lifespan about 8,128 m³ and 41.7kg/GWh, assumed to be replaced once.

Glass 27 m² / lifespan and 0,3m²/GWh.

Lightning conductor made of chromium steel (available data) 7680 kg/ lifespan and 87.6k/GWh, assumed to be replaced once.

Pillars for fencing made of chromium steel - 28 estimated weight: 3 kg for one – 168 kg/lifespan and 1,9kg/GWh assumed to be replaced once. Weld mesh for fencing made of chromium steel - 28 estimated weight: 5.7 kg for one – 319,2kg/lifespan and 3,63kg/GWh assumed to be replaced once.

Readymade components such as the roof window dome and the doors were considerate. Window frame aluminum: 27 m²/lifespan and 0.3m²/GWh, assumed to be replaced once. Doors made out of wood and aluminum 31m² /lifespan and 0,35m²/GWh, assumed to be replaced once.

As processes there were inventoried: plaster or concrete mixing – 610499,3kg and 6960,43kg/GWh. Wood preservation, spray tunnel for 3657.6kg about 8,128 m³ and 41,7kg/GWh. Zinc coating for 1.22m² and 0,014m²/GWh. Wire drawing, steel for the fencing 319,2kg and 3,63kg/GWh. Welding, gas, steel for fencing 8 meters and 0,09m/GWh. Metal product manufacturing, average metal working for the lighting conductor, the pillars and mesh for fencing 8167.5kg and 93,12kg/GWh. Diesel, burned in building machine

INVENTORY OF MATERIALS AND PROCESS

Abbreviation of name of LCA:

PP = Pre-production , P = Production, DT = Distribution, U = Use, DM = Dismantail, FU= Functional Unit SHP = Small hydropower

	Parts	Quantity one module	Quantity/ SHP	Unit	N. Module per F.U.	Lifespan (years)	N° parts / lifespan	Quantity per F.U. (kg/GWh)	Calculation	Material	In SimaPro	Comment
	Macro-component : Powerhouse											
	Walls, Floors, Roofs, Fondation, Beams	69,59	69590	kg	1	70	1	793.4101015	kg/GWh	cement	Cement, portland CH	11,1%
		253,35	253350	kg	1	70	1	2888.496181	kg/GWh	gravel	gravel, round CH	41,5%
		244,81	244810	kg	1	70	1	2791.12986	kg/GWh	sand	Sand CH	40,1%
		41,51	41510	kg	1	70	1	473.264166	kg/GWh	water	Tap water CH or Water (tap) in other	6,8%
		0,18	180	kg	1	70	1	2.052217535	kg/GWh	water loss	Tap water CH	0,03%
	Total concrete	251,03m³ *2432kg/m³ = 610,5 ton	609440	kg	1	70	1	6948.352525	kg/GWh	concrete		2432kg/m³(cement:279kg, gravel:1010kg ,sand:976kg, water:166kg, water loss: 0,9kg)
	Reinforced steel	47,73	47730	kg	1	70	1	544.179683	kg/GWh	reinforced steel	Steel rebar, blast furnace	Process inside material
	Insulation of building	4,128 m³ (4,128*450 = 1857.6 kg)	8.128	m³	1	70	1	41.70106031	kg/GWh	wood	Sawn timber, softwood,planed, air dried, at plant	(1m³=450kg)
	Roof window frame	13,44 m² (13,44*50,7=6 81,408 kg)	13.44	m²	1	35	2	0.306464485	m2/GWh	aluminium	Window frame aluminium	Process inside material (1m²=50.7 kg)
	Doors	15,5 m² (15.5*38.8 = 601,4kg)	15.5	m²	1	35	2	0.353437464	m2/GWh	wood aluminium	Door, outer, wood-aluminium	Process inside material (1m²=38.8kg)
	Glass	13,44 m² (13.44*20= 268,8kg)	13.44	m²	1	35	2	0.306464485	m2/GWh	glass	Glazing, double	Process inside material (1m²= 20 kg)
	Lightning conductor	3,84	3840	kg	1	35	2	87.5612815	kg/GWh	steel	Steel ETH S	
	Pillars (fence)	3	84	kg	28	35	2	1.915403033	kg/GWh	steel	Steel ETH S	
	Weld mesh Fencing	5.7	159.6	kg	28	35	2	3.639265762	kg/GWh	steel	Steel ETH S	

7.2.5. Equipment

The power generation equipment is composed of: one vertical shaft Pelton Turbine 3.2MW with three jets composed of inlet pipes, elbows, valves, casing, pulley, runners, nozzles and supports roller bearings. A three-phase asynchronous generator, self-exciting, 220 V 60Hz, 1800RPM 50kW composed of: unit, pulley, U shaped anchor base and support attached to casing, anchored base, and a cooling coil installation. Two 2500kVA 20/0,4kV energy transformer cells and two medium tension cells 24kV 630A 16kA. Some cables were also inventoried. The data comes from the explanatory report and the practical guide. For the purpose of simplification this were assumed to be composed only of three materials: iron, steel and copper with additional mineral oil for the cooling installation. The lifespan of this machinery is 35 years, thus replaced once.

For the pre-production the result were: the turbine made of cast iron 1720kg/lifespan and 19,61kg/GWh. Steel low alloyed 50195,5 kg/lifespan and 572,29kg/GWh, carcasses and different parts. Copper 12.000kg/lifespan and 136,81kg/GWh, wires mainly for the energy transformer. Cable, three-conductor cable 345,6 m 3,94m/GWh.

Processes: Turning, chromium steel, CNC, average 395.5kg and 4,51kg/GWh, the turbine. Metal product manufacturing, average metal working 51915.549kg and 591.9kg/Gwh. Wire drawing, copper 12.000kg and 136,81kg/GWh.

In the use phase were inventoried the lighting system: three safety lights 8W, three - 150W lights, three – 58W lights, two – 36W lights and other automatization devices one command panel – estimating 10Kwh and two motors of 4 KWh for which an average consumption was assumed. The sum is: 268,8Mw/lifespan and 3,06Mw/GWh.

The turbine power efficiency loss (10% of the overall power generated) were considerate as specified in the explanatory report 9648.1MWh/lifespan and 110MWh/GWh.

The transport for the entire lifespan is: for 86.675kg and 124.515kgkm/GWh.
Disposal was assumed: recycled: 80% and landfill: 20%.

INVENTORY OF MATERIALS AND PROCESS

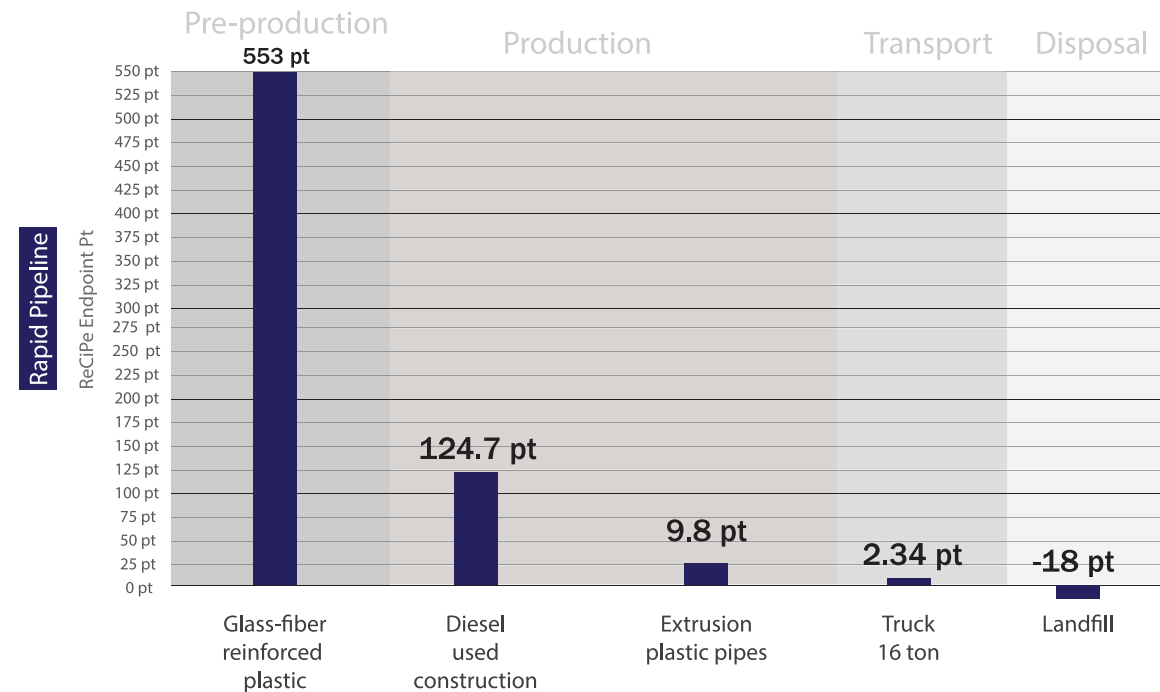
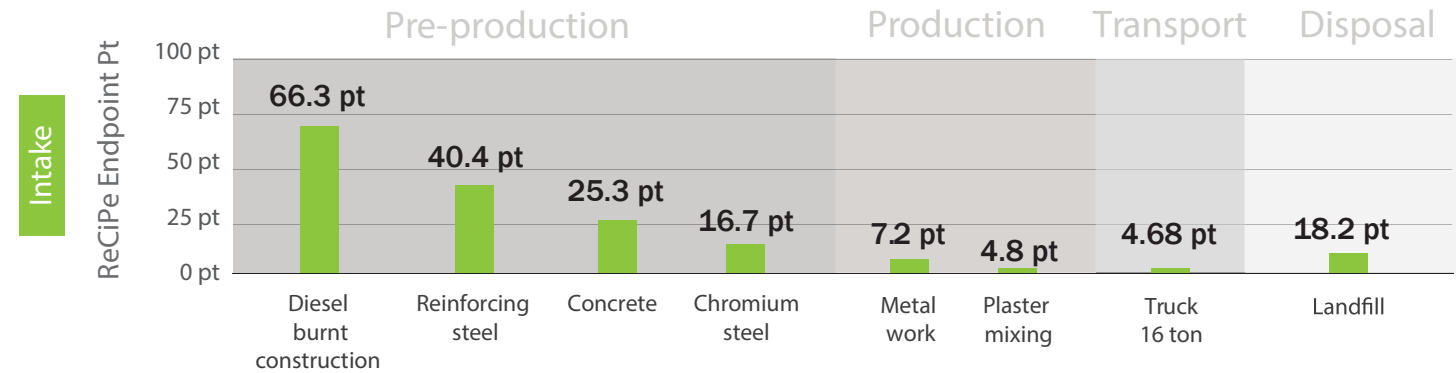
Abbreviation of name of LCA:

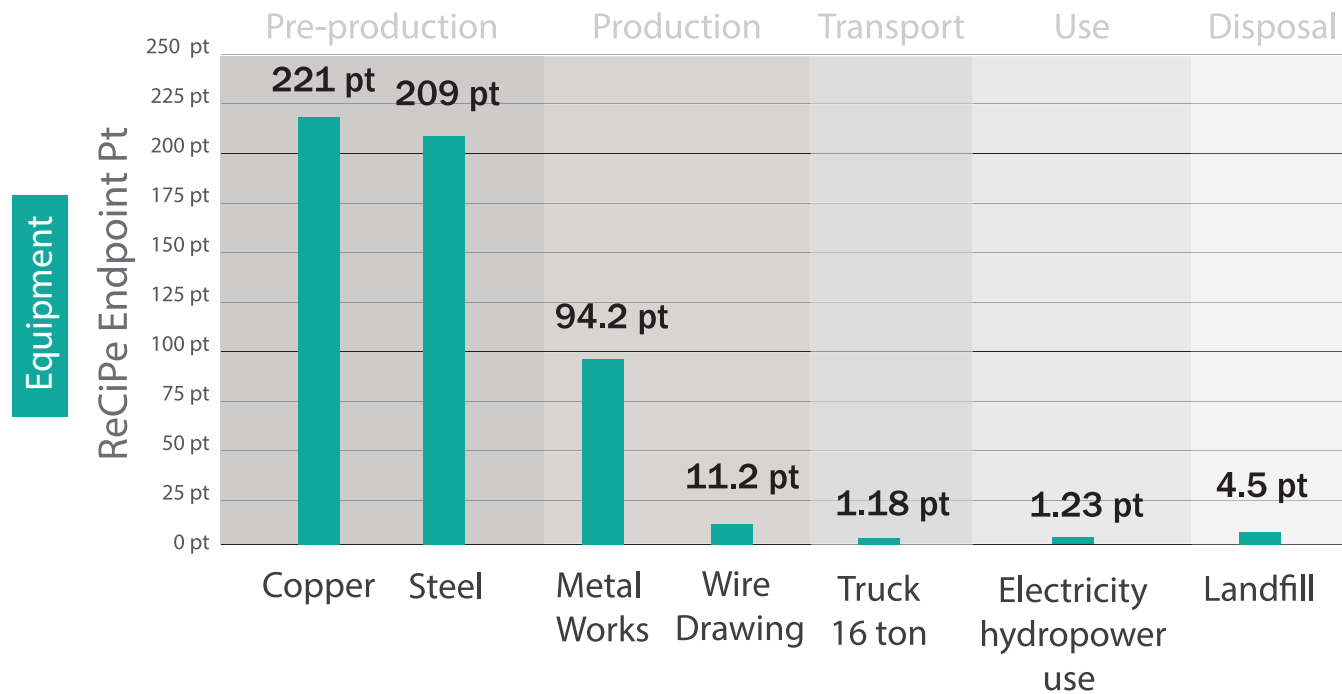
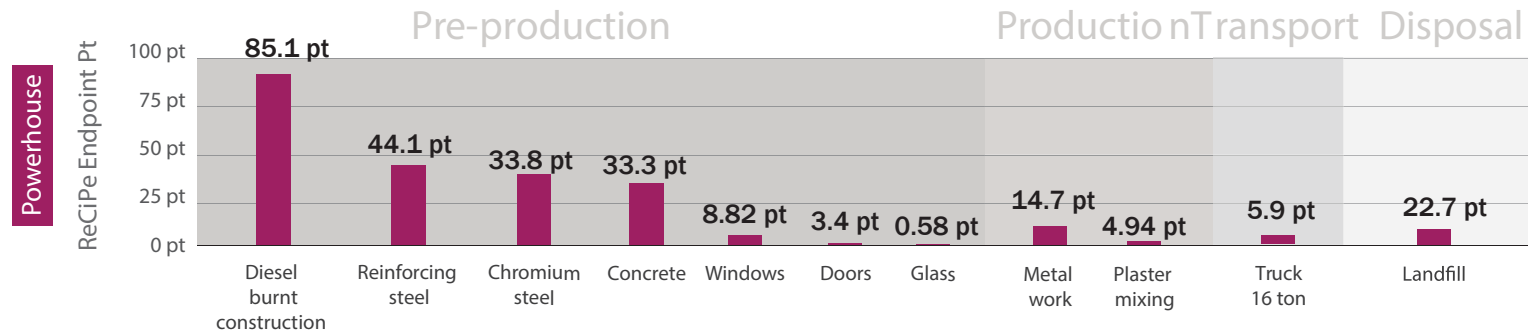
P = Pre-production , P = Production, DT = Distribution, U = Use, DM = Dismantail, FU= Functional Unit SHP = Small hydropower

	Parts	Quantity one module	Quantity/ SHP	Unit	N. Module per F.U.	Lifespan (years)	N° parts / lifespam	Quantity per F.U. (kg/GWh)	Calculation	Material	In SimaPro	Comment	
	Micro-component : Powerhouse equipment												
	Turbine	860	860	kg	1	35	2	19.61007867	kg/GWh	iron	Steel, low alloyed, at plant/RES S		
	Generator	578	578	kg	1	35	2	13.17979706	kg/GWh	steel	Steel, low alloyed, at plant/RES S		
	Transformer 2500kVA materials	2680	5360	kg	2	20	4	244.4419108	kg/GWh	steel	Steel, low alloyed, at plant/RES S		
	Medium Tension cell	3,45 ton	6900	kg	2	20	4	314.6733554	kg/GWh	steel	Steel, low alloyed, at plant/RES S		
	Transformer 2500kVA materials	1500	3000	kg	2	20	4	136.8145023	kg/GWh	copper	Copper, at regional storage/ RER		
	Transformer 2500kVA oil	70000	70000	kg				798.084597	kg/GWh	mineral oil	White mineral oil, at plant/RNA		
	Cables	21,6ml (172.8ml*1.04 kg = 179,712kg total)	172.8	ml	4	70	2	3.940257667	kg/GWh	copper	Cable, three-conductor cable (GLO) production	Process inside material (1m= 1.04 kg)	
P	Parts	Total quantity						Quantity per F.U.		Processing	In SimaPro		
	Turbine	860	kg					0,23/kg -> 0,23*860 = (197,8kg/87.71)*2= 4.51kg		Turning	Turning, cast iron, conventional, average	0,23kg iron removed for each kilo	
	Turbine+Generator+Transformer 2500kVA+Medium Tension cell	63916	kg					728.7196443	kg	Assembling of steel parts	Metal product manufacturing, average metal working/RER U		
	Transformer 2500kVA	12000	kg					136.8145023		Wire drawing copper	Wire drawing		
DT	Means	Transported quantity				Distance		KgKm		KgKm/FU	In SimaPro	Comment	
	Transfort in construction faze												
	Truck	16,698.000	kg			126 km truck full + 126km truck empty		2,104,074	kgkm	23988.98643	Transport, lorry 16t, EURO4	Equipment/ lifespan	
U	Activity	Processes and Materials		Amount	Unit	Quantity per U.F. (kWh)					In SimaPro		
	Power usage/ year	137.83*70	Mwh	9648.1	Mwh			110	Mwh		Electricity, hydropower, at reservoir power plant, alpine region	Power loss by turbine	
	Power usage/ year	3.84 *70 = 268.8 Mwh/an		268.8	Mwh			3.064644852	Mwh		Electricity, hydropower, at reservoir power plant, alpine region	Power used - lighting and automatization	
	Total power			9916.9	Mwh			113.0646449	Mwh/FU		Electricity, hydropower, at reservoir power plant, alpine region	Total power / Functional unit	
	Oil Machinery			70000	kg/70years			798.084597	kg/FU		White mineral oil	0.864kg/l lifespam 30 years.	
DM	Destinazione/Trattamenti										In SimaPro		
	Considerated on average: recycled: 80% and landfill: 20%												

7.3. Phase three: Life Cycle Impact Assessment (LCIA) results

The results can be found in the following graphs and are calculated in Eco-indicator points, the unit used by the SimaPro assessment software and are grouped in life cycle phases.





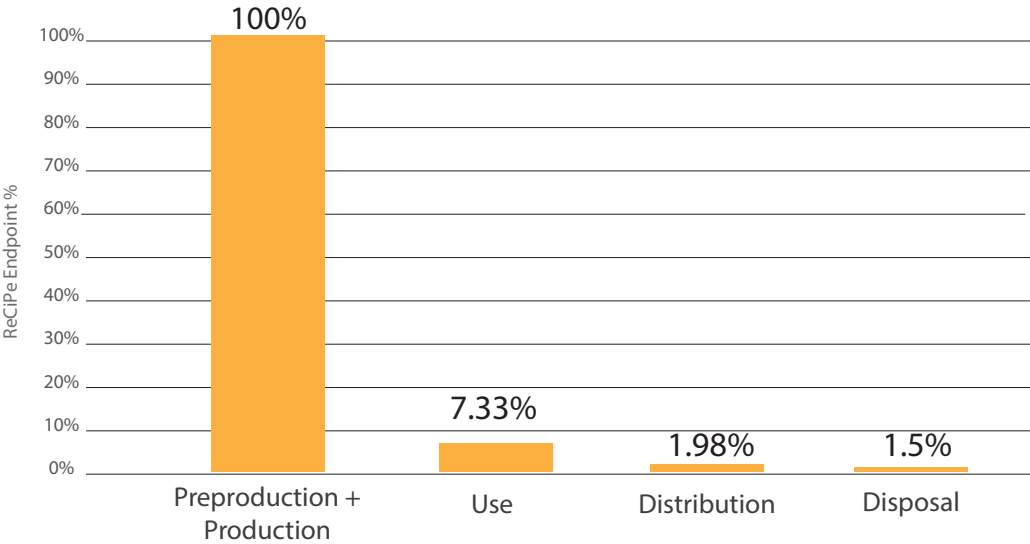
7.4. Phase four: Interpretation

Just by looking at the overall result the component with the highest impact is the rapid pipeline as expected. This is because it has a high amount of plastic and fiber glass which are by no means easily regenerative materials. Furthermore, a lot of energy goes into manufacturing plastic as a raw material as opposed to wood or sand or gravel which only need minimum processing, and the same goes for fiber glass. On top of this we need to take into consideration the process of manufacturing pipes which requires large machinery and huge amounts of energy. Even though the weight cannot be compared to those of the constructed components like the powerhouse or the intake, the pipeline is volumetrically big, spreading on almost two kilometers. Another factor that rises the environmental impact is the fact that fiber glass reinforced with unsaturated polyester resin is a composite material, making it hard to separate in order to recycle and the fiber glass slows down the eventual combustion processes aimed at recovering the energy content within plastic. It also has the longest construction on site time – 6 months and it involves large machinery.

The second most impacting component is the equipment. This is due to the fact that it is composed mainly of metal which is an expensive material that goes through a lot of processing before it can be considered raw, and this processing requires high amount of energy. Not to be overlooked is the fact that this processing can be highly polluting and has harmful impacts on human health. When looking at its weight, the Equipment is the lightest of all components but has ranked second in terms of environmental impact. It has no fuel consumption during installation as is the case with other components.

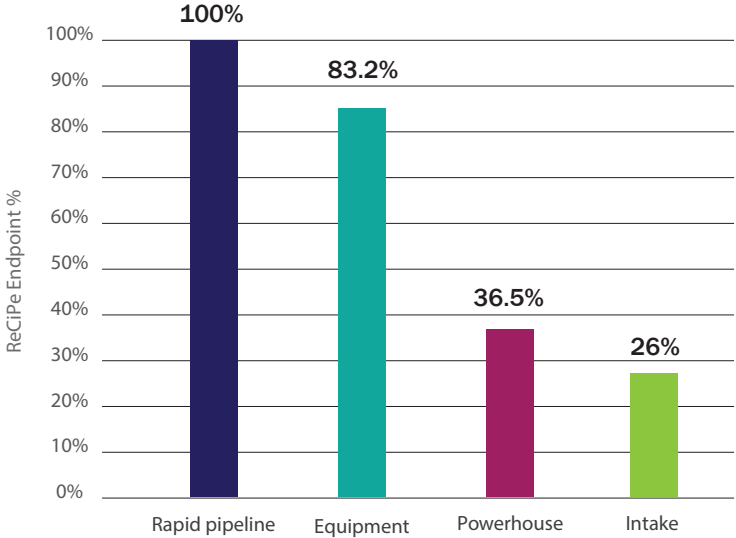
The Powerhouse and the Intake are the constructed immobile parts of the system, the main material inventoried is the concrete with all its components. The powerhouse has a greater impact value mainly because of its size compared to that of the intake and also because more materials go into the construction. However those rank last also because of their long lifespan, which is 70 years. It is half of that of the Equipment and 20 year longer than the Rapid Pipeline. The intake has the shortest construction time – 2 months; the Powerhouse's construction lasted 5 months.

Life cycle phase

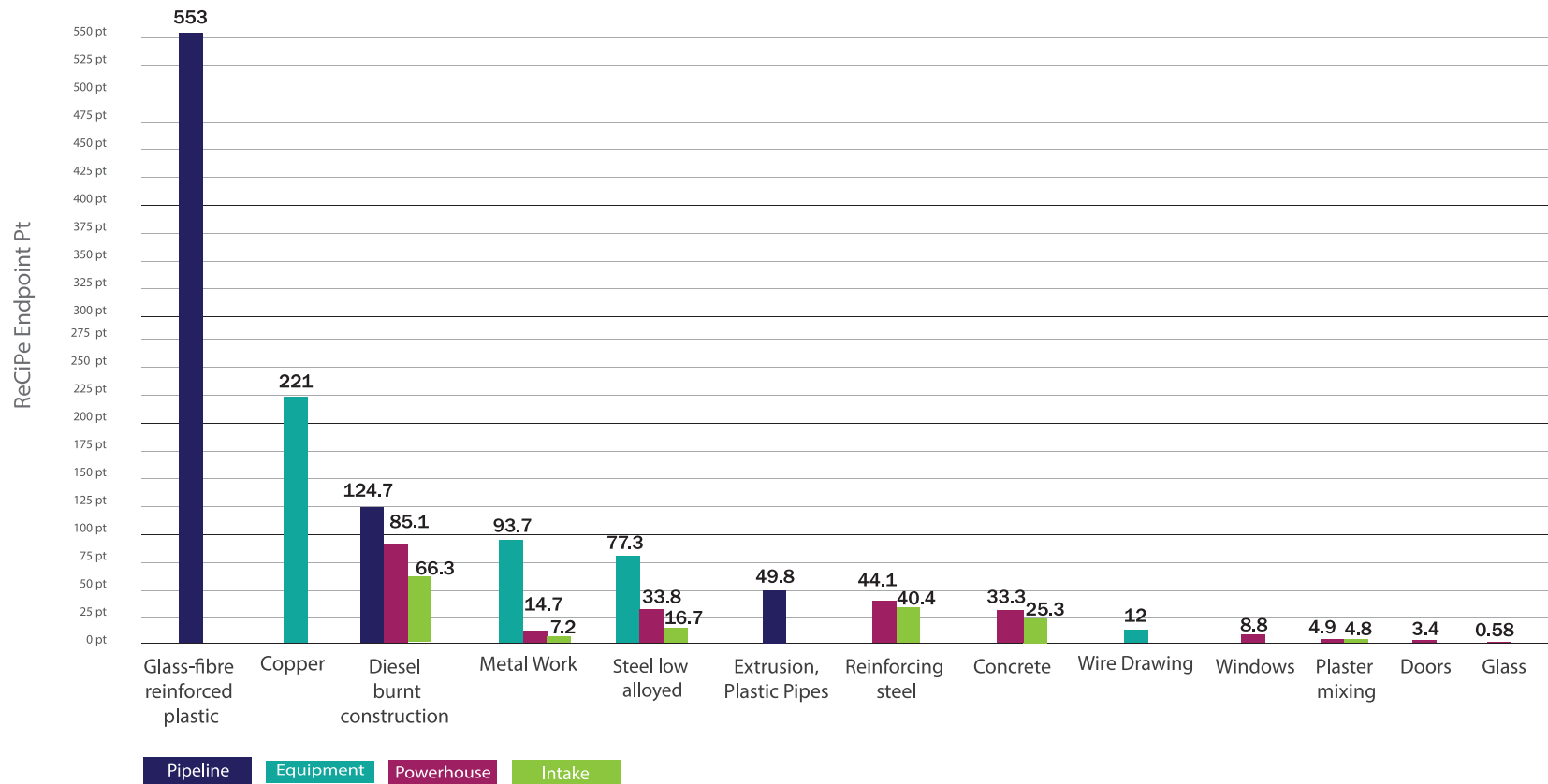


LIFE CYCLE PHASE	UNIT	POINTS
Preproduction +Production	ReCiPe Endpoint	1760,4
Use	ReCiPe Endpoint	129,2
Distribution	ReCiPe Endpoint	35
Disposal	ReCiPe Endpoint	26,46

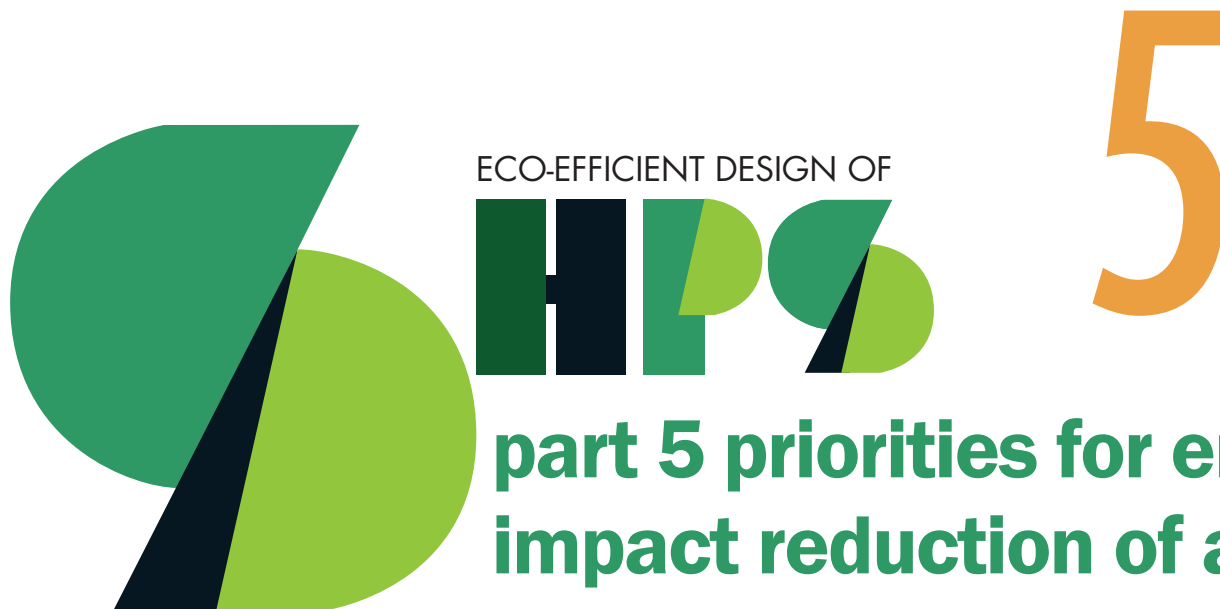
Component Life cycle



COMPONENT	UNIT	POINTS
Rapid Pipeline	ReCiPe Endpoint	706
Equipment	ReCiPe Endpoint	588
Powerhouse	ReCiPe Endpoint	258
Intake	ReCiPe Endpoint	184



Comparative values of EcoIndicator point of the materials inventoried.



**part 5 priorities for environmental
impact reduction of a SHPS**

8. SMALL HYDROPOWER SPECIFIC LIFE CYCLE GUIDELINES AND PRIORITIES

8.1. Introduction

The results of LCA have been elaborated through the IPSA (Strategic Design Priorities Identification) method, obtaining a priority list in relation to the seven most important LCD strategies.

- 1) Minimizing Material and Energy Consumption
- 2) Optimization of Product Lifetime, design durable and intensely usable products
- 3) Minimizing Toxicity
- 4) Optimization of Materials Lifespan, design with the purpose of increasing the value of disposed materials via recycling, composting or incineration.
- 5) Renewable and Bio-Compatible Resources, select more eco-compatible materials, processes and energy sources
- 6) Design for Disassembly, design with the purpose of separating the parts of materials.

The priorities for the strategies of environmental impact reduction are a set of formulas that use the results from a Life Cycle Assessment Software, in this case SimaPro, also named Eco-indicator points. Upon those formula coefficients need to be applied according to different reasoning. For each strategy there is one formula. An exception to this are the Renewable and Bio-Compatible Resources and the Design for Disassembly, because the latter does not have an appointed priority. As for Renewable and Bio-Compatible Resources the sum of Eco-indicator points gives the priority rank, without a formula.

Because a Small Hydropower Station is not a consumer good and the economic model is a business to business model some typical requirements of product design become less important like aesthetics, cultural or economic (implementing environmental strategy like material replacement/ reduction does not affect sales) like is the case of other consumer goods. However some strategy can be conflictual, like choosing more renewable materials for long lasting parts can reduces the required lifespan, resulting in using more materials.

Reducing consumption and selecting low-impact resources are objectives for all life cycles stages.

Optimizing product lifespan determines an overall reduction in the environmental impact during stages of pre-production, production, distribution and disposal by means of the reduction of product flow necessary

to satisfy particular needs.

Extension of material lifespan is an objective for the stages of pre-production (less raw material consumption) and disposal.

Facilitating disassembly is needed for optimizing product lifespan and extending material's lifespan.

Component: Small Hydropower Energy Scheme						
Strategy	IPSA formula	IPSA	IPSA n.	Priority	f. m. r	f. m. n
1. Optimization of Product Lifetime	$\sum fDpc.i \times EIc.i[PP + P + DT + DM]$					
		477	0.56	P: MEDIA		
2. Minimizing Material Consumption	$c \times EI[PP + P + DT + DM]$					
		851.823	1.00	P: ALTA		
3.Minimizing Energy Consumption	$c \times EI[\text{consumed energy}]$					
		1.035	0.00	P: BASSA		
4. Optimization of Materials Lifespan	$c \times EI[PP \text{ landfilled materials}] + EI[DM \text{ landfilled materials}]$					
		218.99	0.26	P: BASSA		
5.Minimizing Toxicity	$EI.t[(PP + P + DT + U + DM) \text{ materiali/processi tossici}]$					
		128.32	0.15	P: BASSA		
6. Renewable and Bio-Compatible Resources	$EI.c[\text{consumed energy} + \text{consumed materials}]$					
		28.695	0.03	P: BASSA		
IPSA max		851.823				

How are the priorities calculated?

General criteria: 1. how much can I gain in terms of environmental impact reduction if I design a product pursuing to the fullest a strategy of Life Cycle Design?

2. The LCD strategy pursued to the fullest that have bigger potential of environmental reduction impact will be proportionally prioritized in comparison to the others.

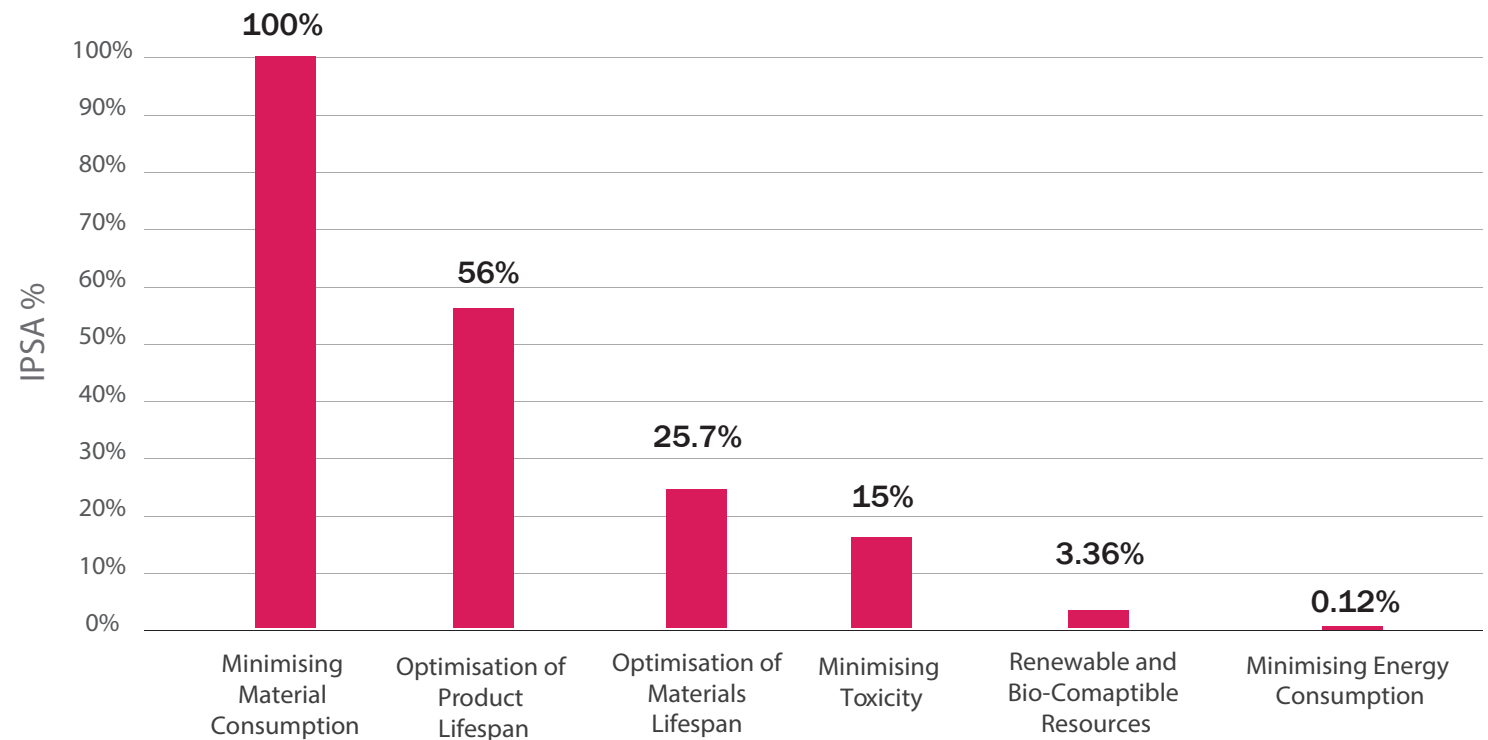
IPSA calculation sheet. Developed by DIS - Design and System Innovation Sustainability - Politecnico di Milano. This graph shows the sum of all the four components of the SHPS.

Strategic Design Priorities - SHPS

The design guidelines for integrating environmental requirements in the development phase of the examined product are grouped into the following strategies:

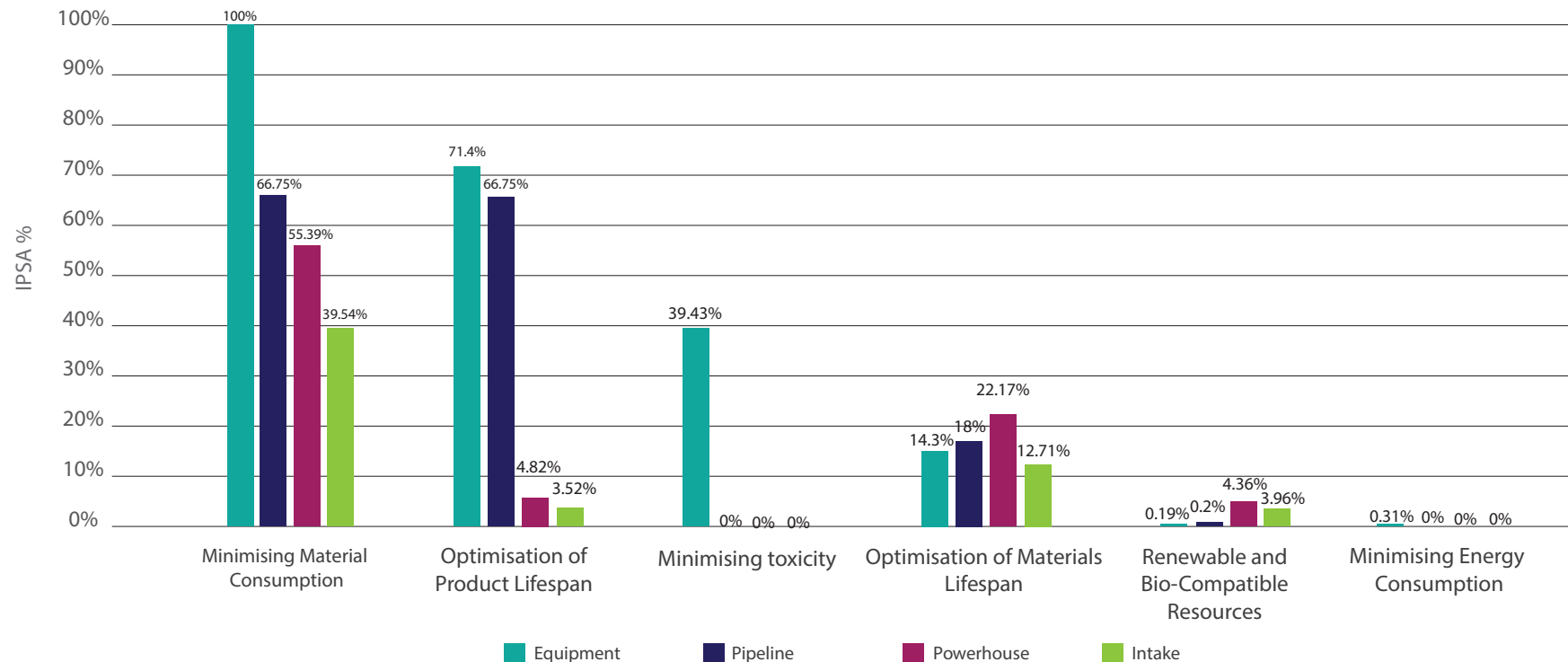
Minimising Material Consumption	(100% high priority)
Optimisation of Product Lifetime	(56% medium priority)
Optimisation of Materials Lifespan	(25.7% medium - low priority)
Minimising Toxicity	(15% low priority)
Renewable and Bio-Comaptible Resources	(3.36% low priority)
Minimising Energy Consumption	(0.12% very low priority)

The six strategies for environmental impact reduction calculated in percentages. This graph shows the sum of the four SHPS components.



Strategic Design Priorities - SHPS components

Minimising Material Consumption	(100% high priority, 66.75%, 55.39%, 39.54% medium priority)
Optimisation of Product Lifetime	(71.4%, 66.75% high, 4.82%, 3.52% low)
Minimising Toxicity	(39.43%, 0% medium)
Optimisation of Materials Lifespan	(14.3%, 18%, 22.17%, 12.71% medium)
Renewable and Bio-Compatible Resources	(0.19%, 0.2%, .36%, 3.96% low)
Minimising Energy Consumption	(0.31%, 0% low)



The 100% value corresponds to the highest IPSA value - in this case the Material Consumption Minimization of the Equipment component that is - 232,515 EcoIndicator points.

8.1. Minimizing Material Consumption (Σ 851,823 points)

How much can it be gained in terms of environmental impact reduction if the design of the product is in such a way that uses infinitely less material in respect to the existing one?

Formula used

$$c \times EI[PP + P + DT + DM]$$

c = maximum reduction coefficient = 0,9 > 0,5; c = 0,7: in uncertainty cases

PP=pre-production; P = production; DT = distribution/transport; DM = disposal

Reducing resources denotes a design aimed at reducing the usage of materials for the entire product life cycle. Using less materials diminishes the environmental impact of a product due to minimizing the resources being extracted, but also due to the reduction or diminishing of the fabrication processes and the produced waste. Apart from their environmental costs products obviously also have economical costs. Less materials means savings in both contexts.

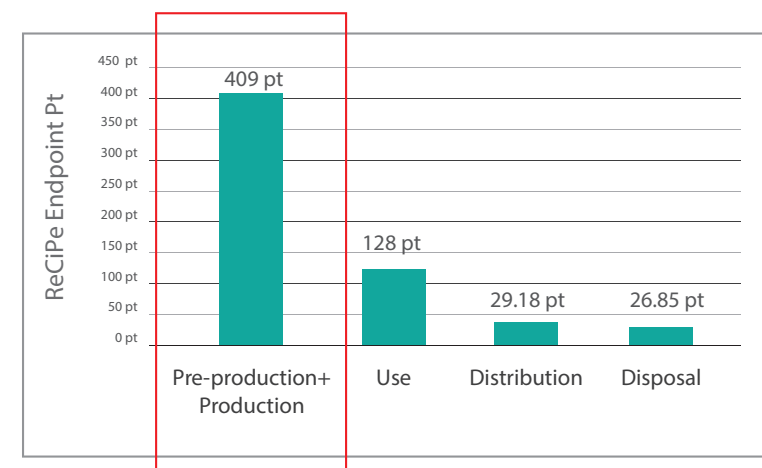
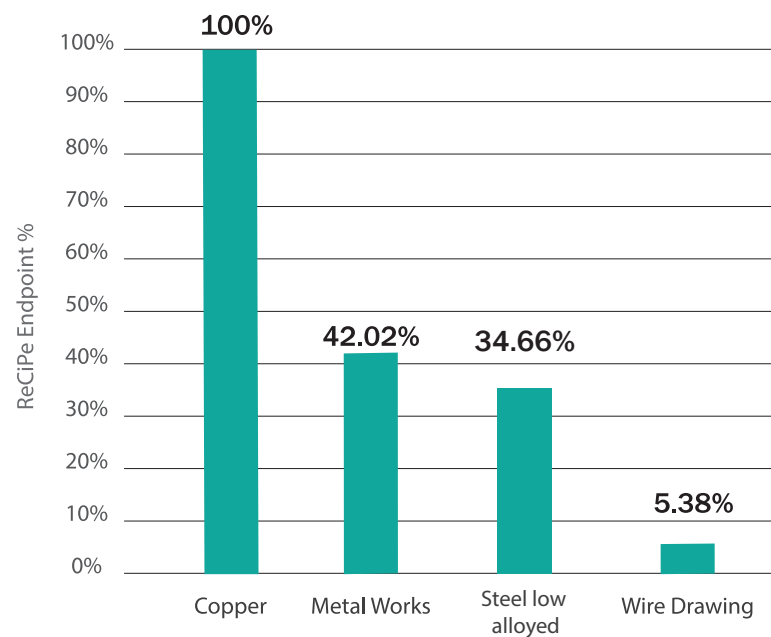
Following the results of this calculation Minimizing Material Consumption has the highest priority with a combined sum of 851.823 points (325,5 Equipment; 217,3 Rapid Pipeline; 180,3 Powerhouse, 128,7 Intake). A sum of the individual components was made because applying a coefficient for all the system results would have proven inaccurate.

The coefficients used to calculate this priority vary from one component to the other, that is why, even though the glass-fiber reinforce plastic (the materials of the pipeline) has a greater environmental impact the reduction coefficient cannot be so big (0,5 would mean reducing the materials to half) that is why a coefficient of 0,3 was used. And as a result the reduction of the materials of the pipeline has a lower priority than that of the Equipment. In the case of the Equipment the Intake and the Powerhouse there is more flexibility so an uncertainty coefficient was used 0,7.

The results are also unexpected if we look at the quantities in kilograms. The Equipment has the smallest amount 6,4 ton the Pipeline 8,6 ton second, Intake 53,3 ton third and Powerhouse 67.1 ton last.

Strategia	formula IPSA	IPSA	IPSA n.	Priorità	f. m. r	f. m
2. Minimizing Material Consumption	$c \times EI[PP + P + DT + DM]$					
INTAKE	0.7*(161+4.68+18.2)	128.716	0.40	P: MEDIA		
2. Minimizing Material Consumption	$c \times EI[PP + P + DT + DM]$					
PIPELINE	0.3*(722+2.34)	217.302	0.67	P: ALTA		
2. Minimizing Material Consumption	$c \times EI[PP + P + DT + DM]$					
POWERHOUSE	0.7*(229+5.9+22.7)	180.32	0.55	P: MEDIA		
2. Minimizing Material Consumption	$c \times EI[PP + P + DT + DM]$					
EQUIPMENT	0.7*(409+29.18+26.85)	325.521	1.00	P: ALTA		
IPSA max		325.521				

8.1.1. EQUIPMENT



Pre-Production+Production	UNIT	POINTS
Copper	ReCiPe Endpoint	223
Metal Work (average)	ReCiPe Endpoint	93.7
Steel low alloyed	ReCiPe Endpoint	77.3
Wire Drawing Copper	ReCiPe Endpoint	12

MIMIMIZE MATERIAL CONSUMPTION - EQUIPMENT

DESIGN GUIDELINES

Design indications are grouped as:

MINIMIZE MATERIAL CONTENT OF PRODUCT

MINIMIZE OR AVOID PACKAGING

CHOOSE THE MOST EFFICIENT SYSTEM TO REDUCE THE MATERIAL CONSUMPTION IN USE

MINIMIZE MATERIAL CONTENT OF PRODUCT

- Dematerialise the product or some of its components
- Digitalise the product or some of its components
- Miniaturise
- Avoid over-sized dimensions
- Reduce thickness
- Apply ribbed to the structure to increase structural stiffness.
- Avoid extra components with little functionality

MINIMISE SCRAPS AND DISCARDS:

- Select processes that reduce scraps and discarded materials during production
- Use efficient molds for steel parts
- Engage simulation systems to optimize transformation processes.

MINIMISE OR AVOID PACKAGING:

- Avoid packaging
- Apply materials only where absolutely necessary
- Design the package to be part (or to become a part) of the product

ENGAGE MORE CONSUMPTION-EFFICIENT SYSTEMS:

- Design for more efficient consumption of operational materials
- Consider optimizing the shape of the cooling coils installation
- Choosing a type of oil with higher lifespan for the cooling coils installation
- Design for more efficient supply of raw materials
- Design for more efficient use of maintenance materials
- Design for cascading recycling systems
- Reuse mineral oil as paint for protecting wood surfaces from exterior degradation.
- Facilitate the person managing maintenance to reduce materials consumption

ENGAGE SYSTEMS OF FLEXIBLE MATERIALS CONSUMPTION:

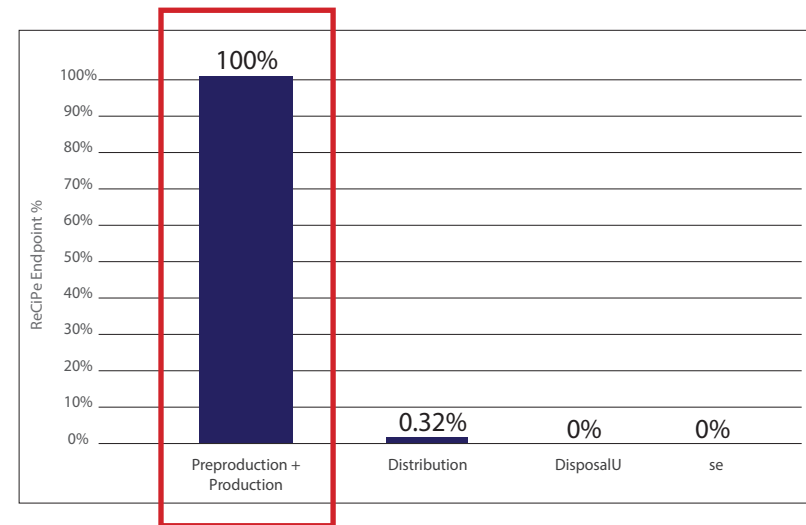
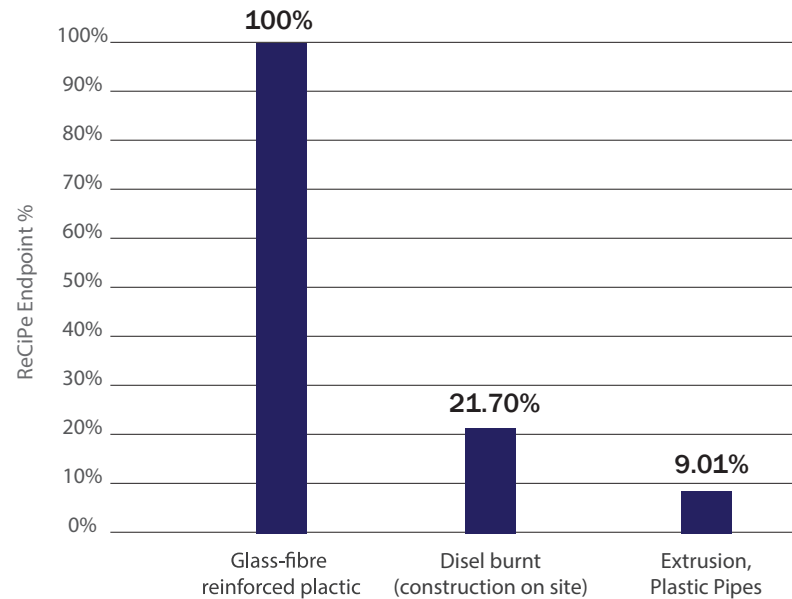
For the oil from the cooling coils installations of the electromechanical equipment

- Engage digital support systems with dynamic configuration
- Engage a remote system for adjusting the oil consumption
- Design a reserve tank in addition to the cooling installation, that refills the lost oil
- Design dynamic materials consumption for different operational stages
- Engage sensors to adjust materials consumption according to differentiated operational stages
- Use an adjusting system to optimize the use of oil during periods of high energy generation
- Reduce resource consumption in the product's default state

MINIMISE MATERIALS CONSUMPTION DURING THE PRODUCT DEVELOPMENT PHASE:

- Minimise the consumption of stationery goods and their packages
- Engage digital tools in designing, modelling and prototype creation
- Engage digital tools for documentation, communication and presentation

8.1.2. PIPELINE



	UNIT	POINTS
Glass-fibre reinforced plastic	ReCiPe Endpoint %	553
Extrusion plastic pipes	ReCiPe Endpoint %	49.8
Diesel Burnt (construction on site)	ReCiPe Endpoint %	120

MIMIMIZE MATERIAL CONSUMPTION - PIPELINE DESIGN GUIDELINES

Design indications are grouped as:

MINIMIZE MATERIAL CONTENT OF PRODUCT

MINIMIZE OR AVOID PACKAGING

CHOOSE THE MOST EFFICIENT SYSTEM TO REDUCE THE MATERIAL CONSUMPTION IN USE

MINIMIZE MATERIAL CONTENT OF PRODUCT

- Dematerialise the product or some of its components
- Apply ribbed to the structure to increase structural stiffness.
- Apply ribbed to the structure to increase structural stiffness for the pipeline

MINIMISE SCRAPS AND DISCARDS:

- Select processes that reduce scraps and discarded materials during production
- Use efficient molds for plastic parts
- Engage simulation systems to optimize transformation processes

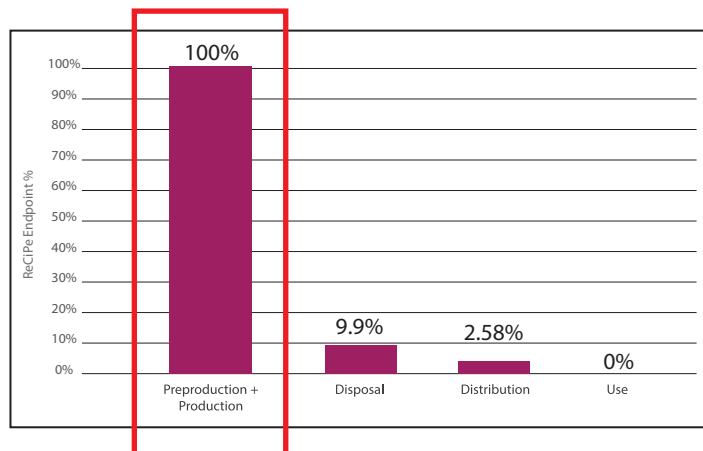
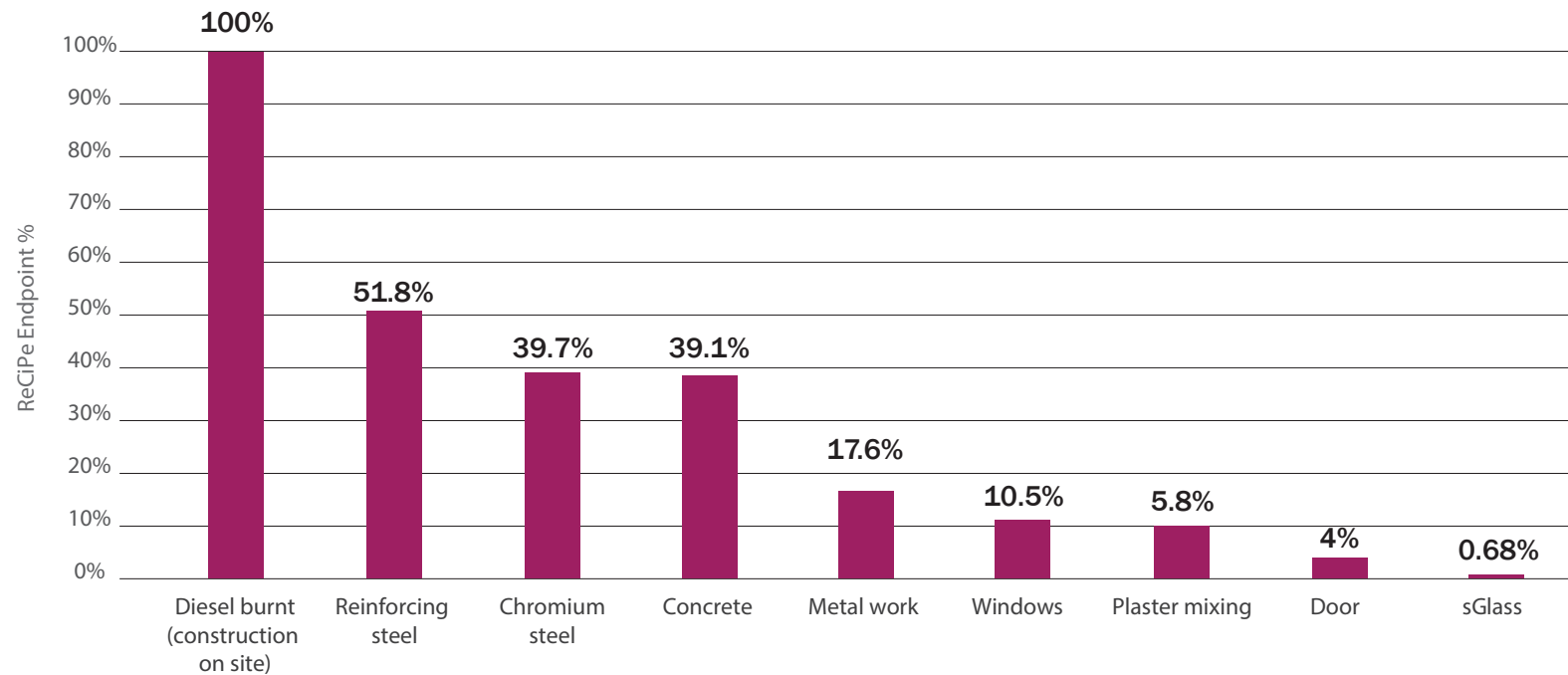
ENGAGE MORE CONSUMPTION-EFFICIENT SYSTEMS:

- Design for more efficient consumption of operational materials
- Design for more efficient supply of raw materials
- Design for cascading recycling systems

MINIMISE MATERIALS CONSUMPTION DURING THE PRODUCT DEVELOPMENT PHASE:

- Minimise the consumption of stationery goods and their packages
- Engage digital tools in designing, modelling and prototype creation
- Engage digital tools for documentation, communication and presentation

8.1.3. POWERHOUSE



PRE-PRODUCTION+PRODUCTION	UNIT	POINTS
Diesel burt (construction on site)	ReCiPe Endpoint %	85.1
Reinforcing Steel	ReCiPe Endpoint %	44.1
Chromium Steel	ReCiPe Endpoint %	33.8
Concrete	ReCiPe Endpoint %	33.3
Metal Work (average)	ReCiPe Endpoint %	15
Windows frames	ReCiPe Endpoint %	8.82
Plaster Mixing	ReCiPe Endpoint %	4.94
Doors	ReCiPe Endpoint %	3.38
Glass	ReCiPe Endpoint %	0.58

MIMIMIZE MATERIAL CONSUMPTION - POWERHOUSE DESIGN GUIDELINES

Design indications are grouped as:

MINIMIZE MATERIAL CONTENT OF PRODUCT

MINIMIZE OR AVOID PACKAGING

CHOOSE THE MOST EFFICIENT SYSTEM TO REDUCE THE MATERIAL CONSUMPTION IN USE

MINIMISE MATERIAL CONTENT:

- Dematerialise the product or some of its components
- If the site allows it build the Powerhouse partially buried underground or constructed close to a stone wall, in order to minimize the amount of material used
- Use on site ground to provide soundproofing by partially covering the house
- Use a remote control system for the station in order to avoid the need of a separate control room. If possible design all the component in one room.
- Avoid over-sized dimensions
- Start the design of the machine room from the size of the turbine that is going to be used for the specific flow.
- Research up to date standards for structural design dimensions.
- Research for new and more performing materials available to reduce the overall amount of materials.
- Use appropriate software to understand, test and make simulations for new resistance specifications and materials.
- Reduce thickness – of walls of construction

Powerhouse – not on site

- Use performant ready made parts with required configuration for the concrete components to reduce thickness of the walls of the construction
- Use a diverse range of concretes for different parts of the construction e.g. the parts in direct contact to the water can be denser and more resistant to freezing and the ones buried can be less.
- Consider changing the steel rebar with a lighter more efficient reinforcement like: using fiber

glass, carbon fiber, reinforced polymer or bronze-aluminum

Powerhouse – on site

- Changing the quality of the concrete by adding more cement will reduce the need of thicker walls.
- Apply ribbed to the structure to increase structural stiffness.
- Apply ribbed to the structure to increase structural stiffness for the walls of the powerhouse

MINIMISE SCRAPS AND DISCARDS:

- Select processes that reduce scraps and discarded materials during production
- Use efficient molds for readymade concrete products to reduce the scraps and discarded materials during the production
- Engage simulation systems to optimize transformation processes.
- Vibration pumps can be used on site to optimize the density of concrete.

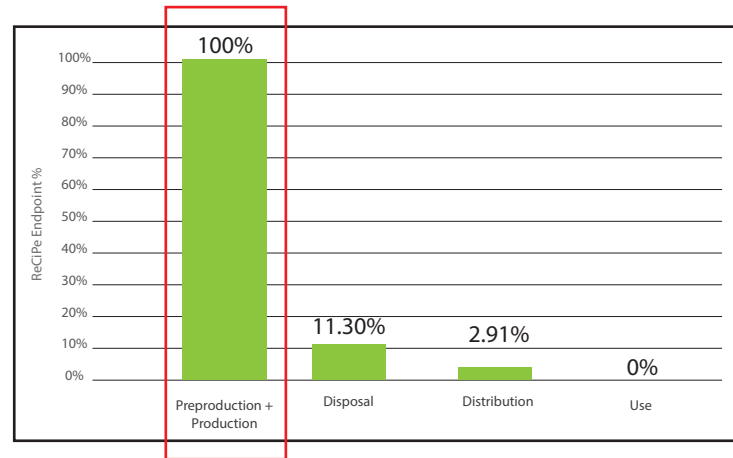
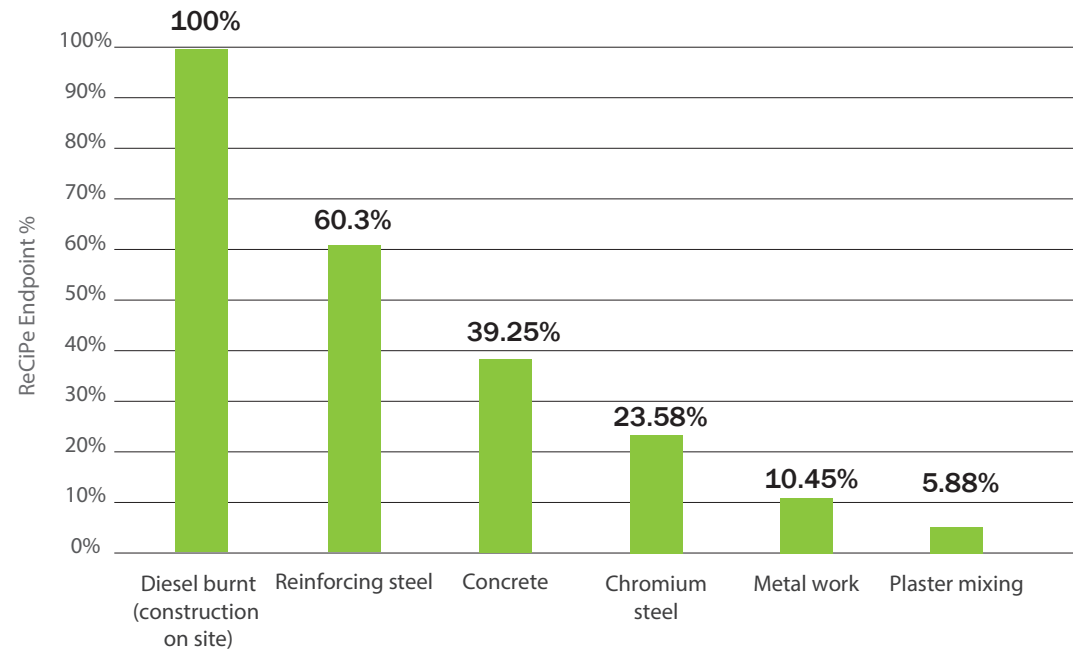
ENGAGE MORE CONSUMPTION-EFFICIENT SYSTEMS:

- Design for more efficient consumption of operational materials
- Design for more efficient supply of raw materials
- Use/acquire the necessary aggregates for concrete on site or closer from the construction site
- Design for more efficient use of maintenance materials
- Design systems for consumption of passive materials
- Design for cascading recycling systems

MINIMISE MATERIALS CONSUMPTION DURING THE PRODUCT DEVELOPMENT PHASE:

- Minimise the consumption of stationery goods and their packages
- Engage digital tools in designing, modelling and prototype creation
- Engage digital tools for documentation, communication and presentation

8.1.4. INTAKE



PRE-PRODUCTION+PRODUCTION	UNIT	POINTS
Diesel burt (construction on site)	ReCiPe Endpoint	67
Reinforcing Steel	ReCiPe Endpoint	40.4
Concrete	ReCiPe Endpoint	26.51
Chromium Steel	ReCiPe Endpoint	15.8
Metal Work (average)	ReCiPe Endpoint	7
Plaster Mixing	ReCiPe Endpoint	3.94

MIMIMIZE MATERIAL CONSUMPTION - INTAKE

DESIGN GUIDELINES

MINIMISE MATERIAL CONTENT:

- Dematerialise the product or some of its components
- Avoid over-sized dimensions
- Research up to date standards for structural design dimensions.
- Research for new and more performing materials available to reduce the overall amount of materials.
- Use appropriate software to understand, test and make simulations for new resistance specifications and materials.
- Reduce thickness – of walls of construction

Intake – not on site

- Use performant ready made parts with required configuration for the concrete components to reduce thickness of the walls of the construction
- Use a diverse range of concretes for different parts of the construction e.g. the parts in direct contact to the water can be denser and more resistant to freezing and the ones buried can be less.
- Consider changing the steel rebar with a lighter more efficient reinforcement like: using fiber glass, carbon fiber, reinforced polymer or bronze-aluminum

Intake – on site

- Changing the quality of the concrete by adding more cement will reduce the need of thicker walls.
- Apply ribbed to the structure to increase structural stiffness.
- Apply ribbed to the structure to increase structural stiffness for the walls of the powerhouse, of the intake exterior basin and of the pipeline

- Avoid extra components with little functionality

MINIMISE SCRAPS AND DISCARDS:

- Select processes that reduce scraps and discarded materials during production
- Use efficient molds for readymade concrete products to reduce the scraps and discarded materials during the production
- Engage simulation systems to optimize transformation processes.
- Vibration pumps can be used on site to optimize the density of concrete.

ENGAGE MORE CONSUMPTION-EFFICIENT SYSTEMS:

- Design for more efficient consumption of operational materials
- Design for more efficient supply of raw materials
- Use/acquire the necessary aggregates for concrete on site or closer from the construction site
- Design for more efficient use of maintenance materials

Silt basin (intake)

- Choose long lasting tools (shovel, brooms or other) for maintenance materials.
- Design systems for consumption of passive materials
- Design a system that uses the water of the rain or the river to clean the exterior surfaces.
- Design side gates at the bottom of the silt basin that allows water from the river to clean the silt from the basin
- Design for cascading recycling systems
- Facilitate the person managing maintenance to reduce materials consumption

ENGAGE SYSTEMS OF FLEXIBLE MATERIALS CONSUMPTION:

- Engage digital support systems with dynamic configuration
- Design dynamic materials consumption for different operational stages
- Engage sensors to adjust materials consumption according to differentiated operational stages
- Reduce resource consumption in the product's default state

MINIMISE MATERIALS CONSUMPTION DURING THE PRODUCT DEVELOPMENT PHASE:

- Minimise the consumption of stationery goods and their packages
- Engage digital tools in designing, modelling and prototype creation
- Engage digital tools for documentation, communication and presentation

8.2. Optimization of Product Lifetime (Σ 477 points)

How much can it can be gained in terms of environmental impact reduction if the design of the product is in such a way that is infinitely more durable in comparison to the existing product?

Formula used

$$\sum fD_{p,i} \times EI_{c,i} [PP + P + DT + DM]$$

fD_p = fattore Durata uso potenziale

c = maximum reduction coefficient= 0,9>0,5; $c = 0,7$: in uncertainty cases

EI = Eco-Indicator= indicator of aggregated environmental impact

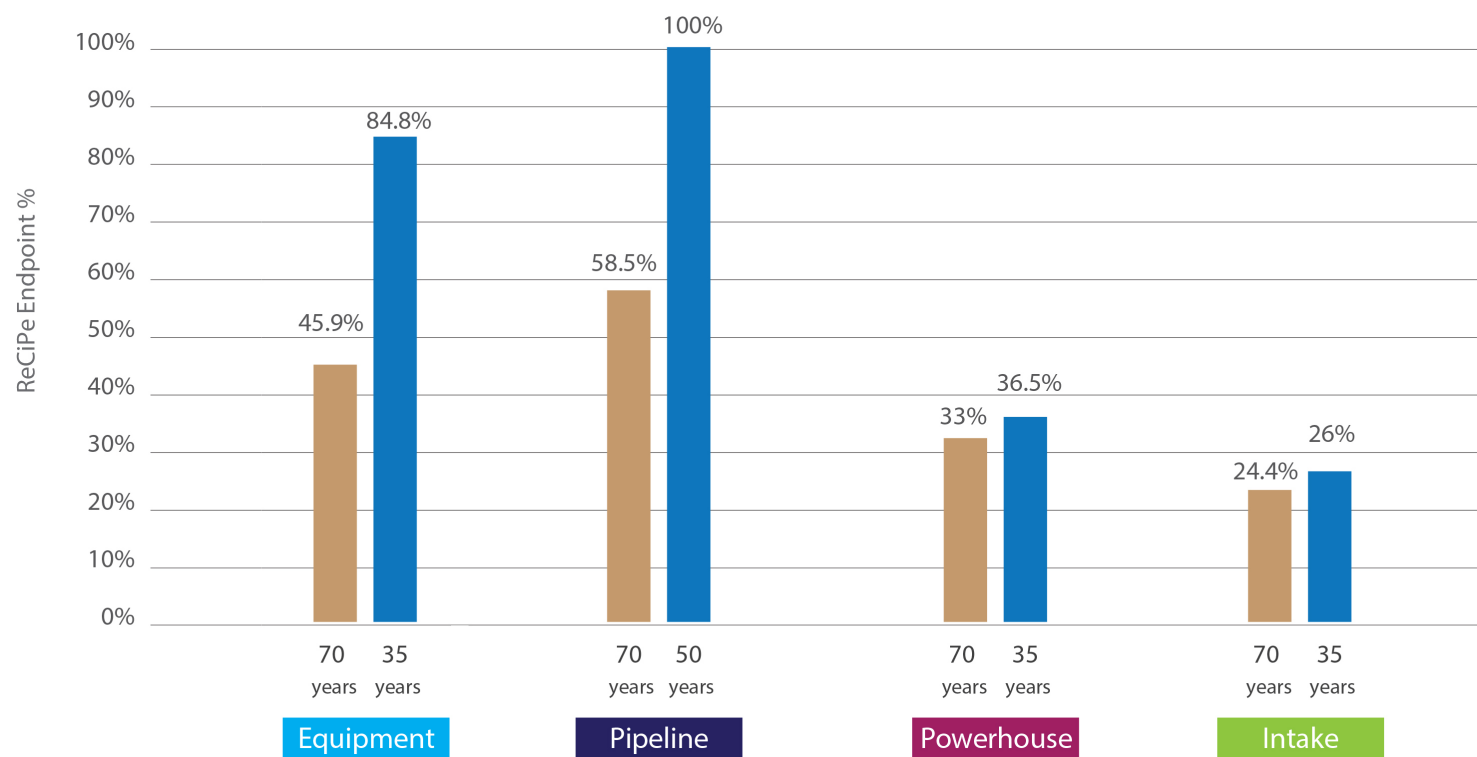
PP=pre-production; P = production; DT = distribution/transport; DM = disposal

Optimizing the lifespan of a products is to design for the extending of the product and its components lifespan and for intensifying product (and its components) use. A product with longer lifespan than another with the same functionality, generally determines smaller environmental impact. A product with accelerated wear will not only generate untimely waste, but will also determine further impact due to the need of replacing it. Production and distribution of a new product to replace its function involves the consumption of new resources and the further generation of emissions.

This was calculated for those parts of the components of the station, which have an inferior life than that of the station (70 years). As follows: for Equipment: all the parts; for the pipeline: all the parts; for the Powerhouse: doors, windows, fencing system, lighting conductor; for the Intake: the grills and the sluice gates. All of this were calculated as replaced only once. So the coefficient used was 0,5 (double existing the lifespan- 35 years increase) for parts that were assumed on average with a lifespan of 35 years (powerhouse, intake, equipment) and 0.3 (25 years increase) for the pipeline that has a lifespan of 50 years.

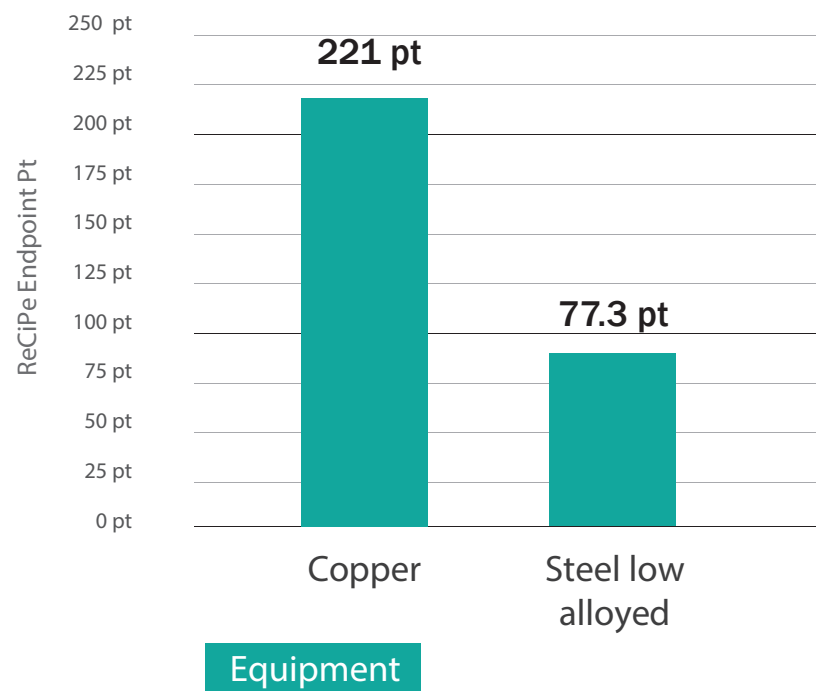
Because the Pipeline and the Equipment have the higher eco-indicator points and because those are replaced entirely, those have a much greater priority compared to the Powerhouse and Intake, also those have fewer replacement parts. Resulting moreover that the optimization of materials lifespan has even a greater priority in those cases than that of optimizing the product's lifespan.

Strategia	formula IPSA	IPSA	IPSA n.	Priorità	f. m. r	f. m. n
1. Optimization of Product Lifetime	$\Sigma fDpc.i \times Eic.i[PP + P + DT + DM]$					
INTAKE	$0.5 \cdot (22.7 + 0.0168 + 0.248)$	11.4824		P:		
1. Optimization of Product Lifetime	$\Sigma fDpc.i \times Eic.i[PP + P + DT + DM]$					
PIPELINE	$0.3 \cdot (722 + 2.34)$	217.302	0.93	P: ALTA		
1. Optimization of Product Lifetime	$\Sigma fDpc.i \times Eic.i[PP + P + DT + DM]$					
POWERHOUSE	$0.5 \cdot (31.1 + 0.0668 + 0.266)$	15.7164	0.07	P:		
1. Optimization of Product Lifetime	$\Sigma fDpc.i \times Eic.i[PP + P + DT + DM]$					
EQUIPMENT	$0.5 \cdot (409 + 29.18 + 26.85)$	232.515	1.00	P: ALTA		
IPSA max		232.515				



Total EcoIndicator points (35 years) of current design - compared to 70 years lifetime extension

8.2.1. EQUIPMENT



The components that have a lifespan inferior to the lifespan of the whole Small Hydropower energy scheme, that in the pre-production, production, distribution and disposal have the highest environmental impact are:

Macro component Equipment (Turbine, Generator, Medium Tension Cells, Transformers) - material: Copper

Macro component Equipment (Turbine, Generator, Medium Tension Cells, Transformers) - material: Steel low alloyed

PRODUCT LIFETIME OPTIMISATION - EQUIPMENT DESIGN GUIDELINES

DESIGN APPROPRIATE LIFESPAN:

- Design components with co-extensive lifespan
- Make a part by part lifespan assessment of all of the components to understand if there are parts that need works of maintenance or reparations and not total replacement.
- Design lifespan of replaceable components according to scheduled duration
- Design according to 70 years multiples
- Select durable materials according to the product performance and lifespan.

RELIABILITY DESIGN:

- Reduce overall number of components
- Simplify products
- Eliminate weak liaisons

FACILITATE UPGRADING AND ADAPTABILITY:

- Enable and facilitate software upgrading
- Design the software for oil consumption installations in order to be upgradable for use of new, more efficient or more ecofriendly oils consumption
- Enable and facilitate hardware upgrading for more efficient turbines.
- Design modular and dynamically configured products to facilitate their adaptability for changing environments.
- Design onsite upgradeable and adaptable products
- Consider an approach in which several smaller turbines are linked, so that the energy generation can continue also with low water flows
- Design complementary tools and documentation for product upgrading and adaptation

FACILITATE MAINTENANCE:

In the case of the SHPS we are talking of two kinds of maintenance:

The cleaning processes that ensures the proper functioning of the system.

The power generation machinery maintenance. In this case it is usually performed by technicians due to high safety risks.

- Simplify access and disassembly to components to be maintained
- Simplify access to the silt basin for manually cleaning.
- Avoid narrow slits and holes to facilitate access for cleaning
- Equip the product with easily usable tools for maintenance
- Equip products with diagnostic and/or auto-diagnostic systems for maintainable components
- A remote system checking the well-functioning of the system and the safety parameters of the turbine.
- An advanced remote system of surveillance and adjustments for the cooling coils oil consumption and quality.
- Place a diagnostic system on the nozzles prevent damage due to high water pressure or high speed
- nozzles have to be designed or chosen to be performant because they are subject to high pressure and friction.
- Sensors are also needed for the pipes, the inlets and jets or nozzles composed in the water supply inside the Powerhouse
- Design products for easy on-site maintenance
- Integrity inspection of the cooling coils can be tested on site by the conductivity or helium gas methods.
- Design complementary maintenance tools and documentation
- Design products that need less maintenance

FACILITATE REPAIRS:

- Arrange and facilitate disassembly and re-attachment of easily damageable components
- Choose or design a turbine with replaceable and detachable buckets
- Replaceable buckets for the turbine need to be available on site for repairs.

- Design components according to standards to facilitate substitution of damaged parts
- Equip products with automatic damage diagnostics system
- Damage diagnostic system can be placed on nozzles, on pipes under high pressure and on bearings or their proximity.
- Design products for facilitated onsite repair
- Design complementary repair tools, materials and documentation

FACILITATE RE-USE:

- Increase the resistance of easily damaged and expendable components
- Arrange and facilitate access and removal of retrievable components
- Design modular and replaceable components
- Design components according to standards to facilitate replacement
- Design re-usable auxiliary parts
- Facilitate cleaning the filters of oil that are in place
- Design or choose filters made of a durable material

FACILITATE RE-MANUFACTURE:

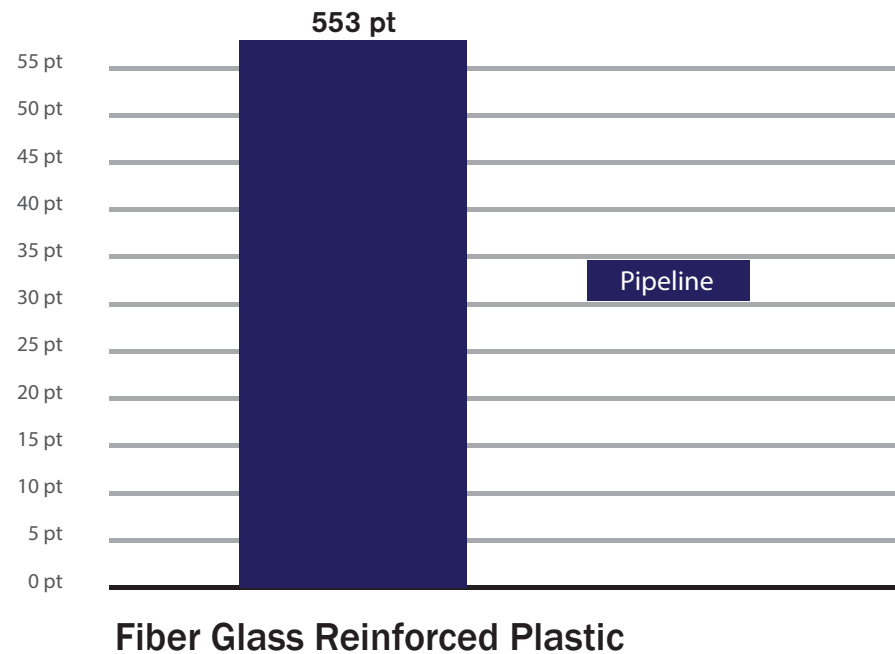
The industrial equipment that have long lifespans (turbine 35 years) are more suitable for remanufacturing. A design aimed at easy removal and replacement has to be considered.

- Design and facilitate removal and substitution of easily expendable components
- Design structural parts that can be easily separated from external/visible ones
- Provide easier access to components to be re-manufactured
- Calculate accurate tolerance parameters for easily expendable connections like the nozzles.
- Design for excessive use of materials in places more subject to deterioration
- Design for excessive use of material for easily deteriorating surfaces
- Design a smaller bearing box around the place of the bearings, independent from the body of the casing, so overall replacement of the casing will not be necessary

DESIGN APPROPRIATE LIFESPAN:

- Design components with co-extensive lifespan
- Extend the lifespan of the pipeline from 50 to 70 years by installing a diagnostic system that points damaged or vulnerable parts

8.2.2. PIPELINE



The components that have a lifespan inferior to the lifespan of the whole Small Hydropower energy scheme, that in the pre-production, production, distribution and disposal have the highest environmental impact are:

Macro component:

Pipeline - material: Fiber Glass Reinforced Plastic

PRODUCT LIFETIME OPTIMISATION - PIPELINE DESIGN GUIDELINES

- Design lifespan of replaceable components according to scheduled duration
- Select durable materials according to the product performance and lifespan. For the pipeline lifespan from 50 years to 70 years.

RELIABILITY DESIGN:

- Reduce overall number of components
- Simplify products
- Eliminate weak liaisons

FACILITATE UPGRADING AND ADAPTABILITY:

- Design modular and dynamically configured products to facilitate their adaptability for changing environments.
- Design onsite upgradeable and adaptable products
- Design complementary tools and documentation for product upgrading and adaptation

FACILITATE MAINTENANCE:

- Simplify access and disassembly to components to be maintained
- Avoid narrow slits and holes to facilitate access for cleaning
- Equip the product with easily usable tools for maintenance
- Equip products with diagnostic and/or auto-diagnostic systems for maintainable components
- Sensors for pressure, temperature and eventual deposits can be placed inside the pipeline to signal if there are any hydraulic leaks that can create slits and cracks during freezing seasons.
- Sensors are also needed for the pipes, the inlets and jets or nozzles composed in the water supply inside the Powerhouse
- Design products for easy on-site maintenance

- Design complementary maintenance tools and documentation
- Design products that need less maintenance

FACILITATE REPAIRS:

- Arrange and facilitate disassembly and re-attachment of easily damageable components
- Design components according to standards to facilitate substitution of damaged parts
- Equip products with automatic damage diagnostics system
- Damage diagnostic system can be placed on nozzles, on pipes under high pressure and on bearings or their proximity.
- Design products for facilitated onsite repair
- Make local excavations to fix the cracks of the pipeline, using the diagnostic system
- A bandage system can be used, or a collar like module can be fixed in place of the damaged one after cutting the cracked part.
- Design complementary repair tools, materials and documentation

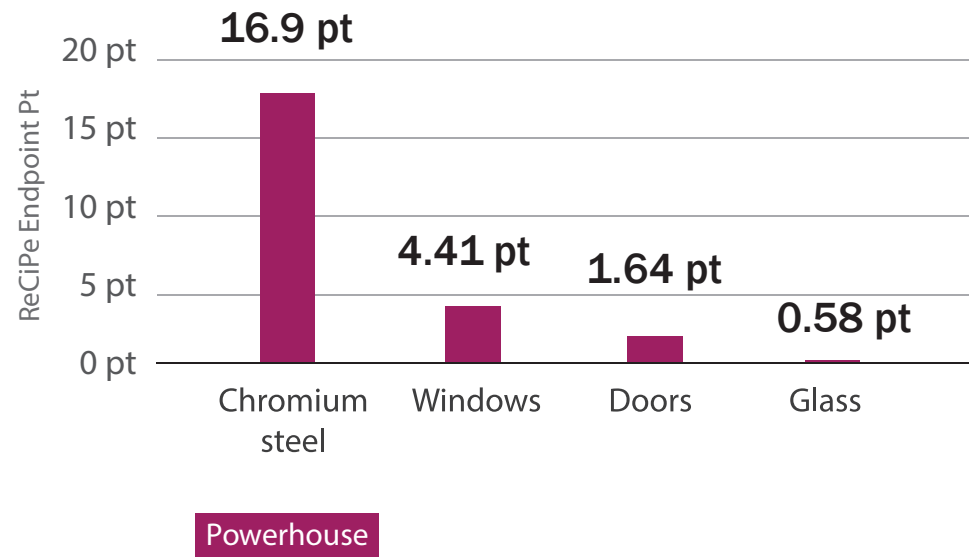
FACILITATE RE-USE:

- Increase the resistance of easily damaged and expendable components
- The wood formworks can be replaced with readymade metal or plastic ones.
- Arrange and facilitate access and removal of retrievable components
- Design modular and replaceable components
- Design components according to standards to facilitate replacement
- Design re-usable auxiliary parts

FACILITATE RE-MANUFACTURE:

- Design and facilitate removal and substitution of easily expendable components
- Provide easier access to components to be re-manufactured
- Calculate accurate tolerance parameters for easily expendable connections for the Pipeline, inlets, jets or nozzles.
- Design for excessive use of materials in places more subject to deterioration
- Design for excessive use of material for easily deteriorating surfaces

8.2.3. POWERHOUSE



The components that have a lifespan inferior to the lifespan of the whole Small Hydropower energy scheme, that in the pre-production, production, distribution and disposal have the highest environmental impact are:

Macro component: Miscellaneous: Chromium Steel

Macro component: Window frames

Macro component: Doors

PRODUCT LIFETIME OPTIMISATION - POWERHOUSE DESIGN GUIDELINES

DESIGN APPROPRIATE LIFESPAN:

- Design components with co-extensive lifespan
- Design lifespan of replaceable components according to scheduled duration
- Design according to 70 years multiples
- Select durable materials according to the product performance and lifespan

RELIABILITY DESIGN:

- Reduce overall number of components
- Simplify products
- Eliminate weak liaisons

FACILITATE UPGRADING AND ADAPTABILITY:

- Design modular and dynamically configured products to facilitate their adaptability for changing environments.
- Design multifunctional and dynamically configured products to facilitate their adaptability for changing cultural and physical individual backgrounds
- Design onsite upgradeable and adaptable products
- Design complementary tools and documentation for product upgrading and adaptation

FACILITATE MAINTENANCE:

- Simplify access and disassembly to components to be maintained
- Avoid narrow slits and holes to facilitate access for cleaning
- Equip the product with easily usable tools for maintenance
- Equip products with diagnostic and/or auto-diagnostic systems for maintainable components

- Design products for easy on-site maintenance
- Design complementary maintenance tools and documentation
- Design products that need less maintenance

FACILITATE REPAIRS:

- Arrange and facilitate disassembly and re-attachment of easily damageable components
- Design components according to standards to facilitate substitution of damaged parts
- Design products for facilitated onsite repair
- Design complementary repair tools, materials and documentation

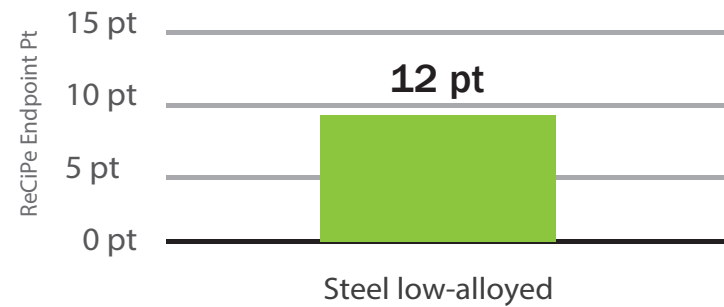
FACILITATE RE-USE:

- Increase the resistance of easily damaged and expendable components
- Avoid damaging the formworks used for concrete, in order to facilitate their reuse.
The wood formworks can be replaced with readymade metal or plastic ones.
- Arrange and facilitate access and removal of retrievable components
- Design modular and replaceable components
- Use modular readymade concrete parts for the construction of walls, tops or lids or other simple components.
- Design components according to standards to facilitate replacement
- Design re-usable auxiliary parts

FACILITATE RE-MANUFACTURE:

- Design and facilitate removal and substitution of easily expendable components
- Design structural parts that can be easily separated from external/visible ones
- Provide easier access to components to be re-manufactured
- Calculate accurate tolerance parameters for easily expendable connections
- Design for excessive use of materials in places more subject to deterioration
- Design for excessive use of material for easily deteriorating surfaces

8.2.4. INTAKE



The components that have a lifespan inferior to the lifespan of the whole Small Hydropower energy scheme, that in the pre-production, production, distribution and disposal have the highest environmental impact are:

Macro component: Sluice Gates and Grills - material: Steel Low-alloyed

PRODUCT LIFETIME OPTIMIZATION - **INTAKE**

DESIGN GUIDELINES

DESIGN APPROPRIATE LIFESPAN:

- Design components with co-extensive lifespan
- Design lifespan of replaceable components according to scheduled duration
- Design according to 70 years multiples
- Select durable materials according to the product performance and lifespan

RELIABILITY DESIGN:

- Reduce overall number of components
- Simplify products
- Eliminate weak liaisons

FACILITATE MAINTENANCE:

- Simplify access and disassembly to components to be maintained
- Simplify access to the silt basin for manually cleaning
- Design a bigger lid, made of a lighter material to allow a person entering and more light.
- Avoid narrow slits and holes to facilitate access for cleaning - all of the components of the Intake
- Equip the product with easily usable tools for maintenance
- Equip products with diagnostic and/or auto-diagnostic systems for maintainable components
- Implement sensors showing if maintenance is needed
- Trigger automatic cleaning systems for the silt basin
- Trigger automatic systems for opening the sluice gates in case of over flooding or obstruction.
- Design products for easy on-site maintenance

- Design complementary maintenance tools and documentation
- Design products that need less maintenance

FACILITATE REPAIRS:

- Arrange and facilitate disassembly and re-attachment of easily damageable components
- Design components according to standards to facilitate substitution of damaged parts
- Equip products with automatic damage diagnostics system
- Design products for facilitated onsite repair
- Design complementary repair tools, materials and documentation

FACILITATE RE-USE:

- Increase the resistance of easily damaged and expendable components
- Avoid damaging the formworks used for concrete, in order to facilitate their reuse.
The wood formworks can be replaced with readymade metal or plastic ones.
- Arrange and facilitate access and removal of retrievable components
- Design modular and replaceable components
- Use modular readymade concrete parts for the construction of walls, tops or lids or other simple components.
- Design components according to standards to facilitate replacement
- Design re-usable auxiliary parts
- Facilitate cleaning the filters of oil that are in place
- Design or choose filters made of a durable material

FACILITATE RE-MANUFACTURE:

- Design and facilitate removal and substitution of easily expendable components
- Provide easier access to components to be re-manufactured
- Calculate accurate tolerance parameters for easily expendable connections
- Design for excessive use of materials in places more subject to deterioration
- Design for excessive use of material for easily deteriorating surfaces

8.3. Minimising Toxicity (128,3 points)

How much can it can be gained in terms of environmental impact reduction, if the design of the product avoids the use of toxic or harmful processes existing already in the product?

Formula used

$EI.t[(PP + P + DT + U + DM) \text{ materials/toxic processes}]$

EI .t = Eco-Indicator of toxicity [Carcinogens + Resp. organics + Resp. inorganics + Radiations]

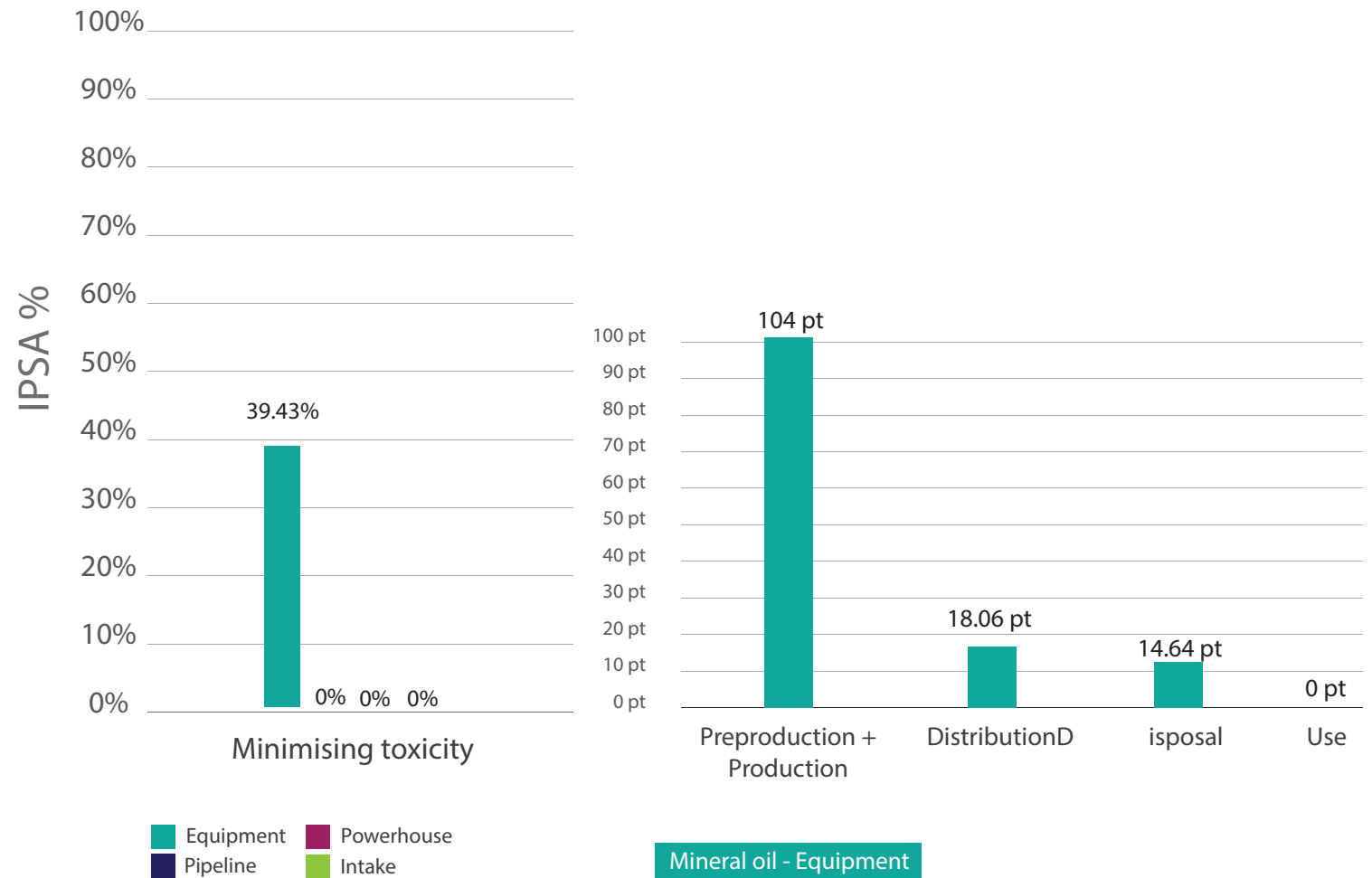
PP=pre-production; P = production; DT = distribution/transport; DM = disposal

Design to favor the use of resources (materials) that relative to the entire life cycle minimize dangerous emissions and all the processes that characterize it. However it must be remembered that toxic or harmful emissions occur during any stage of the products life cycle and might be caused by certain additives to the material rather than the material itself (therefore they are substituted or avoided).

In this section, the mineral oil was considered in the priorities calculation as a harmful material used in the cooling coils and the electric transformer part of the Equipment component. High values are going to be generated, one ton per year. The material was inventoried in SimaPro with all its life cycle phases, including also different transportation for maintenance because it needs changing every year.

Strategia	formula IPSA	IPSA	IPSA n.	Priorità	f. m. r	f. m. n
5.Minimizing Toxicity	$EI.t[(PP + P + DT + U + DM) \text{ toxic materials/processes}]$					
EQUIPMENT	104+1.62+22.7	128.32	1.00	P: ALTA		
IPSA max		128.32				

8.3.1. EQUIPMENT



MINIMIZE TOXICITY - EQUIPMENT DESIGN GUIDELINES

Many of the materials commonly used for construction are or contain toxic compounds. However those were not included in the priorities for environmental strategy (IPSA) calculations of minimizing toxicity that is why this strategy ranked in the third place. However the following guidelines include minimization of toxicity also of other materials, together with the mineral oil.

SELECT NON-TOXIC AND HARMLESS MATERIALS:

- Avoid toxic or harmful materials for product components
- Minimise the hazard of toxic and harmful materials

The mineral oil

- Measurements for safe transport need to be taken to prevent spilling, absorbing materials should be available on site for cleaning.
- Avoid materials that emit toxic or harmful substances during pre-production (cement, steel)
- Avoid additives that emit toxic or harmful substances
- Avoid technologies that process toxic and harmful materials (concrete and steel manufacturing)
- Avoid toxic or harmful surface treatments
- Design products that do not consume toxic and harmful materials
- Avoid materials that emit toxic or harmful substances during usage
- Avoid materials that emit toxic or harmful substances during disposal

SELECT NON TOXIC AND HARMLESS ENERGY RESOURCES:

- Select energy resources that reduce dangerous emissions during pre-production and production
- Select energy resources that reduce dangerous emissions during distribution
- Select energy resources that reduce dangerous emissions during usage
- Select energy resources that reduce dangerous residues and toxic and harmful waste

8.4. Optimization of Material Lifetime (Σ 218 points)

How much can it can be gained in terms of environmental impact reduction, if the design of the product achieves for all the material used the following: to recycle, compost or to incinerate in order to regain its energetic content?

Formula used

$c \times EI[PP \text{ materials to landfill}] + EI[DM \text{ materials to landfill}]$

c = maximum reduction coefficient= 0,9>0,5; $c = 0,7$: in uncertainty cases

EI = Eco-Indicator= indicator of aggregated environmental impact

PP=pre-production; P = production; DT = distribution/transport; DM = disposal

A design of adding environmental value to materials (within a product) to avoid premature disposal, by reprocessing them to obtain new prime secondary materials (by recycling or composting) or burning them to recuperate their energetic content.

There is a double advantage in the process:

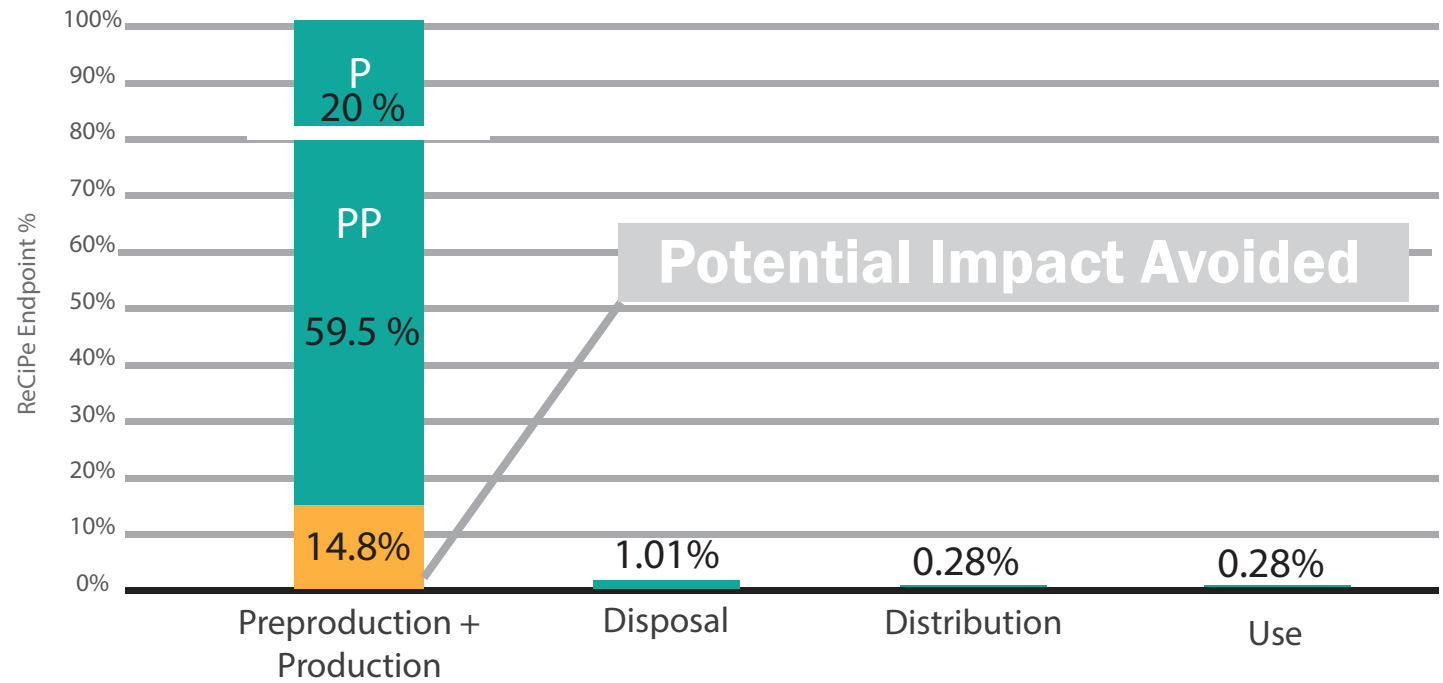
- a) The environmental impact and the cost of disposal of the materials are avoided.
- b) The production and acquisition costs connected with buying virgin materials are avoided. Naturally the processes of composting, recycling and burning also have their own environmental and economic costs. In conservatory terms we can adopt a series of measures in relation with all the phases of the process of recycling to minimize such costs: collection and transportation; identification and separation; disassembly and/or fragmentation; cleaning and/or washing; pre-production of prime secondary materials. Generally the following principle is followed: the material should be recycled as much as possible before it loses its material properties, then, at that point, the object should be incinerated to recuperate its energy content.

In the SimaPro software an average of most commonly recycled was made because recycling data was not available to this detail. The landfill percentages are as follows: Equipment (iron, steel, copper) 20%, Pipeline (glass-fiber reinforced with polyester resin) 20%, Powerhouse (concrete, reinforcing steel, steel) 57%, Intake (concrete, reinforcing steel, steel) 40%. However this percentage can vary in reality.

Because it has the highest amount of landfill and of material in general the Powerhouse has the biggest priority among the four, followed by the Pipeline the Equipment and the Intake. Again because of the high values of the eco-indicator points, the Pipeline and the Equipment over rank the Intake at the priority even though the Intake has more materials overall.

Strategia	formula IPSA	IPSA	IPSA n.	Priorità	f. m. r	f. m. n
4. Optimization of Materials Lifespan	$c \times EI[PP \text{ landfilled materials}] + EI[DM \text{ landfilled materials}]$					
INTAKE	<u>$0.7 \times 33.12 + 18.2$</u>	41.384	0.57	P: MEDIA		
4. Optimization of Materials Lifespan	$c \times EI[PP \text{ landfilled materials}] + EI[DM \text{ landfilled materials}]$					
PIPELINE	<u>$0.7 \times 110.6 - 18.7$</u>	58.72	0.81	P: MEDIA		
4. Optimization of Materials Lifespan	$c \times EI[PP \text{ landfilled materials}] + EI[DM \text{ landfilled materials}]$					
POWERHOUSE	<u>$0.7 \times 70.68 + 22.7$</u>	72.176	1.00	P: MEDIA		
4. Optimization of Materials Lifespan	$c \times EI[PP \text{ landfilled materials}] + EI[DM \text{ landfilled materials}]$					
EQUIPMENT	<u>$0.7 \times 60.8 + 4.15$</u>	46.71	0.65	P: MEDIA		
IPSA max		72.176				

8.4.1. EQUIPMENT



LIFE CYCLE PHASE - no oil	UNIT	POINTS
Preproduction (59.4%)	ReCiPe Endpoint	243.2
Preproduction (14.8%)	ReCiPe Endpoint	60.8
Production	ReCiPe Endpoint	105
Preproduction + Production	ReCiPe Endpoint	409
Disposal	ReCiPe Endpoint	4.15
Distribution	ReCiPe Endpoint	1.18
Use (lights)	ReCiPe Endpoint	1.15

EXTENDING THE LIFESPAN OF MATERIALS - EQUIPMENT DESIGN GUIDELINES

ADOPT THE CASCADE APPROACH:

- Arrange and facilitate recycling of materials in components with lower aesthetical requirements

SELECT MATERIALS WITH MOST EFFICIENT RECYCLING TECHNOLOGIES:

- Select materials that easily recover after recycling the original performance characteristics
- Avoid composite materials or, when necessary, choose easily recyclable ones
- Engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibers
- Prefer thermoplastic polymers to thermosetting
- Prefer heat-proof thermoplastic polymers to fireproof additives
- Design considering the secondary use of the materials once recycled

FACILITATE END-OF-LIFE COLLECTION AND TRANSPORTATION:

- Design in compliance with product retrieval system
- Minimise overall weight
- Minimise cluttering and improve stackability of discarded products
- Design for the compressibility of discarded products
- Provide the beneficiary with information about the disposing modalities of the product or its parts

MATERIAL IDENTIFICATION:

- Codify different materials to facilitate their identification
- Provide additional information about the material's age, number of times recycled in the past and additives used

- Indicate the existence of toxic or harmful materials. Like is the case of the mineral oil.
- Use standardized materials identification systems
- Arrange codifications in easily visible places
- Avoid codifying after component production stages

MINIMISE THE NUMBER OF DIFFERENT INCOMPATIBLE MATERIALS:

- Integrate functions to reduce the overall number of materials and components
- Adopt a strategy, in which components with the same material are grouped together and are split from other materials, in order to reduce the overall number of parts and the duration of disassembly.
- Use only one material, but processed in sandwich structures
- Use compatible materials (that could be recycled together) within the product or sub-assembly
- For joining use the same or compatible materials as in components (to be joined)

FACILITATE CLEANING:

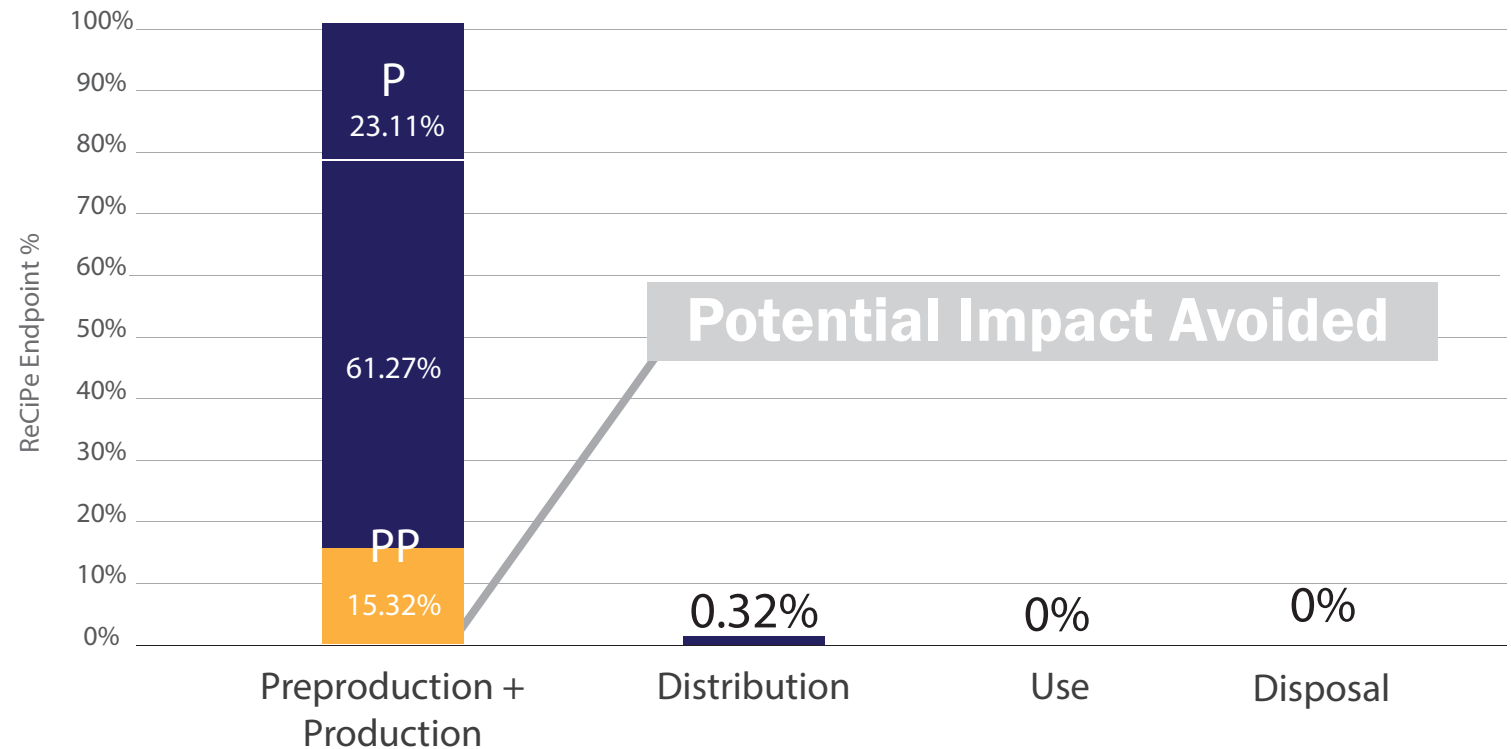
- Avoid unnecessary coating procedures
- Avoid irremovable coating materials
- If possible instead of painting the metal pieces against corrosion use oxidation-resisting steel, or electrical corrosion techniques
- Facilitate removal of coating materials
- Use coating procedures that comply with coated materials
- Avoid adhesives or choose ones that comply with materials to be recycled
- Prefer the dyeing of internal polymers, rather than surface painting
- Avoid using additional materials for marking or codification
- Mark and codify materials during molding
- Codify polymers using lasers

FACILITATE COMBUSTION:

- Avoid materials that emit dangerous substances during incineration

- For the metal parts use oxidation resisting alloys instead of coating. Zinc or tin emanates emissions during recycling processing that are barely filterable.
- Avoid additives that emit dangerous substances during incineration
- Facilitate the separation of materials that would compromise the efficiency of combustion (with low energy value). Like the metals.

8.4.2. PIPELINE



LIFE CYCLE PHASE	UNIT	POINTS
Preproduction (15.32%)	ReCiPe Endpoint	110.6
Preproduction (61.27%)	ReCiPe Endpoint	442.4
Production	ReCiPe Endpoint	169
Preproduction + Production	ReCiPe Endpoint	722
Distribution	ReCiPe Endpoint	2.34
Use	ReCiPe Endpoint	0
Disposal	ReCiPe Endpoint	0

EXTENDING THE LIFESPAN OF MATERIALS - PIPELINE DESIGN GUIDELINES

SELECT MATERIALS WITH MOST EFFICIENT RECYCLING TECHNOLOGIES:

- Select materials that easily recover after recycling the original performance characteristics
- Avoid composite materials or, when necessary, choose easily recyclable ones
- Avoid using glass-fiber reinforced polymers and reinforced concrete
- Engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibers
- Use polymer pipeline with exterior ribbing to increase the stiffness.
- Prefer thermoplastic polymers to thermosetting
- Prefer heat-proof thermoplastic polymers to fireproof additives
- Design considering the secondary use of the materials once recycled

FACILITATE END-OF-LIFE COLLECTION AND TRANSPORTATION:

- Design in compliance with product retrieval system
- Minimise overall weight
- Minimise cluttering and improve stackability of discarded products
- Design for the compressibility of discarded products
- Provide the beneficiary with information about the disposing modalities of the product or its parts

MATERIAL IDENTIFICATION:

- Codify different materials to facilitate their identification
- Provide additional information about the material's age, number of times recycled in the past and additives used
- Indicate the existence of toxic or harmful materials. Like is the case of the mineral oil.
- Use standardized materials identification systems

- Arrange codifications in easily visible places
- Avoid codifying after component production stages

MINIMISE THE NUMBER OF DIFFERENT INCOMPATIBLE MATERIALS:

- Integrate functions to reduce the overall number of materials and components
- Adopt a strategy, in which components with the same material are grouped together and are split from other materials, in order to reduce the overall number of parts and the duration of disassembly.
- Use only one material, but processed in sandwich structures
- Use compatible materials (that could be recycled together) within the product or sub-assembly
- For joining use the same or compatible materials as in components (to be joined)

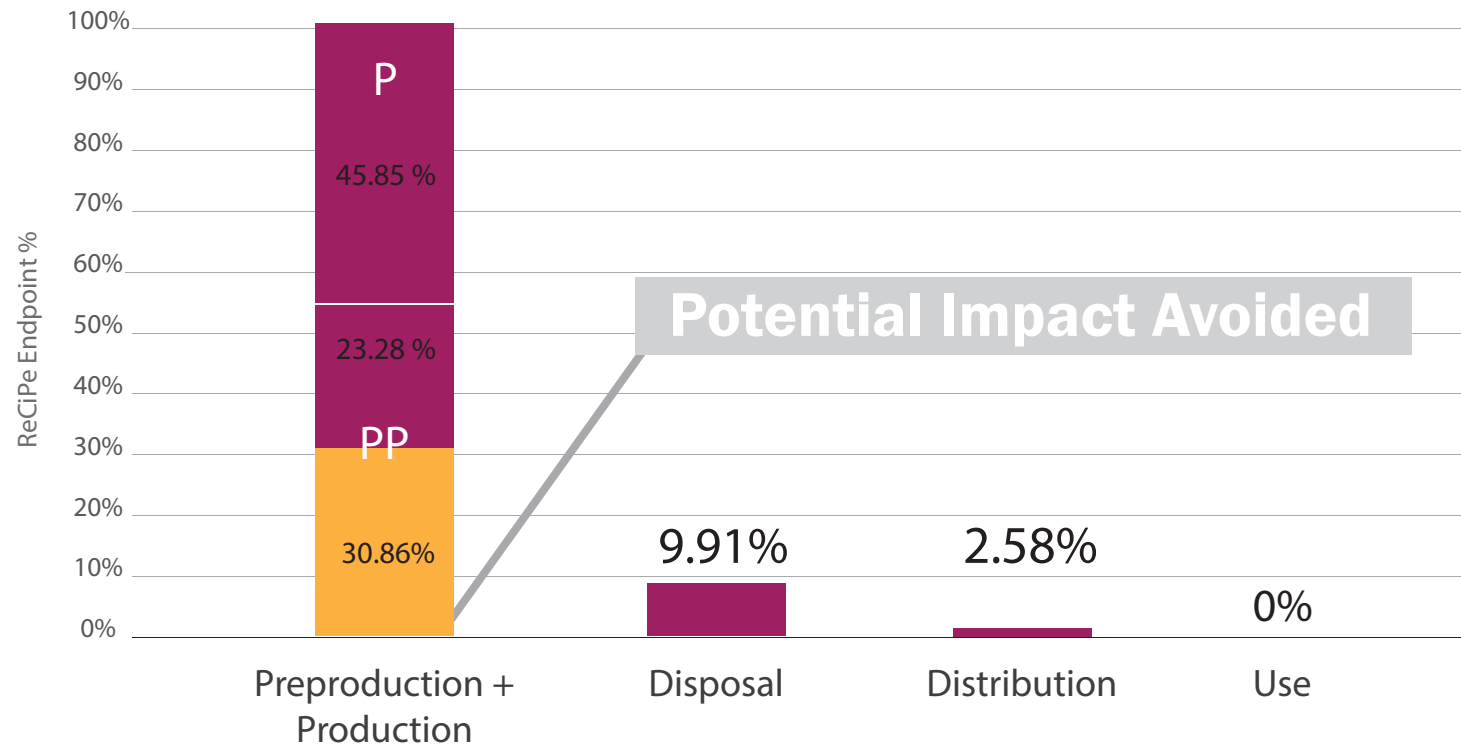
FACILITATE CLEANING:

- Avoid unnecessary coating procedures
- Avoid adhesives or choose ones that comply with materials to be recycled
- The plastic pipe should be chosen or designed to be coupling one inside the other.
- Prefer the dyeing of internal polymers, rather than surface painting
- Avoid using additional materials for marking or codification
- Mark and codify materials during molding
- Codify polymers using lasers

FACILITATE COMBUSTION:

- Select high energy materials for products that are going to be incinerated
- Avoid materials that emit dangerous substances during incineration
- Avoid additives that emit dangerous substances during incineration
- Facilitate the separation of materials that would compromise the efficiency of combustion (with low energy value). For the glass fiber inside the pipeline.

8.4.3. POWERHOUSE



LIFE CYCLE PHASE	UNIT	POINTS
Preproduction (30.86%)	ReCiPe Endpoint	70.68
Preproduction (23.38%)	ReCiPe Endpoint	53.32
Production	ReCiPe Endpoint	105
Preproduction + Production	ReCiPe Endpoint	229
Distribution	ReCiPe Endpoint	5.9
Use	ReCiPe Endpoint	0
Disposal	ReCiPe Endpoint	22.7

EXTENDING THE LIFESPAN OF MATERIALS - POWERHOUSE DESIGN GUIDELINES

ADOPT THE CASCADE APPROACH:

- Arrange and facilitate recycling of materials in components with lower aesthetical requirements

SELECT MATERIALS WITH MOST EFFICIENT RECYCLING TECHNOLOGIES:

- Select materials that easily recover after recycling the original performance characteristics
- Avoid composite materials or, when necessary, choose easily recyclable ones
- Avoid using reinforced concrete
- Prefer thermoplastic polymers to thermosetting
- Prefer heat-proof thermoplastic polymers to fireproof additives
- Design considering the secondary use of the materials once recycled

FACILITATE END-OF-LIFE COLLECTION AND TRANSPORTATION:

- Design in compliance with product retrieval system
- Minimise overall weight
- Replace steel rebar with other reinforcing non rusting materials like: Fiber glass, Carbon fiber, reinforced polymer, and bronze-aluminum bars.
- Minimise cluttering and improve stackability of discarded products
- Design for the compressibility of discarded products
- Provide the beneficiary with information about the disposing modalities of the product or its parts

MATERIAL IDENTIFICATION:

- Codify different materials to facilitate their identification
- Provide additional information about the material's age, number of times recycled in the past

- and additives used
- Indicate the existence of toxic or harmful materials. Like is the case of the mineral oil.
- Use standardized materials identification systems
- Arrange codifications in easily visible places
- Avoid codifying after component production stages

MINIMISE THE NUMBER OF DIFFERENT INCOMPATIBLE MATERIALS:

- Integrate functions to reduce the overall number of materials and components
- Use only one material, but processed in sandwich structures
- Use compatible materials (that could be recycled together) within the product or sub-assembly
- For joining use the same or compatible materials as in components (to be joined)

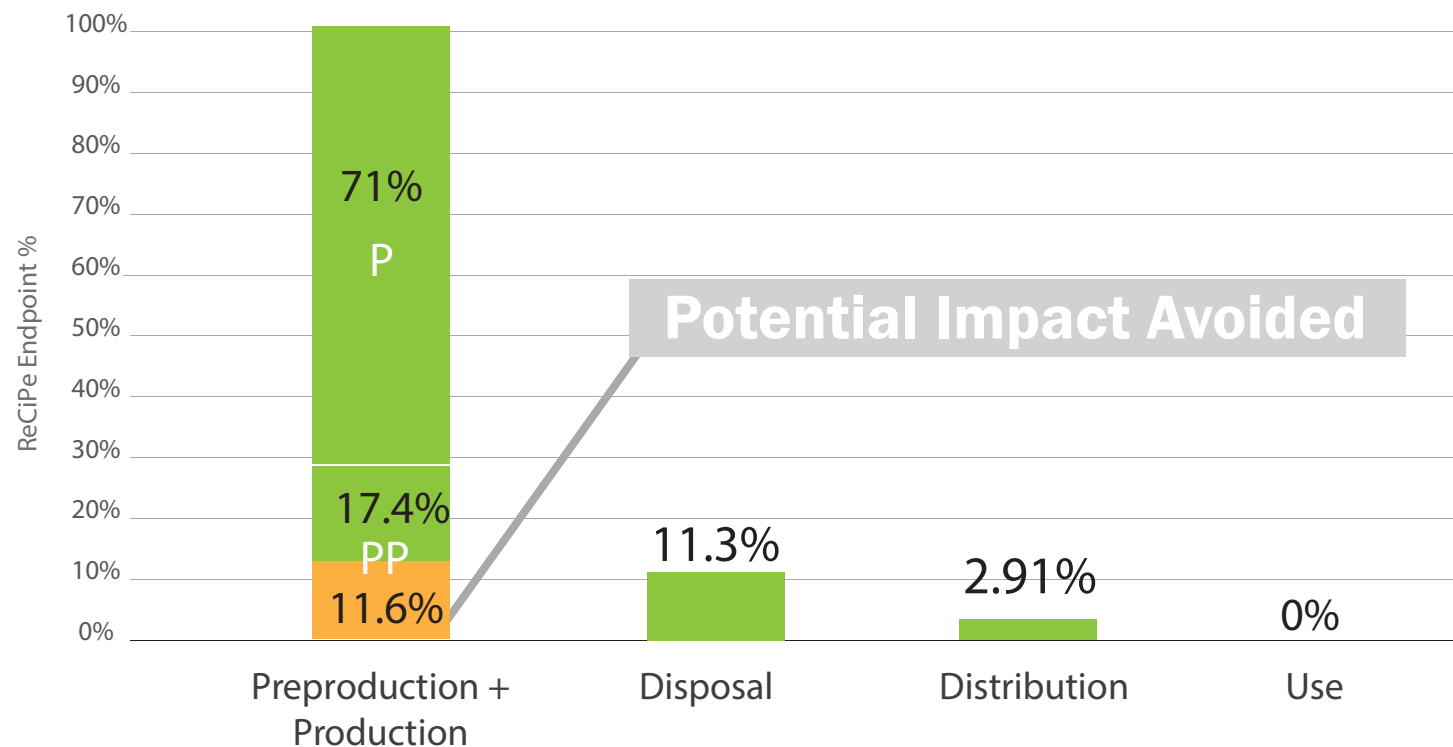
FACILITATE CLEANING:

- Avoid unnecessary coating procedures
- Avoid irremovable coating materials
- If possible instead of painting the metal pieces against corrosion use oxidation-resisting steel, or electrical corrosion techniques
- Facilitate removal of coating materials
- Use coating procedures that comply with coated materials
- Avoid adhesives or choose ones that comply with materials to be recycled
- Prefer the dyeing of internal polymers, rather than surface painting
- Avoid using additional materials for marking or codification
- Mark and codify materials during molding
- Codify polymers using lasers

FACILITATE COMBUSTION:

- Select high energy materials for products that are going to be incinerated
- Avoid materials that emit dangerous substances during incineration
- For the metal parts use oxidation resisting alloys instead of coating. Zinc or tin emanates emissions during recycling processing that are barely filterable.
- Avoid additives that emit dangerous substances during incineration
- Facilitate the separation of materials that would compromise the efficiency of combustion (with low energy value). Like concrete and ceramic materials that oppose incineration.
- To recycle the reinforcing steel from the concrete, a good cleaning will increase the efficiency during processing and re-use.

8.4.4. INTAKE



LIFE CYCLE PHASE	UNIT	POINTS
Preproduction (11.6%)	ReCiPe Endpoint	33.08
Preproduction (17.4%)	ReCiPe Endpoint	49.62
Production	ReCiPe Endpoint	78.3
Preproduction + Production	ReCiPe Endpoint	161
Distribution	ReCiPe Endpoint	4.68
Use	ReCiPe Endpoint	0
Disposal	ReCiPe Endpoint	18.2

EXTENDING THE LIFESPAN OF MATERIALS - **INTAKE**

DESIGN GUIDELINES

ADOPT THE CASCADE APPROACH:

- Arrange and facilitate recycling of materials in components with lower aesthetical requirements

SELECT MATERIALS WITH MOST EFFICIENT RECYCLING TECHNOLOGIES:

- Select materials that easily recover after recycling the original performance characteristics
- Avoid composite materials or, when necessary, choose easily recyclable ones
- Avoid using reinforced concrete
- Design considering the secondary use of the materials once recycled

FACILITATE END-OF-LIFE COLLECTION AND TRANSPORTATION:

- Design in compliance with product retrieval system
- Minimise overall weight
- Replace steel rebar with other reinforcing non rusting materials like: Fiber glass, Carbon fiber, reinforced polymer, and bronze-aluminum bars.
- Minimise cluttering and improve stackability of discarded products
- Design for the compressibility of discarded products
- Provide the beneficiary with information about the disposing modalities of the product or its parts

MATERIAL IDENTIFICATION:

- Codify different materials to facilitate their identification
- Provide additional information about the material's age, number of times recycled in the past and additives used
- Indicate the existence of toxic or harmful materials.
- Use standardized materials identification systems
- Arrange codifications in easily visible places
- Avoid codifying after component production stages

MINIMISE THE NUMBER OF DIFFERENT INCOMPATIBLE MATERIALS:

- Integrate functions to reduce the overall number of materials and components
- Use only one material, but processed in sandwich structures
- Use compatible materials (that could be recycled together) within the product or sub-assembly
- For joining use the same or compatible materials as in components (to be joined)

FACILITATE CLEANING:

- Avoid unnecessary coating procedures
- Avoid irremovable coating materials
- If possible instead of painting the metal pieces against corrosion use oxidation-resisting steel, or electrical corrosion techniques
- Facilitate removal of coating materials
- Use coating procedures that comply with coated materials
- Avoid adhesives or choose ones that comply with materials to be recycled
- Avoid using additional materials for marking or codification
- Mark and codify materials during molding

FACILITATE COMBUSTION:

- Select high energy materials for products that are going to be incinerated
- Avoid materials that emit dangerous substances during incineration
- For the metal parts use oxidation resisting alloys instead of coating. Zinc or tin emanates emissions during recycling processing that are barely filterable.
- Avoid additives that emit dangerous substances during incineration
- Facilitate the separation of materials that would compromise the efficiency of combustion (with low energy value). Like concrete and ceramic materials that oppose incineration.
- To recycle the reinforcing steel from the concrete, a good cleaning will increase the efficiency during processing and re-use.

8.5. Renewable and Bio-Compatible Resources (Σ 28,7 points)

How much can it can be gained in terms of environmental impact reduction, if the design of the product uses exclusively renewable materials and energy, also for those not present in the product at the beginning?

Formula

$EI.c[\text{consumed energy} + \text{consumed materials}]$

$EI .c = \text{Eco-Indicator conservation} [\text{Resources} = \text{Minerals} + \text{Fossil fuels}]$

For this formula the Eco-indicator points from the life cycle assessment software (SimaPro) that are generated are introduced directly in the calculation sheet.

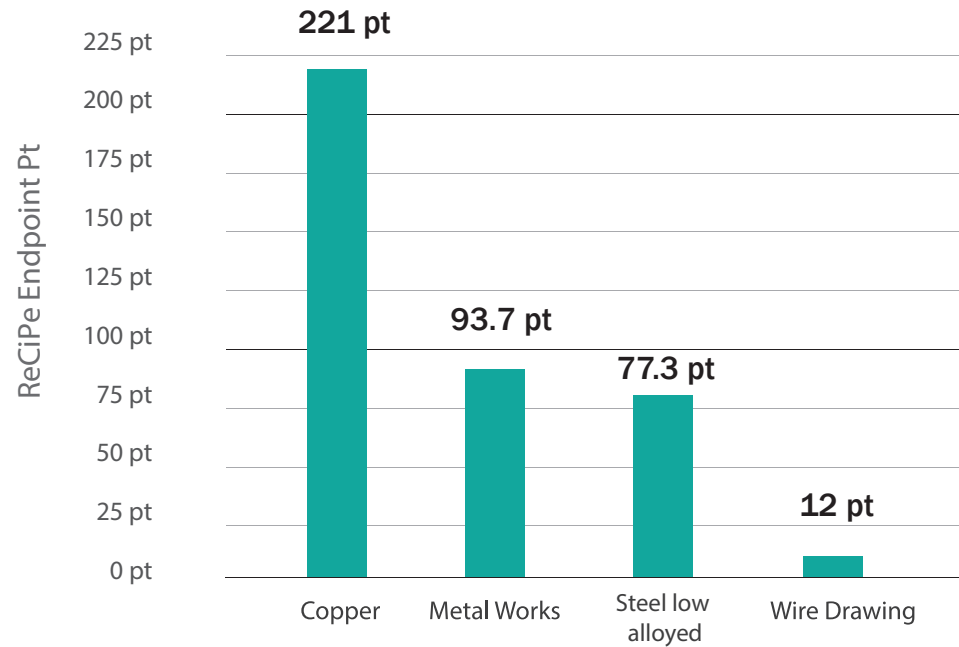
Design with the aim to save resources for future generations, preferring renewable resources, or at least non-exhaustible ones. It refers both to selection of renewable and bio-compatible materials and energy resources.

Many of the inventoried materials if not all, are not renewable, moreover some of them like copper are in short supplies. The same can be said about the pre-production of cement and steel that require huge amount of energy, which is usually generated in the traditional way using fossil fuel. A high impact is also brought by the use of carburant in large machinery during construction on site.

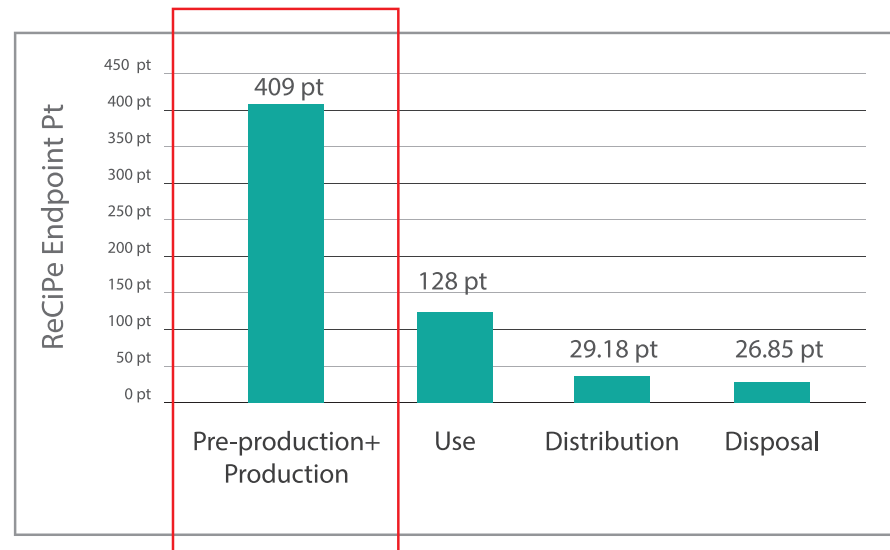
Apart from this appreciations the results tend to be characterized by the overall weight of the materials used during construction which consequently are bigger in the case of the Powerhouse (67.1 ton) and Intake (53,3 ton) compared to those of the Equipment (6,4 ton) and Pipeline (8,6 ton).

Strategia	formula IPSA	IPSA	IPSA n.	Priorità	f. m. r	f. m. n
6. Renewable and Bio-Compatible Resources	EI.c[consumed energy + consumed materials]					
INTAKE	12.9	12.9	0.91	P: ALTA		
6. Renewable and Bio-Compatible Resources	EI.c[consumed energy + consumed materials]					
PIPELINE	0.673	0.673	0.05	P: BASSA		
6. Renewable and Bio-Compatible Resources	EI.c[consumed energy + consumed materials]					
POWERHOUSE	14.2	14.2	1.00	P: ALTA		
6. Renewable and Bio-Compatible Resources	EI.c[consumed energy + consumed materials]					
EQUIPMENT	0.617+0.0159	0.6329	0.04	P: BASSA		
IPSA max		14.2				

8.5.1. EQUIPMENT



Equipment



EXTENDING THE LIFESPAN OF MATERIALS - EQUIPMENT DESIGN GUIDELINES

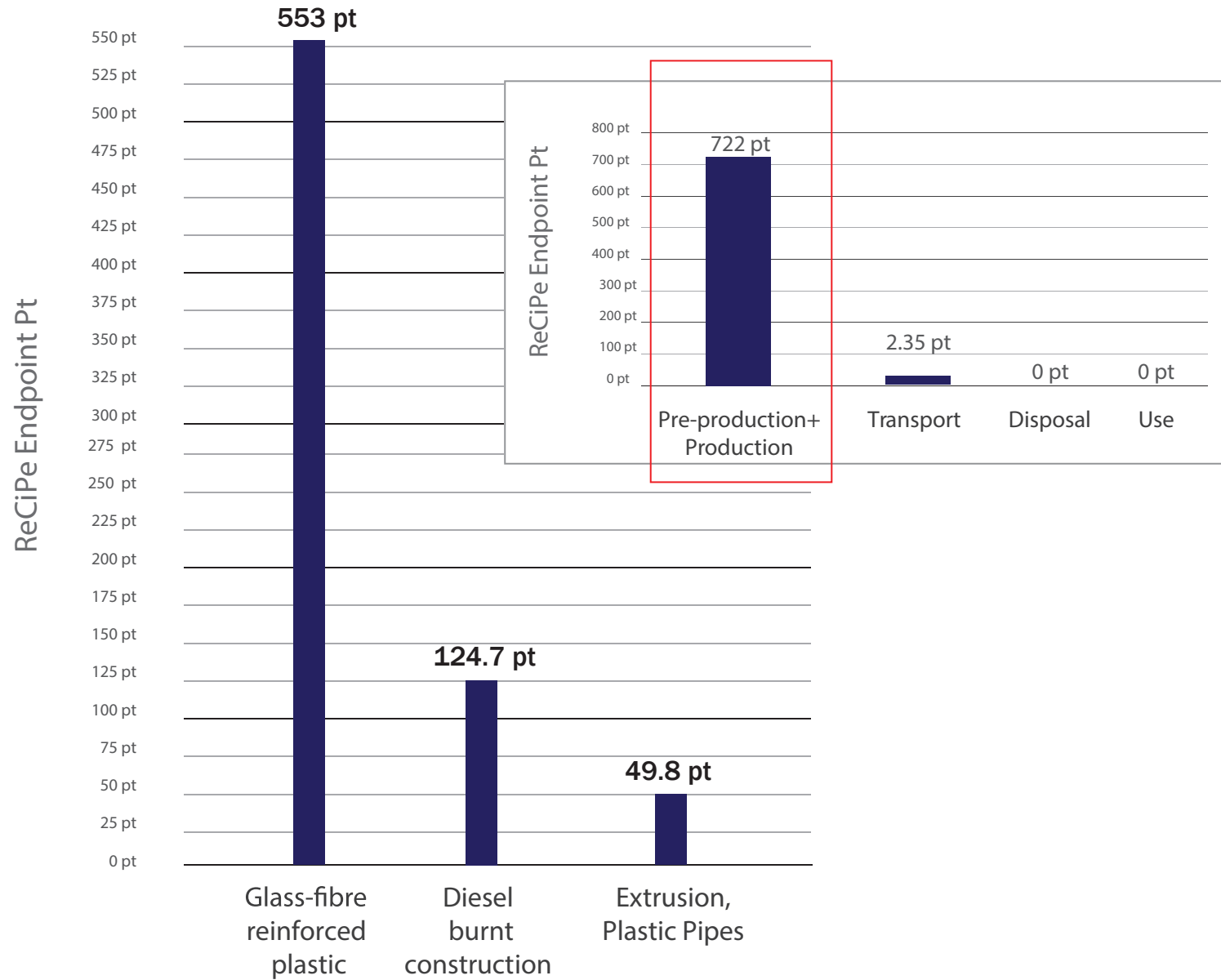
SELECT RENEWABLE AND BIO-COMPATIBLE MATERIALS:

- Avoid exhaustive materials
- Replace copper used in the cooling coils with a mixture of stainless steel and other alloys can be combined to substitute partially or entirely the copper.
- Use residual materials of production processes
- Use retrieved components from disposed products
- Use recycled materials, alone or combined with primary materials

SELECT RENEWABLE AND BIO-COMPATIBLE ENERGY RESOURCES:

- Use renewable energy resources
- Engage the cascade approach
- Select energy resources with high second-order efficiency

8.5.2. PIPELINE



EXTENDING THE LIFESPAN OF MATERIALS - PIPELINE DESIGN GUIDELINES

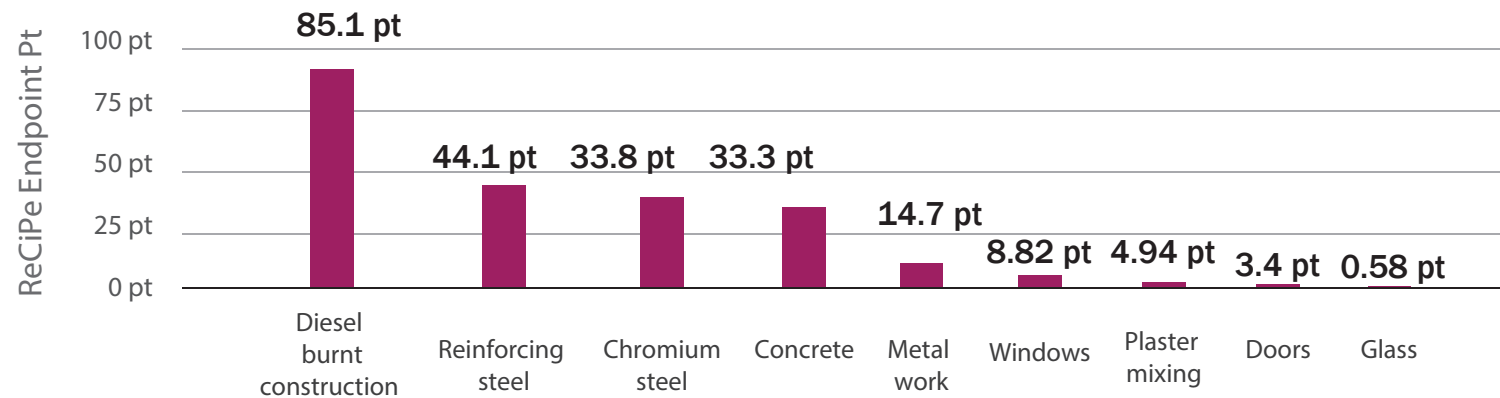
SELECT RENEWABLE AND BIO-COMPATIBLE MATERIALS:

- Avoid exhaustive materials.
- Use residual materials of production processes
- Use retrieved components from disposed products
- Use recycled materials, alone or combined with primary materials

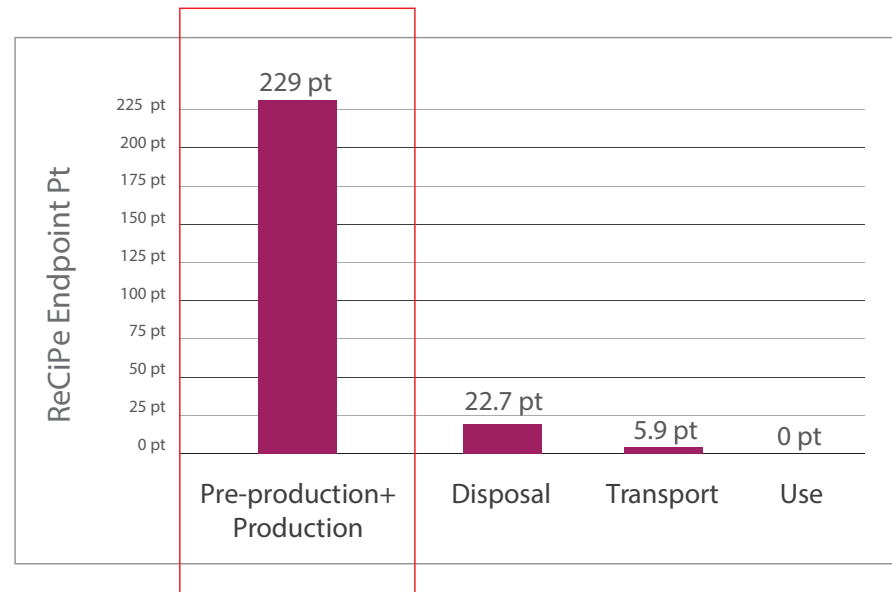
SELECT RENEWABLE AND BIO-COMPATIBLE ENERGY RESOURCES:

- Use renewable energy resources
- Biofuel can replace the classic fuel for the construction machinery (construction phase)
- Engage the cascade approach
- Select energy resources with high second-order efficiency

8.5.3. POWERHOUSE



Powerhouse



EXTENDING THE LIFESPAN OF MATERIALS - POWERHOUSE

DESIGN GUIDELINES

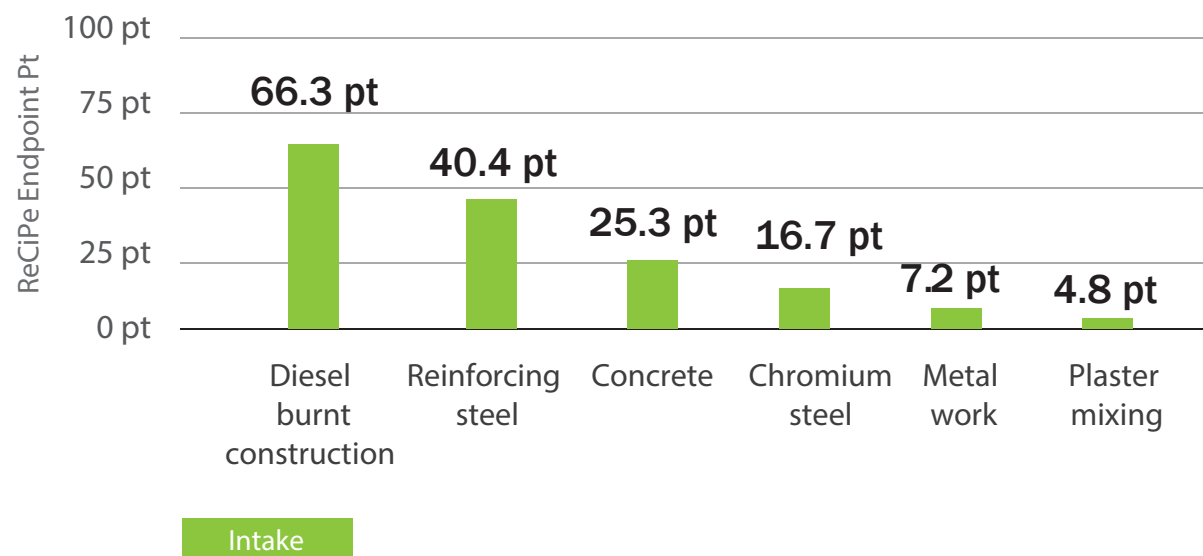
SELECT RENEWABLE AND BIO-COMPATIBLE MATERIALS:

- Use renewable materials
- Research substitutes for cement, like “green” cement
- Design lattice beams made of wood instead of metal for ceiling support and roof windows.
- Eco friendly materials of construction such as wood, clay or eco bricks combined with a strong structural design, can substitute the concrete used for the powerhouse construction
- Avoid exhaustive materials
- Use residual materials of production processes
- Select cement suppliers that use residual materials for processing. Selected waste and by-products with recoverable calorific value can be used as fuels, replacing a portion of conventional fossil fuels, like coal, if they meet strict specifications.
- Square haystacks and clay can provide a very good sound and temperature insulation and can also be used to construct walls.
- Use retrieved components from disposed products
- Choose cement containing fly ash from coal thermic energy generation processes. Because fly ash addition allows a lower concrete water content, early strength can also be maintained.
- Use recycled materials, alone or combined with primary materials
- Select cement suppliers that use waste and by-products in cement generation. (calcium, silica, alumina, and iron can be used as raw materials in the cement kiln, replacing raw materials such as clay, shale, and limestone.
- Use bio-degradable materials
- Research and use traditional building materials that are bio-degradable.

SELECT RENEWABLE AND BIO-COMPATIBLE ENERGY RESOURCES:

- Use renewable energy resources
- Biofuel can replace the classic fuel for the construction machinery
- Engage the cascade approach
- Select energy resources with high second-order efficiency

8.5.4. INTAKE



EXTENDING THE LIFESPAN OF MATERIALS - INTAKE

DESIGN GUIDELINES

SELECT RENEWABLE AND BIO-COMPATIBLE MATERIALS:

- Use renewable materials
- Research substitutes for cement, like “green” cement
- Avoid exhaustive materials
- Use residual materials of production processes
- Select cement suppliers that use residual materials for processing. Selected waste and by-products with recoverable calorific value can be used as fuels, replacing a portion of conventional fossil fuels, like coal, if they meet strict specifications.
- Use retrieved components from disposed products
- Choose cement containing fly ash from coal thermic energy generation processes. Because fly ash addition allows a lower concrete water content, early strength can also be maintained.
- Use recycled materials, alone or combined with primary materials
- Select cement suppliers that use waste and by-products in cement generation. (calcium, silica, alumina, and iron can be used as raw materials in the cement kiln, replacing raw materials such as clay, shale, and limestone.
- Use bio-degradable materials

SELECT RENEWABLE AND BIO-COMPATIBLE ENERGY RESOURCES:

- Use renewable energy resources
- Biofuel can replace the classic fuel for the construction machinery (construction phase)
- Engage the cascade approach
- Select energy resources with high second-order efficiency

8.6. Minimising Energy Consumption

How much can it can be gained in terms of environmental impact reduction, if the design of the product uses infinitely less energy during use phase, compared to the existing product?

Formula

$c \times EI[\text{consumed energy}]$

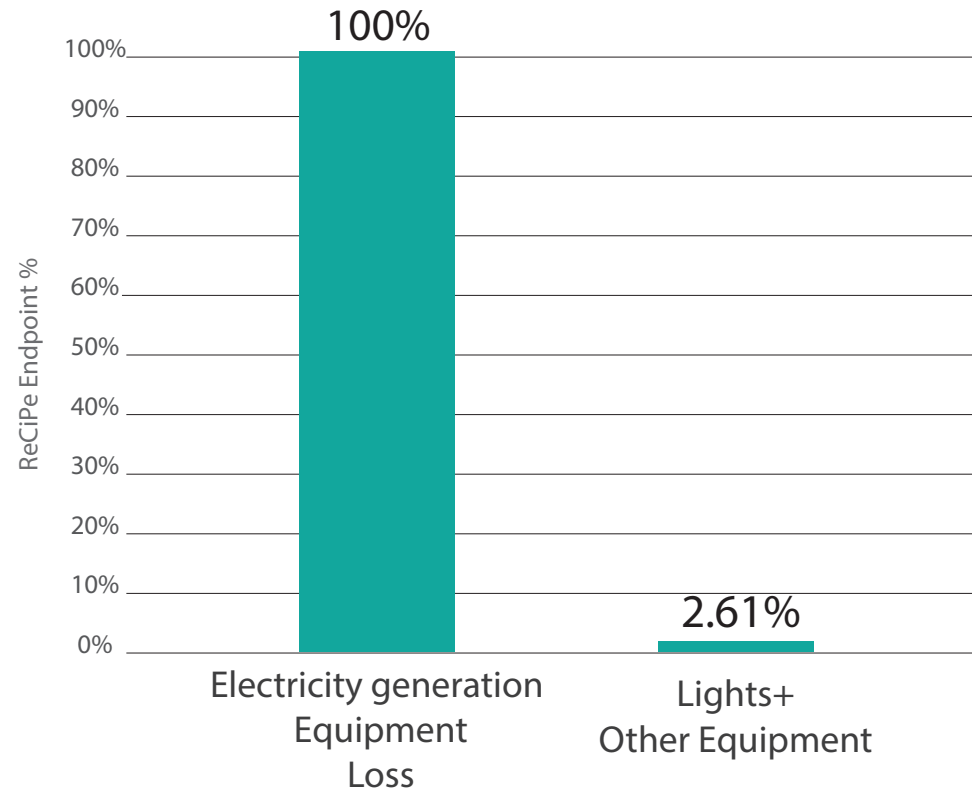
c = maximum reduction coefficient= 0,9>0,5; c = 0,7: in uncertainty cases

EI = Eco-Indicator= indicator of aggregated environmental impact

For this calculation the eco-indicator points of the energy used during the lifetime of the station were used and not the turbine loss that adds up to 10% of the total energy created, this is essentially the energy used in order to generate energy. Instead the lighting system and other automatization devices were taken into account. With a total of 1.035 eco-indicator points, minimizing energy is in last place for priority of environmental impact reduction. This value was considered under Equipment in the overall result for each component.

Strategia	formula IPSA	IPSA	IPSA n.	Priorità	f. m. r	f. m. n
3.Minimizing Energy Consumption	$c \times EI[\text{consumed energy}]$					
Equipment	<u>0.9*1.15</u>	1.035	1.00	P: ALTA		
IPSA max		1.035				

8.6.1. EQUIPMENT



LIFE CYCLE PHASE	UNIT	POINTS
Power Generation Equipment Loss	ReCiPe Endpoint	44.1
Lights + Other Equipment	ReCiPe Endpoint	1.15

MINIMIZE ENERGY CONSUMPTION - EQUIPMENT DESIGN GUIDELINES

The energy that the SHPS uses for electricity generation is considered under turbine loss, however the Pelton turbine has a high efficiency rate around 90% at optimal flow. In the calculation of the functional unit, which is the total amount of energy generated by the station in 70 years (its lifespan), an efficiency of 90% was used, so basically excluding the turbine loss. The size of the turbine and the number of buckets is customized according to the available flow and drop specification for the proper functioning of the station. Maximizing this parameters, if the site allows it, will result in lower environmental impact because the same station generates more energy. So this should always be the first consideration in projecting a small power station.

However the aim is to generate guidelines to reduce the overall environmental impact resulted from SHPS for this amount of energy produced. Hence to produce the same energy with a lower environmental impact.

As such, in the minimizing the energy consumption priority, only the adjacent energy used was considered: the interior and exterior lights, the control equipment and outside engines (of the two sluice gates).

However the next guidelines will refer to the all life cycle system of this station.

MINIMISE ENERGY CONSUMPTION DURING PRE-PRODUCTION AND PRODUCTION:

In the Pre-production and production we understand all the exploitation and processing that the raw materials undergo before becoming suitable for construction and the construction and assembly manufacturing phases. In this inventory a particular emphasis was put on the construction on site duration, because detailed data was available.

- Select materials with low energy intensity
- Research replacement for cement and steel parts that can be constructed using less energy intensive materials.
- Select processing technologies with the lowest energy consumption possible
- Engage efficient machinery
- Choose suppliers for readymade concrete components that are using new and efficient manufacturing technologies

- New or well-maintained machinery should be used to reduce as much as possible the fuel emissions in the environment, during construction on site.
- Engage pump and motor speed regulators with dynamic configuration
- Equip the machinery with intelligent power-off utilities
- Optimise the overall dimensions of the engines
- Facilitate engine maintenance
- Define accurately the tolerance parameters
- Optimise transportation systems and scale down the weight and dimensions of all transportable materials and semi-products
- Engage efficient general heating, illumination and ventilation in buildings

MINIMISE ENERGY CONSUMPTION DURING TRANSPORTATION AND STORAGE:

- Equip products with onsite assembly
- Scale down the packaging weight
- Decentralise activities to reduce transportation volumes
- Select local material and energy sources

SELECT SYSTEMS WITH ENERGY-EFFICIENT OPERATION STAGE:

- Design for energy-efficient operational stages
- A fine tuning and a proficient design of the turbine's nozzles can, together with a proficient monitoring system, decrease the power lost during generation providing more efficiency.
- Design for energy-efficient maintenance
- Design systems for consumption of passive energy sources
- Design the partially underground powerhouse with roof windows structure that can substitute the side windows.
- Engage highly efficient energy conversion systems
- Choose efficient lamp type according to the specific need.
- Design/engage highly efficient engines/generators
- Design/engage highly efficient power transmission
- Use highly caulked materials and technical components

- Design for localized energy supply
- Measure the vicinity to villages or small manufacturing workshops, which would require energy, before choosing the station's location
- Scale down the weight of transportable goods
- Design energy-saving systems

ENGAGE DYNAMIC CONSUMPTION OF ENERGY:

- Engage digital dynamic support systems
- Design dynamic energy consumption systems for differentiated operational stages
- Engage sensors to adjust consumption during differentiated operational stages
- Use sensor of presence or light intensity that can save energy during the changing seasons.
- Equip machinery with intelligent power-off utilities for safety
- Program product's default state at minimal energy consumption

MINIMISE ENERGY CONSUMPTION DURING PRODUCT DEVELOPMENT:

- Engage efficient workplace heating, illumination and ventilation
- Engage digital tools for communicating with remote working sites

8.7. Design for Disassembly, design with the purpose of separating the parts of materials.

Design for Disassembly does not have a priority assigned nor does it have a formula. However some of the guidelines can be found as part of Product and components lifetime extension and to Material lifetime extension priority calculations.

Design for disassembly is an individual guideline not only because it's practical for many of the strategies of environmental impact but also because here the designer can play a substantial role.

Design for Disassembly is a strategy aimed at creating easily disassembled components, this will simplify products maintenance, repair, updating and re-manufacturing. Facilitate materials separation is positive both for their recycle (if they were incompatible) and for their special treatment (if they were toxic or harmful).

Because not much data was available to create the life cycle model, a best case scenario was used for the disposal and end of life treatments priority calculation for the Renewable and Bio-Compatible Resources. This can complicate the generation of disassembly guidelines. Many parts of the station that are made out of reinforced concrete are not disassembled, because their tearing down are additional costs that might not be justified by the return value recycling.

Moreover, the end of life treatment of reinforced concrete is somewhat different from the configuration of disassembling structures. Consequently this is made on site and the resulting waste is carried to landfill sites or recycling companies (for the recyclable steel). After 70 years the rebar reinforcement would be in an aggravated state of rusting causing it to shatter in small pieces.

In the case of this SHPS, the concrete parts already have the durability as long as their lifespan. But if a strategy to prolong the overall lifespan of the power station is adopted, using fiber glass, carbon fiber, reinforced polymer or bronze-aluminum as reinforcement then the lifespan can increase.

DESIGN FOR DISASSEMBLY - ALL DESIGN GUIDELINES

REDUCE AND FACILITATE OPERATIONS OF DISASSEMBLY AND SEPARATION:
OVERALL ARCHITECTURE:

- Prioritize the disassembly of toxic and dangerous components or materials. Start with the turbine and the electromechanical equipment, electric transformer, engine, sensors of the turbine, sluices gates, silt basin, the pipeline and then the concrete
- Prioritize the disassembly of components or materials with higher economic value. Start with the turbine and the electromechanical equipment, electric transformer, engine, sensors of the turbine, sluices gates, silt basin, the pipeline and then the concrete
- Prioritize the disassembly of more easily damageable components
- Engage modular structures
- If readymade concrete parts are in place, design those to be easily assembled/ disassembled and provide an assembly scheme to be put on site.
- Divide the product into easily separable and manipulable sub-assemblies
- The casing of the turbine should be separate from the wheel with buckets.
- Minimise overall dimensions of the product
- Minimise hierarchically dependent connections between components
- Provide an oposite scheme of disassembly.
- Minimise different directions in the disassembly route of components and materials
- Choose a readymade concrete provider that has a disassembly route.
- Choose disassembly processors that can process electric components and metal pieces.
- Increase the linearity of the disassembly route
- Engage a sandwich system of disassembly with central joining elements.
- The turbine, and the powerhouse building should be easily disassembled with a crane.

SHAPE OF COMPONENTS AND PARTS:

- Avoid difficult-to-handle components
- Avoid asymmetrical components, unless required
- Design leaning surfaces and grabbing features in compliance with standards
- For the readymade components: to be designed with anchoring features that are easily attachable to the crane cables
- Arrange leaning surfaces around the product's center of gravity
- Design for easy centering on the component base

SHAPE AND ACCESSIBILITY OF JOINTS:

- Avoid joining systems that require simultaneous interventions for opening
- Minimise the overall number of fasteners
- Minimise the overall number of different fastener types (that demand different tools)
- Achievable by modular readymade components for the concrete parts.
- Avoid difficult-to-handle fasteners
- Design accessible and recognizable entrances for dismantling
- A marking arrow system should be used.
- Design accessible and controllable dismantling points

ENGAGE REVERSIBLE JOINING SYSTEMS

- Employ two-way snap-fit for the electrical components.
- Employ joints that are opened with common tools
- Employ joints that are opened with special tools, when opening could be dangerous
- Design joints made of materials that become reversible only in determined conditions?
- Use screws with hexagonal heads
- Prefer removable nuts and clips to self-tapping screws
- Use screws made of materials compatible with joint components, to avoid their separation before recycling

ENGAGE EASILY COLLAPSIBLE PERMANENT JOINING SYSTEMS:

- Avoid rivets on incompatible materials
- Avoid additional materials while welding
- Use successive coupling for plastic pipes.
- Avoid gluing with adhesives

CO-DESIGN SPECIAL TECHNOLOGIES AND FEATURES FOR CRUSHING SEPARATION:

- Co-design cutting or breaking paths with appropriate separation technologies for incompatible materials separation
- Employ joining elements that allow their chemical or physical destruction
- Make the breaking points easily accessible and recognizable
- Provide the products with information for the beneficiary about the characteristics of crushing separation

Use materials that are easily separable after being crushed.

Use additional parts that are easily separable after crushing of materials.

ECO-EFFICIENT DESIGN OF

6

part 6: checklist

CHECKLIST

Minimize Materials Consumption

Intake

	YES	PARTLY	NO	NOT APPLICABLE
Did you dematerialise the product or some of its components?	☐	☐	☐	☐
Did you research and use up to date standards for structural design dimensions?	☐	☐	☐	☐
Did you research for new and more performing materials available to reduce the overall amount of materials?	☐	☐	☐	☐
Did you use appropriate software to understand, test and make simulations for new resistance specifications and materials?	☐	☐	☐	☐
Did you reduce thickness of the walls of construction?	☐	☐	☐	☐
Did you use performant ready made parts with required configuration for the concrete components to reduce thickness of the walls of the construction?	☐	☐	☐	☐
Did you use a wider range of concretes for the intake (the parts in direct contact to the water can be denser and more resistant to freezing and the ones buried can be less)?	☐	☐	☐	☐
Did you change the steel rebar with a lighter more efficient reinforcement like: using fiber glass, carbon fiber, reinforced polymer or bronze-aluminum?	☐	☐	☐	☐
Did you change the quality of the concrete by adding more cement in order to reduce the need of thicker walls?	☐	☐	☐	☐
Did you apply ribbed to the structure to increase structural stiffness of the intake walls?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you select processes that reduce scraps and discarded materials during production ?	☐	☐	☐	☐
Did you use efficient molds for readymade concrete products to reduce the scraps and discarded materials during the production?	☐	☐	☐	☐
Did you engaged simulation systems to optimize transformation processes?	☐	☐	☐	☐
Did you use vibration pumps can be used on site to optimize the density of concrete?	☐	☐	☐	☐
Did you redesign for more efficient supply of raw materials?	☐	☐	☐	☐
Did you use/acquire the necessary aggregates for concrete on site or closer from the construction site?	☐	☐	☐	☐
Did you design for more efficient use of maintenance materials ?	☐	☐	☐	☐
Did you choose long lasting tools (shovel, brooms or other) for maintenance materials, for the silt basin?	☐	☐	☐	☐
Did you design systems for consumption of passive materials?	☐	☐	☐	☐
Did you design a system that uses the water of the rain or the river to clean the exterior surfaces?	☐	☐	☐	☐
Did you design side gates at the bottom of the silt basin that allows water from the river to clean the silt from the basin?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design for cascading recycling systems?	☐	☐	☐	☐
Did you facilitate the person managing maintenance to reduce materials consumption ?	☐	☐	☐	☐
Did you minimise the consumption of stationery goods and their packages?	☐	☐	☐	☐
Did you engage digital tools in designing, modelling and prototype creation?	☐	☐	☐	☐
Did you engage digital tools for documentation, communication and presentation?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Minimize Materials Consumption

Pipeline

YES PARTLY NO NOT APPLICABLE

Did you avoid over-sized dimensions ?

☐
☐
☐
☐

Did you reduce thickness of the walls of construction?

☐
☐
☐
☐

Did you reduce thickness of the walls of construction?

☐
☐
☐
☐

Did you apply ribbed to the structure to increase structural stiffness of the pipeline walls?

☐
☐
☐
☐

Did you select processes that reduce scraps and discarded materials during production ?

☐
☐
☐
☐

Did you use efficient molds for readymade plastic products to reduce the scraps and discarded materials during the production?

☐
☐
☐
☐

Did you engaged simulation systems to optimize transformation processes?

☐
☐
☐
☐

Did you minimise the consumption of stationery goods and their packages?

☐
☐
☐
☐

Did you engage digital tools in designing, modelling and prototype creation?

☐
☐
☐
☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you engage digital tools for documentation, communication and presentation?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Minimize Materials Consumption

Powerhouse

YES PARTLY NO NOT APPLICABLE

Did you dematerialise the product or some of its components?

☐
☐
☐
☐

Did you build the Powerhouse partially buried underground or constructed close to a stone wall ?

☐
☐
☐
☐

Did you use on site ground to provide soundproofing by partially covering the house?

☐
☐
☐
☐

Did you digitalise the product or some of its components ?

☐
☐
☐
☐

Did you use a remote control system for the station in order to avoid the need of a separate control room. Did you design all the component in one room?

☐
☐
☐
☐

Did you avoid over-sized dimensions ?

☐
☐
☐
☐

Did you start the design of the machine room from the size of the turbine that is going to be used for the specific flow.?

☐
☐
☐
☐

Did you research and use up to date standards for structural design dimensions?

☐
☐
☐
☐

Did you research for new and more performing materials available to reduce the overall amount of materials?

☐
☐
☐
☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use appropriate software to understand, test and make simulations for new resistance specifications and materials?	☐	☐	☐	☐
Did you reduce thickness of the walls of construction?	☐	☐	☐	☐
Did you use performant ready made parts with required configuration for the concrete components to reduce thickness of the walls of the construction?	☐	☐	☐	☐
Did you use a wider range of concretes (the parts in direct contact to the water can be denser and more resistant to freezing and the ones buried can be less)?	☐	☐	☐	☐
Did you change the steel rebar with a lighter more efficient reinforcement like: using fiber glass, carbon fiber, reinforced polymer or bronze-aluminum?	☐	☐	☐	☐
Did you change the quality of the concrete by adding more cement in order to reduce the need of thicker walls?	☐	☐	☐	☐
Did you apply ribbed to the structure to increase structural stiffness of the intake walls?	☐	☐	☐	☐
Did you select processes that reduce scraps and discarded materials during production ?	☐	☐	☐	☐
Did you use efficient molds for readymade concrete products to reduce the scraps and discarded materials during the production?	☐	☐	☐	☐
Did you engaged simulation systems to optimize transformation processes?	☐	☐	☐	☐
Did you use vibration pumps can be used on site to optimize the density of concrete?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use/acquire the necessary aggregates for concrete on site or closer from the construction site?	☐	☐	☐	☐
Did you design for more efficient use of maintenance materials ?	☐	☐	☐	☐
Did you choose long lasting tools (shovel, brooms or other) for maintenance materials, for the silt basin?	☐	☐	☐	☐
Did you design systems for consumption of passive materials?	☐	☐	☐	☐
Did you design a system that uses the water of the rain or the river to clean the exterior surfaces?	☐	☐	☐	☐
Did you design for cascading recycling systems?	☐	☐	☐	☐
Did you facilitate the person managing maintenance to reduce materials consumption ?	☐	☐	☐	☐
Did you minimise the consumption of stationery goods and their packages?	☐	☐	☐	☐
Did you engage digital tools in designing, modelling and prototype creation?	☐	☐	☐	☐
Did you engage digital tools for documentation, communication and presentation?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐

Minimize Materials Consumption

Electromechanic Equipment

	YES	PARTLY	NO	NOT APPLICABLE
Did you dematerialise the product or some of its components?	☐	☐	☐	☐
Did you research and use up to date standards for structural design dimensions?	☐	☐	☐	☐
Did you research for new and more performing materials available to reduce the overall amount of materials?	☐	☐	☐	☐
Did you use appropriate software to understand, test and make simulations for new resistance specifications and materials?	☐	☐	☐	☐
Did you reduce thickness of the walls of parts?	☐	☐	☐	☐
Did you apply ribbed to the structure to increase structural stiffness of the intake walls?	☐	☐	☐	☐
Did you select processes that reduce scraps and discarded materials during production ?	☐	☐	☐	☐
Did you use efficient molds for readymade parts to reduce the scraps and discarded materials during the production?	☐	☐	☐	☐
Did you engaged simulation systems to optimize transformation processes?	☐	☐	☐	☐
Did you design for more efficient consumption of operational materials ?	☐	☐	☐	☐
Did you consider optimizing the shape of the cooling installation ?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use a type of oil with higher lifespan ?	☐	☐	☐	☐
Did you redesign for more efficient supply of raw materials?	☐	☐	☐	☐
Did you design for more efficient use of maintenance materials ?	☐	☐	☐	☐
Did you design for cascading recycling systems?	☐	☐	☐	☐
Did you facilitate the person managing maintenance to reduce materials consumption ?	☐	☐	☐	☐
Did you engage digital support systems with dynamic configuration ?	☐	☐	☐	☐
Did you engage a remote system for adjusting the oil consumption ?	☐	☐	☐	☐
Did you design a reserve tank in addition to the cooling installation, that refills the lost oil ?	☐	☐	☐	☐
Did you engage sensors to adjust materials consumption according to differentiated operational stages?	☐	☐	☐	☐
Did you use an adjusting system to optimize the use of oil during periods of high energy generation?	☐	☐	☐	☐
Did you minimise the consumption of stationery goods and their packages?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you engage digital tools in designing, modelling and prototype creation?	☐	☐	☐	☐
Did you engage digital tools for documentation, communication and presentation?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Optimization of Product Lifetime

Intake

	YES	PARTLY	NO	NOT APPLICABLE
Did you design components with co-extensive lifespan?	☐	☐	☐	☐
Did you select durable materials according to the product performance and lifespan ?	☐	☐	☐	☐
Did you eliminate weak liaisons?	☐	☐	☐	☐
Did you simplify access and disassembly to components to be maintained (silt basin)?	☐	☐	☐	☐
Did you simplify access to the silt basin for manually cleaning?	☐	☐	☐	☐
Did you design a bigger lid, made of a lighter material to allow a person entering and more light ?	☐	☐	☐	☐
Did you avoid narrow slits and holes to facilitate access for cleaning - all of the components of the Intake ?	☐	☐	☐	☐
Did you equip the product with easily usable tools for maintenance?	☐	☐	☐	☐
Did you research for new and more performing materials available to reduce the overall amount of materials?	☐	☐	☐	☐
Did you equip products with diagnostic and/or auto-diagnostic systems for maintainable components?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you implement sensors showing if the silt basin needs maintenance ?	☐	☐	☐	☐
Did you trigger automatic cleaning systems for the silt basin?	☐	☐	☐	☐
Did you trigger automatic systems for opening the sluice gates in case of over flooding or obstruction?	☐	☐	☐	☐
Did you design products for easy on-site maintenance?	☐	☐	☐	☐
Did you design complementary maintenance tools and documentation?	☐	☐	☐	☐
Did you design products that need less maintenance?	☐	☐	☐	☐
Did you arrange and facilitate disassembly and re-attachment of easily damageable components?	☐	☐	☐	☐
Did you equip products with automatic damage diagnostics system ?	☐	☐	☐	☐
Did you design products for facilitated onsite repair?	☐	☐	☐	☐
Did you design complementary repair tools, materials and documentation?	☐	☐	☐	☐
Did you increase the resistance of easily damaged and expendable components?	☐	☐	☐	☐
Did you avoid damaging the formworks used for concrete, in order to facilitate their reuse. Or did you replaced the wood formworks with readymade metal or plastic ones?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you arrange and facilitate access and removal of retrievable components ?	☐	☐	☐	☐
Did you design modular and replaceable components?	☐	☐	☐	☐
Did you use modular readymade concrete parts for the construction of walls, tops or lids or other simple components.?	☐	☐	☐	☐
Did you design components according to standards to facilitate replacement?	☐	☐	☐	☐
Did you design re-usable auxiliary parts?	☐	☐	☐	☐
Did you design and facilitate removal and substitution of easily expendable components like the filtering nets?	☐	☐	☐	☐
Did you design for excessive use of material for easily deteriorating surfaces ?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Optimization of Product Lifetime

Pipeline

	YES	PARTLY	NO	NOT APPLICABLE
Did you design components with co-extensive lifespan?	☐	☐	☐	☐
Did you extend the lifespan of the pipeline from 50 to 70 years by installing a diagnostic system that points damaged or vulnerable parts ?	☐	☐	☐	☐
Did you select durable materials according to the product performance and lifespan ?	☐	☐	☐	☐
Did you eliminate weak liaisons?	☐	☐	☐	☐
Did you simplify access and disassembly to components to be maintained ?	☐	☐	☐	☐
Did you equip the product with easily usable tools for maintenance?	☐	☐	☐	☐
Did you research for new and more performing materials available to reduce the overall amount of materials?	☐	☐	☐	☐
Did you equip products with diagnostic and/or auto-diagnostic systems for maintainable components?	☐	☐	☐	☐
Did you install sensors for pressure, temperature and eventual deposits can be placed inside the pipeline to signal if there are any hydraulic leaks that can create slits and cracks during freezing seasons?	☐	☐	☐	☐
Did you design complementary maintenance tools and documentation?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design products that need less maintenance?	☐	☐	☐	☐
Did you equip products with automatic damage diagnostics system ?	☐	☐	☐	☐
Did you design products for facilitated onsite repair?	☐	☐	☐	☐
Did you make local excavations to fix the cracks of the pipeline, using the diagnostic system?	☐	☐	☐	☐
Did you use a bandage system, or a collar like module can be fixed in place of the damaged one after cutting the cracked part?	☐	☐	☐	☐
Did you design complementary repair tools, materials and documentation?	☐	☐	☐	☐
Did you arrange and facilitate access and removal of retrievable components ?	☐	☐	☐	☐
Did you design modular and replaceable components?	☐	☐	☐	☐
Did you design components according to standards to facilitate replacement?	☐	☐	☐	☐
Did you design re-usable auxiliary parts?	☐	☐	☐	☐
Did you design and facilitate removal and substitution of easily expendable components like the filtering nets?	☐	☐	☐	☐

YES PARTLY NO NOT APPLICABLE

Did you provide easier access to components to be re-manufactured ?

☐
☐
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NR. OF ASWERS

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PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)

☐
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Optimization of Product Lifetime

Powerhouse

	YES	PARTLY	NO	NOT APPLICABLE
Did you design components with co-extensive lifespan?	☐	☐	☐	☐
Did you design lifespan of replaceable components according to scheduled duration?	☐	☐	☐	☐
Did you select durable materials according to the product performance and lifespan ?	☐	☐	☐	☐
Did you reduce overall number of components ?	☐	☐	☐	☐
Did you simplify products ?	☐	☐	☐	☐
Did you eliminate weak liaisons?	☐	☐	☐	☐
Did you simplify access and disassembly to components to be maintained ?	☐	☐	☐	☐
Did you avoid narrow slits and holes to facilitate access for cleaning ?	☐	☐	☐	☐
Did you equip the product with easily usable tools for maintenance?	☐	☐	☐	☐
Did you design products for easy on-site maintenance?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design complementary maintenance tools and documentation?	☐	☐	☐	☐
Did you design products that need less maintenance?	☐	☐	☐	☐
Did you arrange and facilitate disassembly and re-attachment of easily damageable components?	☐	☐	☐	☐
Did you design components according to standards to facilitate substitution of damaged parts?	☐	☐	☐	☐
Did you design products for facilitated onsite repair?	☐	☐	☐	☐
Did you design complementary repair tools, materials and documentation?	☐	☐	☐	☐
Did you increase the resistance of easily damaged and expendable components ?	☐	☐	☐	☐
Did you avoid damaging the formworks used for concrete, in order to facilitate their reuse. The wood formworks can be replaced with readymade metal or plastic ones ?	☐	☐	☐	☐
Did you arrange and facilitate access and removal of retrievable components ?	☐	☐	☐	☐
Did you design modular and replaceable components?	☐	☐	☐	☐
Did you use modular readymade concrete parts for the construction of walls, tops or lids or other simple components.t?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design re-usable auxiliary parts?	☐	☐	☐	☐
Did you design and facilitate removal and substitution of easily expendable components ?	☐	☐	☐	☐
Did you design structural parts that can be easily separated from external/visible ones?	☐	☐	☐	☐
Did you provide easier access to components to be re-manufactured ?	☐	☐	☐	☐
Did you calculate accurate tolerance parameters for easily expendable connections ?	☐	☐	☐	☐
Did you design for excessive use of materials in places more subject to deterioration ?	☐	☐	☐	☐
Did you use a bandage system, or a collar like module can be fixed in place of the damaged one after cutting the cracked part?	☐	☐	☐	☐
Did you design for excessive use of material for easily deteriorating surfaces?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Optimization of Product Lifetime

Electromechanic Equipment

	YES	PARTLY	NO	NOT APPLICABLE
Did you design components with co-extensive lifespan?	☐	☐	☐	☐
Did you make a part by part lifespan assessment of all of the components to understand if there are parts that need works of maintenance or reparations and not total replacement?	☐	☐	☐	☐
Did you design lifespan of replaceable components according to scheduled duration?	☐	☐	☐	☐
Did you design according to 70 years multiples ?	☐	☐	☐	☐
Did you select durable materials according to the product performance and lifespan ?	☐	☐	☐	☐
Did you reduce overall number of components ?	☐	☐	☐	☐
Did you simplify products ?	☐	☐	☐	☐
Did you eliminate weak liaisons?	☐	☐	☐	☐
Did you enable and facilitate software upgrading?	☐	☐	☐	☐
Did you design the software for oil consumption installations in order to be upgradable for use of new, more efficient or more ecofriendly oils consumption?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you enable and facilitate hardware upgrading ?	☐	☐	☐	☐
Did you design modular and dynamically configured products to facilitate their adaptability for changing environments. ?	☐	☐	☐	☐
Did you design onsite upgradeable and adaptable products ?	☐	☐	☐	☐
Did you consider an approach in which several smaller turbines are linked, so that the energy generation can continue also with low water flows ?	☐	☐	☐	☐
Did you design complementary tools and documentation for product upgrading and adaptation ?	☐	☐	☐	☐
Did you simplify access and disassembly to components to be maintained?	☐	☐	☐	☐
Did you avoid narrow slits and holes to facilitate access for cleaning ?	☐	☐	☐	☐
Did you equip the product with easily usable tools for maintenance?	☐	☐	☐	☐
Did you equip products with diagnostic and/or auto-diagnostic systems for maintainable components?	☐	☐	☐	☐
Did you create a remote system checking the well-functioning of the system and the safety parameters of the turbine?	☐	☐	☐	☐
Did you use an advanced remote system of surveillance and adjustments for the cooling coils oil consumption and quality?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you place a diagnostic system on the nozzles prevent damage due to high water pressure or high speed?	☐	☐	☐	☐
Did you design nozzles to be performant as they are subject to high pressure and friction ?	☐	☐	☐	☐
Did you design products for easy on-site maintenance?	☐	☐	☐	☐
Did you perform integrity inspection of the cooling coils can be tested on site by the conductivity or helium gas methods?	☐	☐	☐	☐
Did you design complementary maintenance tools and documentation?	☐	☐	☐	☐
Did you design products that need less maintenance?	☐	☐	☐	☐
Did you arrange and facilitate disassembly and re-attachment of easily damageable	☐	☐	☐	☐
Did you choose or design a turbine with replaceable and detachable buckets ?	☐	☐	☐	☐
Did you arrange and facilitate access and removal of retrievable components ?	☐	☐	☐	☐
Did you make available replaceable buckets for the turbine on site for repairs?	☐	☐	☐	☐
Did you design components according to standards to facilitate substitution of damaged parts?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you equip products with automatic damage diagnostics system?	☐	☐	☐	☐
Did you assign damage diagnostic system can be placed on nozzles, on pipes under high pressure and on bearings or their proximity ?	☐	☐	☐	☐
Did you design products for facilitated onsite repair?	☐	☐	☐	☐
Did you design complementary repair tools, materials and documentation?	☐	☐	☐	☐
Did you increase the resistance of easily damaged and expendable components?	☐	☐	☐	☐
Did you arrange and facilitate access and removal of retrievable components?	☐	☐	☐	☐
Did you design modular and replaceable components ?	☐	☐	☐	☐
Did you design components according to standards to facilitate replacement ?	☐	☐	☐	☐
Did you design re-usable auxiliary parts ?	☐	☐	☐	☐
Did you facilitate cleaning the filters of oil that are in place?	☐	☐	☐	☐
Did you design or choose filters made of a durable material?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design and facilitate removal and substitution of easily expendable components?	☐	☐	☐	☐
Did you design structural parts that can be easily separated from external/visible ones ?	☐	☐	☐	☐
Did you provide easier access to components to be re-manufactured?	☐	☐	☐	☐
Did you calculate accurate tolerance parameters for easily expendable connections for the Pipeline, inlets, jets or nozzles?	☐	☐	☐	☐
Did you design for excessive use of materials in places more subject to deterioration?	☐	☐	☐	☐
Did you design for excessive use of material for easily deteriorating surfaces?	☐	☐	☐	☐
Did you design a smaller bearing box around the place of the bearings, independent from the body of the casing, so overall replacement of the casing will not be necessary ?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Minimising Toxic Emissions

Intake

	YES	PARTLY	NO	NOT APPLICABLE
Did you minimise the hazard of toxic and harmful materials?	☐	☐	☐	☐
Did you take measurements for safe transport need to be taken to prevent spilling, absorbing materials should be available on site for cleaning	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during pre-production (cement, steel) ?	☐	☐	☐	☐
Did you avoid technologies that process toxic and harmful materials (concrete and steel manufacturing)?	☐	☐	☐	☐
Did you avoid toxic or harmful surface treatments?	☐	☐	☐	☐
Did you design products that do not consume toxic and harmful materials?	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during usage?	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during disposal?	☐	☐	☐	☐
Did you research for new and more performing materials available to reduce the overall amount of materials?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Minimising Toxic Emissions

Pipeline

	YES	PARTLY	NO	NOT APPLICABLE
Did you minimise the hazard of toxic and harmful materials?	☐	☐	☐	☐
Did you take measurements for safe transport need to be taken to prevent spilling, absorbing materials should be available on site for cleaning	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during pre-production (cement, steel) ?	☐	☐	☐	☐
Did you avoid technologies that process toxic and harmful materials (concrete and steel manufacturing)?	☐	☐	☐	☐
Did you avoid toxic or harmful surface treatments?	☐	☐	☐	☐
Did you design products that do not consume toxic and harmful materials?	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during usage?	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during disposal?	☐	☐	☐	☐
Did you research for new and more performing materials available to reduce the overall amount of materials?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Minimising Toxic Emissions

Powerhouse

	YES	PARTLY	NO	NOT APPLICABLE
Did you minimise the hazard of toxic and harmful materials?	☐	☐	☐	☐
Did you take measurements for safe transport need to be taken to prevent spilling, absorbing materials should be available on site for cleaning	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during pre-production (cement, steel) ?	☐	☐	☐	☐
Did you avoid technologies that process toxic and harmful materials (concrete and steel manufacturing)?	☐	☐	☐	☐
Did you avoid toxic or harmful surface treatments?	☐	☐	☐	☐
Did you design products that do not consume toxic and harmful materials?	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during usage?	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during disposal?	☐	☐	☐	☐
Did you research for new and more performing materials available to reduce the overall amount of materials?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Minimising Toxic Emissions

Electromechanic Equipment

	YES	PARTLY	NO	NOT APPLICABLE
Did you minimise the hazard of toxic and harmful materials?	☐	☐	☐	☐
Did you take measurements for safe transport need to be taken to prevent spilling, absorbing materials should be available on site for cleaning	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during pre-production (cement, steel) ?	☐	☐	☐	☐
Did you avoid technologies that process toxic and harmful materials (concrete and steel manufacturing)?	☐	☐	☐	☐
Did you avoid toxic or harmful surface treatments?	☐	☐	☐	☐
Did you design products that do not consume toxic and harmful materials?	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during usage?	☐	☐	☐	☐
Did you avoid materials that emit toxic or harmful substances during disposal?	☐	☐	☐	☐
Did you research for new and more performing materials available to reduce the overall amount of materials?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Optimization of Material Lifetime

Intake

	YES	PARTLY	NO	NOT APPLICABLE
Did you select materials that easily recover after recycling the original performance characteristics?	☐	☐	☐	☐
Did you avoid composite materials or, when necessary, choose easily recyclable ones	☐	☐	☐	☐
Did you avoid using glass-fiber reinforced polymers or reinforced concrete?	☐	☐	☐	☐
Did you engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibers ?	☐	☐	☐	☐
Did you use polymer pipeline with exterior ribbing to increase the stiffness ?	☐	☐	☐	☐
Did you choose thermoplastic polymers to thermosetting ?	☐	☐	☐	☐
Did you choose heat-proof thermoplastic polymers to fireproof additives ?	☐	☐	☐	☐
Did you design considering the secondary use of the materials once recycled?	☐	☐	☐	☐
Did you design in compliance with product retrieval system?	☐	☐	☐	☐
Did you minimise overall weight?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you replace steel rebar with other reinforcing non rusting materials like: Fiber glass, Carbon fiber, reinforced polymer or bronze-aluminum bars?	☐	☐	☐	☐
Did you minimise cluttering and improve stackability of discarded products ?	☐	☐	☐	☐
Did you design for the compressibility of discarded products?	☐	☐	☐	☐
Did you provide the beneficiary with information about the disposing modalities of the product or its parts?	☐	☐	☐	☐
Did you codify different materials to facilitate their identification?	☐	☐	☐	☐
Did you provide additional information about the material's age, number of times recycled in the past and additives used?	☐	☐	☐	☐
Did you indicate the existence of toxic or harmful materials. Like is the case of the mineral oil ?	☐	☐	☐	☐
Did you use standardized materials identification systems ?	☐	☐	☐	☐
Did you arrange codifications in easily visible places ?	☐	☐	☐	☐
Did you avoid codifying after component production stages?	☐	☐	☐	☐
Did you integrate functions to reduce the overall number of materials and components?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you adopt a strategy, in which components with the same material are grouped together and are split from other materials, in order to reduce the overall number of parts and the duration of disassemblies?	☐	☐	☐	☐
Did you use only one material, but processed in sandwich structures ?	☐	☐	☐	☐
Did you use compatible materials (that could be recycled together) within the product or sub-assembly?	☐	☐	☐	☐
Did you use the same or compatible materials as in components (to be joined)?	☐	☐	☐	☐
Did you avoid unnecessary coating procedures?	☐	☐	☐	☐
Did you avoid irremovable coating materials?	☐	☐	☐	☐
Did you, instead of painting the metal pieces against corrosion use oxidation-resisting steel, or electrical corrosion techniques ?	☐	☐	☐	☐
Did you facilitate removal of coating materials ?	☐	☐	☐	☐
Did you use coating procedures that comply with coated materials ?	☐	☐	☐	☐
Did you avoid adhesives or choose ones that comply with materials to be recycled?	☐	☐	☐	☐
Did you chosen or designed the plastic pipe module to be coupling one inside the other?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you prefer the dyeing of internal polymers, rather than surface painting parts and the duration of disassemblies?	☐	☐	☐	☐
Did you avoid using additional materials for marking or codification?	☐	☐	☐	☐
Did you mark and codify materials during molding?	☐	☐	☐	☐
Did you codify polymers using lasers?	☐	☐	☐	☐
Did you select high energy materials for products that are going to be incinerated?	☐	☐	☐	☐
Did you avoid materials that emit dangerous substances during incineration?	☐	☐	☐	☐
Did you use oxidation resisting alloys instead of coating for the metal parts ?	☐	☐	☐	☐
Did you avoid additives that emit dangerous substances during incineration?	☐	☐	☐	☐
Did you facilitate the separation of materials that would compromise the efficiency of combustion (with low energy value). For the glass fiber inside the pipeline. Glass, metals, concrete and ceramic materials that oppose incineration. ?	☐	☐	☐	☐
Did you use a good cleaning in order to increase the efficiency during processing and re-use, for the recycled reinforcing steel?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Optimization of Material Lifetime

Pipeline

	YES	PARTLY	NO	NOT APPLICABLE
Did you select materials that easily recover after recycling the original performance characteristics?	☐	☐	☐	☐
Did you avoid composite materials or, when necessary, choose easily recyclable ones	☐	☐	☐	☐
Did you avoid using glass-fiber reinforced polymers or reinforced concrete?	☐	☐	☐	☐
Did you engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibers ?	☐	☐	☐	☐
Did you use polymer pipeline with exterior ribbing to increase the stiffness ?	☐	☐	☐	☐
Did you choose thermoplastic polymers to thermosetting ?	☐	☐	☐	☐
Did you choose heat-proof thermoplastic polymers to fireproof additives ?	☐	☐	☐	☐
Did you design considering the secondary use of the materials once recycled?	☐	☐	☐	☐
Did you design in compliance with product retrieval system?	☐	☐	☐	☐
Did you minimise overall weight?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you replace steel rebar with other reinforcing non rusting materials like: Fiber glass, Carbon fiber, reinforced polymer or bronze-aluminum bars?	☐	☐	☐	☐
Did you minimise cluttering and improve stackability of discarded products ?	☐	☐	☐	☐
Did you design for the compressibility of discarded products?	☐	☐	☐	☐
Did you provide the beneficiary with information about the disposing modalities of the product or its parts?	☐	☐	☐	☐
Did you codify different materials to facilitate their identification?	☐	☐	☐	☐
Did you provide additional information about the material's age, number of times recycled in the past and additives used?	☐	☐	☐	☐
Did you indicate the existence of toxic or harmful materials. Like is the case of the mineral oil ?	☐	☐	☐	☐
Did you use standardized materials identification systems ?	☐	☐	☐	☐
Did you arrange codifications in easily visible places ?	☐	☐	☐	☐
Did you avoid codifying after component production stages?	☐	☐	☐	☐
Did you integrate functions to reduce the overall number of materials and components?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you adopt a strategy, in which components with the same material are grouped together and are split from other materials, in order to reduce the overall number of parts and the duration of disassemblies?	☐	☐	☐	☐
Did you use only one material, but processed in sandwich structures ?	☐	☐	☐	☐
Did you use compatible materials (that could be recycled together) within the product or sub-assembly?	☐	☐	☐	☐
Did you use the same or compatible materials as in components (to be joined)?	☐	☐	☐	☐
Did you avoid unnecessary coating procedures?	☐	☐	☐	☐
Did you avoid irremovable coating materials?	☐	☐	☐	☐
Did you, instead of painting the metal pieces against corrosion use oxidation-resisting steel, or electrical corrosion techniques ?	☐	☐	☐	☐
Did you facilitate removal of coating materials ?	☐	☐	☐	☐
Did you use coating procedures that comply with coated materials ?	☐	☐	☐	☐
Did you avoid adhesives or choose ones that comply with materials to be recycled?	☐	☐	☐	☐
Did you chosen or designed the plastic pipe module to be coupling one inside the other?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you prefer the dyeing of internal polymers, rather than surface painting parts and the duration of disassemblies?	☐	☐	☐	☐
Did you avoid using additional materials for marking or codification?	☐	☐	☐	☐
Did you mark and codify materials during molding?	☐	☐	☐	☐
Did you codify polymers using lasers?	☐	☐	☐	☐
Did you select high energy materials for products that are going to be incinerated?	☐	☐	☐	☐
Did you avoid materials that emit dangerous substances during incineration?	☐	☐	☐	☐
Did you use oxidation resisting alloys instead of coating for the metal parts ?	☐	☐	☐	☐
Did you avoid additives that emit dangerous substances during incineration?	☐	☐	☐	☐
Did you facilitate the separation of materials that would compromise the efficiency of combustion (with low energy value). For the glass fiber inside the pipeline. Glass, metals, concrete and ceramic materials that oppose incineration. ?	☐	☐	☐	☐
Did you use a good cleaning in order to increase the efficiency during processing and re-use, for the recycled reinforcing steel?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Optimization of Material Lifetime

Powerhouse

	YES	PARTLY	NO	NOT APPLICABLE
Did you select materials that easily recover after recycling the original performance characteristics?	☐	☐	☐	☐
Did you avoid composite materials or, when necessary, choose easily recyclable ones	☐	☐	☐	☐
Did you avoid using glass-fiber reinforced polymers or reinforced concrete?	☐	☐	☐	☐
Did you engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibers ?	☐	☐	☐	☐
Did you use polymer pipeline with exterior ribbing to increase the stiffness ?	☐	☐	☐	☐
Did you choose thermoplastic polymers to thermosetting ?	☐	☐	☐	☐
Did you choose heat-proof thermoplastic polymers to fireproof additives ?	☐	☐	☐	☐
Did you design considering the secondary use of the materials once recycled?	☐	☐	☐	☐
Did you design in compliance with product retrieval system?	☐	☐	☐	☐
Did you minimise overall weight?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you replace steel rebar with other reinforcing non rusting materials like: Fiber glass, Carbon fiber, reinforced polymer or bronze-aluminum bars?	☐	☐	☐	☐
Did you minimise cluttering and improve stackability of discarded products ?	☐	☐	☐	☐
Did you design for the compressibility of discarded products?	☐	☐	☐	☐
Did you provide the beneficiary with information about the disposing modalities of the product or its parts?	☐	☐	☐	☐
Did you codify different materials to facilitate their identification?	☐	☐	☐	☐
Did you provide additional information about the material's age, number of times recycled in the past and additives used?	☐	☐	☐	☐
Did you indicate the existence of toxic or harmful materials. Like is the case of the mineral oil ?	☐	☐	☐	☐
Did you use standardized materials identification systems ?	☐	☐	☐	☐
Did you arrange codifications in easily visible places ?	☐	☐	☐	☐
Did you avoid codifying after component production stages?	☐	☐	☐	☐
Did you integrate functions to reduce the overall number of materials and components?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you adopt a strategy, in which components with the same material are grouped together and are split from other materials, in order to reduce the overall number of parts and the duration of disassemblies?	☐	☐	☐	☐
Did you use only one material, but processed in sandwich structures ?	☐	☐	☐	☐
Did you use compatible materials (that could be recycled together) within the product or sub-assembly?	☐	☐	☐	☐
Did you use the same or compatible materials as in components (to be joined)?	☐	☐	☐	☐
Did you avoid unnecessary coating procedures?	☐	☐	☐	☐
Did you avoid irremovable coating materials?	☐	☐	☐	☐
Did you, instead of painting the metal pieces against corrosion use oxidation-resisting steel, or electrical corrosion techniques ?	☐	☐	☐	☐
Did you facilitate removal of coating materials ?	☐	☐	☐	☐
Did you use coating procedures that comply with coated materials ?	☐	☐	☐	☐
Did you avoid adhesives or choose ones that comply with materials to be recycled?	☐	☐	☐	☐
Did you chosen or designed the plastic pipe module to be coupling one inside the other?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you prefer the dyeing of internal polymers, rather than surface painting parts and the duration of disassemblies?	☐	☐	☐	☐
Did you avoid using additional materials for marking or codification?	☐	☐	☐	☐
Did you mark and codify materials during molding?	☐	☐	☐	☐
Did you codify polymers using lasers?	☐	☐	☐	☐
Did you select high energy materials for products that are going to be incinerated?	☐	☐	☐	☐
Did you avoid materials that emit dangerous substances during incineration?	☐	☐	☐	☐
Did you use oxidation resisting alloys instead of coating for the metal parts ?	☐	☐	☐	☐
Did you avoid additives that emit dangerous substances during incineration?	☐	☐	☐	☐
Did you facilitate the separation of materials that would compromise the efficiency of combustion (with low energy value). For the glass fiber inside the pipeline. Glass, metals, concrete and ceramic materials that oppose incineration. ?	☐	☐	☐	☐
Did you use a good cleaning in order to increase the efficiency during processing and re-use, for the recycled reinforcing steel?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Optimization of Material Lifetime

Electromechanic Equipment

	YES	PARTLY	NO	NOT APPLICABLE
Did you select materials that easily recover after recycling the original performance characteristics?	☐	☐	☐	☐
Did you avoid composite materials or, when necessary, choose easily recyclable ones	☐	☐	☐	☐
Did you avoid using glass-fiber reinforced polymers or reinforced concrete?	☐	☐	☐	☐
Did you engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibers ?	☐	☐	☐	☐
Did you use polymer pipeline with exterior ribbing to increase the stiffness ?	☐	☐	☐	☐
Did you choose thermoplastic polymers to thermosetting ?	☐	☐	☐	☐
Did you choose heat-proof thermoplastic polymers to fireproof additives ?	☐	☐	☐	☐
Did you design considering the secondary use of the materials once recycled?	☐	☐	☐	☐
Did you design in compliance with product retrieval system?	☐	☐	☐	☐
Did you minimise overall weight?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you replace steel rebar with other reinforcing non rusting materials like: Fiber glass, Carbon fiber, reinforced polymer or bronze-aluminum bars?	☐	☐	☐	☐
Did you minimise cluttering and improve stackability of discarded products ?	☐	☐	☐	☐
Did you design for the compressibility of discarded products?	☐	☐	☐	☐
Did you provide the beneficiary with information about the disposing modalities of the product or its parts?	☐	☐	☐	☐
Did you codify different materials to facilitate their identification?	☐	☐	☐	☐
Did you provide additional information about the material's age, number of times recycled in the past and additives used?	☐	☐	☐	☐
Did you indicate the existence of toxic or harmful materials. Like is the case of the mineral oil ?	☐	☐	☐	☐
Did you use standardized materials identification systems ?	☐	☐	☐	☐
Did you arrange codifications in easily visible places ?	☐	☐	☐	☐
Did you avoid codifying after component production stages?	☐	☐	☐	☐
Did you integrate functions to reduce the overall number of materials and components?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you adopt a strategy, in which components with the same material are grouped together and are split from other materials, in order to reduce the overall number of parts and the duration of disassemblies?	☐	☐	☐	☐
Did you use only one material, but processed in sandwich structures ?	☐	☐	☐	☐
Did you use compatible materials (that could be recycled together) within the product or sub-assembly?	☐	☐	☐	☐
Did you use the same or compatible materials as in components (to be joined)?	☐	☐	☐	☐
Did you avoid unnecessary coating procedures?	☐	☐	☐	☐
Did you avoid irremovable coating materials?	☐	☐	☐	☐
Did you, instead of painting the metal pieces against corrosion use oxidation-resisting steel, or electrical corrosion techniques ?	☐	☐	☐	☐
Did you facilitate removal of coating materials ?	☐	☐	☐	☐
Did you use coating procedures that comply with coated materials ?	☐	☐	☐	☐
Did you avoid adhesives or choose ones that comply with materials to be recycled?	☐	☐	☐	☐
Did you chosen or designed the plastic pipe module to be coupling one inside the other?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you prefer the dyeing of internal polymers, rather than surface painting parts and the duration of disassemblies?	☐	☐	☐	☐
Did you avoid using additional materials for marking or codification?	☐	☐	☐	☐
Did you mark and codify materials during molding?	☐	☐	☐	☐
Did you codify polymers using lasers?	☐	☐	☐	☐
Did you select high energy materials for products that are going to be incinerated?	☐	☐	☐	☐
Did you avoid materials that emit dangerous substances during incineration?	☐	☐	☐	☐
Did you use oxidation resisting alloys instead of coating for the metal parts ?	☐	☐	☐	☐
Did you avoid additives that emit dangerous substances during incineration?	☐	☐	☐	☐
Did you facilitate the separation of materials that would compromise the efficiency of combustion (with low energy value). For the glass fiber inside the pipeline. Glass, metals, concrete and ceramic materials that oppose incineration. ?	☐	☐	☐	☐
Did you use a good cleaning in order to increase the efficiency during processing and re-use, for the recycled reinforcing steel?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Renewable and Bio-compatible Resource

Intake

	YES	PARTLY	NO	NOT APPLICABLE
Did you se renewable materials?	☐	☐	☐	☐
Did you research substitutes for cement, like “green” cement?	☐	☐	☐	☐
Did you design lattice beams made of wood instead of metal for celling support and roof windows?	☐	☐	☐	☐
Did you use eco friendly materials of construction such as wood, clay or eco bricks combined with a strong structural design, in order to substitute the concrete used for the powerhouse construction ?	☐	☐	☐	☐
Did you avoid exhaustive materials ?	☐	☐	☐	☐
Did you replace copper used in the cooling coils with a mixture of stainless steel and other alloys?	☐	☐	☐	☐
Did you use residual materials of production processes ?	☐	☐	☐	☐
Did you select cement suppliers that use residual materials for processing?	☐	☐	☐	☐
Did you use square haystacks and clay to provide a better sound and temperature insulation or did you used those to construct walls?	☐	☐	☐	☐
Did you use retrieved components from disposed products?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you choose cement containing fly ash from coal thermic energy generation processes?	☐	☐	☐	☐
Did you use recycled materials, alone or combined with primary materials ?	☐	☐	☐	☐
Did you select cement suppliers that use waste and by-products in cement generation?	☐	☐	☐	☐
Did you use bio-degradable materials?	☐	☐	☐	☐
Did you research and use traditional building materials that are bio-degradable?	☐	☐	☐	☐
Did you use renewable energy resources?	☐	☐	☐	☐
Did you use biofuel as replacement for classic fuel for the construction machinery ?	☐	☐	☐	☐
Did you engage the cascade approach ?	☐	☐	☐	☐
Did you select energy resources with high second-order efficiency ?	☐	☐	☐	☐

Renewable and Bio-compatible Resource

Pipeline

	YES	PARTLY	NO	NOT APPLICABLE
Did you se renewable materials?	☐	☐	☐	☐
Did you research substitutes for cement, like “green” cement?	☐	☐	☐	☐
Did you design lattice beams made of wood instead of metal for celling support and roof windows?	☐	☐	☐	☐
Did you use eco friendly materials of construction such as wood, clay or eco bricks combined with a strong structural design, in order to substitute the concrete used for the powerhouse construction ?	☐	☐	☐	☐
Did you avoid exhaustive materials ?	☐	☐	☐	☐
Did you replace copper used in the cooling coils with a mixture of stainless steel and other alloys?	☐	☐	☐	☐
Did you use residual materials of production processes ?	☐	☐	☐	☐
Did you select cement suppliers that use residual materials for processing?	☐	☐	☐	☐
Did you use square haystacks and clay to provide a better sound and temperature insulation or did you used those to construct walls?	☐	☐	☐	☐
Did you use retrieved components from disposed products?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you choose cement containing fly ash from coal thermic energy generation processes?	☐	☐	☐	☐
Did you use recycled materials, alone or combined with primary materials ?	☐	☐	☐	☐
Did you select cement suppliers that use waste and by-products in cement generation?	☐	☐	☐	☐
Did you use bio-degradable materials?	☐	☐	☐	☐
Did you research and use traditional building materials that are bio-degradable?	☐	☐	☐	☐
Did you use renewable energy resources?	☐	☐	☐	☐
Did you use biofuel as replacement for classic fuel for the construction machinery ?	☐	☐	☐	☐
Did you engage the cascade approach ?	☐	☐	☐	☐
Did you select energy resources with high second-order efficiency ?	☐	☐	☐	☐

Renewable and Bio-compatible Resource

Powerhouse

	YES	PARTLY	NO	NOT APPLICABLE
Did you use renewable materials?	☐	☐	☐	☐
Did you research substitutes for cement, like “green” cement?	☐	☐	☐	☐
Did you design lattice beams made of wood instead of metal for ceiling support and roof windows?	☐	☐	☐	☐
Did you use eco friendly materials of construction such as wood, clay or eco bricks combined with a strong structural design, in order to substitute the concrete used for the powerhouse construction ?	☐	☐	☐	☐
Did you avoid exhaustive materials ?	☐	☐	☐	☐
Did you replace copper used in the cooling coils with a mixture of stainless steel and other alloys?	☐	☐	☐	☐
Did you use residual materials of production processes ?	☐	☐	☐	☐
Did you select cement suppliers that use residual materials for processing?	☐	☐	☐	☐
Did you use square haystacks and clay to provide a better sound and temperature insulation or did you use those to construct walls?	☐	☐	☐	☐
Did you use retrieved components from disposed products?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you choose cement containing fly ash from coal thermic energy generation processes?	☐	☐	☐	☐
Did you use recycled materials, alone or combined with primary materials ?	☐	☐	☐	☐
Did you select cement suppliers that use waste and by-products in cement generation?	☐	☐	☐	☐
Did you use bio-degradable materials?	☐	☐	☐	☐
Did you research and use traditional building materials that are bio-degradable?	☐	☐	☐	☐
Did you use renewable energy resources?	☐	☐	☐	☐
Did you use biofuel as replacement for classic fuel for the construction machinery ?	☐	☐	☐	☐
Did you engage the cascade approach ?	☐	☐	☐	☐
Did you select energy resources with high second-order efficiency ?	☐	☐	☐	☐

Renewable and Bio-compatible Resource

Electromechanic Equipment

	YES	PARTLY	NO	NOT APPLICABLE
Did you se renewable materials?	☐	☐	☐	☐
Did you research substitutes for cement, like “green” cement?	☐	☐	☐	☐
Did you design lattice beams made of wood instead of metal for celling support and roof windows?	☐	☐	☐	☐
Did you use eco friendly materials of construction such as wood, clay or eco bricks combined with a strong structural design, in order to substitute the concrete used for the powerhouse construction ?	☐	☐	☐	☐
Did you avoid exhaustive materials ?	☐	☐	☐	☐
Did you replace copper used in the cooling coils with a mixture of stainless steel and other alloys?	☐	☐	☐	☐
Did you use residual materials of production processes ?	☐	☐	☐	☐
Did you select cement suppliers that use residual materials for processing?	☐	☐	☐	☐
Did you use square haystacks and clay to provide a better sound and temperature insulation or did you used those to construct walls?	☐	☐	☐	☐
Did you use retrieved components from disposed products?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you choose cement containing fly ash from coal thermic energy generation processes?	☐	☐	☐	☐
Did you use recycled materials, alone or combined with primary materials ?	☐	☐	☐	☐
Did you select cement suppliers that use waste and by-products in cement generation?	☐	☐	☐	☐
Did you use bio-degradable materials?	☐	☐	☐	☐
Did you research and use traditional building materials that are bio-degradable?	☐	☐	☐	☐
Did you use renewable energy resources?	☐	☐	☐	☐
Did you use biofuel as replacement for classic fuel for the construction machinery ?	☐	☐	☐	☐
Did you engage the cascade approach ?	☐	☐	☐	☐
Did you select energy resources with high second-order efficiency ?	☐	☐	☐	☐

Minimising Energy Consumption

Intake

	YES	PARTLY	NO	NOT APPLICABLE
Did you select materials with low energy intensity?	☐	☐	☐	☐
Did you research replacement for cement and steel parts that can be constructed using less energy intensive materialsDid you research and used up to date standards for structural design dimensions?	☐	☐	☐	☐
Did you select processing technologies with the lowest energy consumption possible?	☐	☐	☐	☐
Did you engage efficient machinery?	☐	☐	☐	☐
Did you choose suppliers for readymade concrete components that are using new and efficient manufacturing technologies?	☐	☐	☐	☐
Did you use new or well-maintained machinery to reduce as much as possible the fuel emissions in the environment, during construction on site?	☐	☐	☐	☐
Did you engage pump and motor speed regulators with dynamic configuration?	☐	☐	☐	☐
Did you equip the machinery with intelligent power-off utilities?	☐	☐	☐	☐
Did you optimise the overall dimensions of the engines?	☐	☐	☐	☐
Did you facilitate engine maintenance?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you define accurately the tolerance parameters?	☐	☐	☐	☐
Did you optimise transportation systems and scale down the weight and dimensions of all transportable materials and semi-products?	☐	☐	☐	☐
Did you engage efficient general heating, illumination and ventilation in buildings?	☐	☐	☐	☐
Did you equip products with onsite assembly?	☐	☐	☐	☐
Did you scale down the product weight?	☐	☐	☐	☐
Did you decentralise activities to reduce transportation volumes?	☐	☐	☐	☐
Did you select local material and energy sources?	☐	☐	☐	☐
Did you design for energy-efficient operational stages?	☐	☐	☐	☐
Did you use a fine tuning and a proficient design of the turbine's nozzles and proficient monitoring system in order to decrease the power lost during generation?	☐	☐	☐	☐
Did you design for energy-efficient maintenance?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design systems for consumption of passive energy sources?	☐	☐	☐	☐
Did you design the partially underground powerhouse with roof windows structure that can substitute the side windows?	☐	☐	☐	☐
Did you engage highly efficient energy conversion systems?	☐	☐	☐	☐
Did you choose efficient lamp type according to the specific need?	☐	☐	☐	☐
Did you design/engage highly efficient engines/generators?	☐	☐	☐	☐
Did you design/engage highly efficient power transmission?	☐	☐	☐	☐
Did you use highly caulked materials and technical components?	☐	☐	☐	☐
Did you design for localized energy supply?	☐	☐	☐	☐
Did you use a fine tuning and a proficient design of the turbine's nozzles and proficient monitoring system in order to decrease the power lost during generation?	☐	☐	☐	☐
Did you measure the vicinity to villages or small manufacturing workshops, which would require energy, before choosing the station's location?	☐	☐	☐	☐
Did you scale down the weight of transportable goods?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design energy-saving systems?	☐	☐	☐	☐
Did you engage digital dynamic support systems?	☐	☐	☐	☐
Did you design dynamic energy consumption systems for differentiated operational stages?	☐	☐	☐	☐
Did you engage sensors to adjust consumption during differentiated operational stages?	☐	☐	☐	☐
Did you use sensor of presence or light intensity that can save energy during the changing seasons?	☐	☐	☐	☐
Did you equip machinery with intelligent power-off utilities for safety?	☐	☐	☐	☐
Did you program product's default state at minimal energy consumption?	☐	☐	☐	☐
Did you engage efficient workplace heating, illumination and ventilation?	☐	☐	☐	☐
Did you engage digital tools for communicating with remote working sites?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Minimising Energy Consumption

Pipeline

	YES	PARTLY	NO	NOT APPLICABLE
Did you select materials with low energy intensity?	☐	☐	☐	☐
Did you research replacement for cement and steel parts that can be constructed using less energy intensive materialsDid you research and used up to date standards for structural design dimensions?	☐	☐	☐	☐
Did you select processing technologies with the lowest energy consumption possible?	☐	☐	☐	☐
Did you engage efficient machinery?	☐	☐	☐	☐
Did you choose suppliers for readymade concrete components that are using new and efficient manufacturing technologies?	☐	☐	☐	☐
Did you use new or well-maintained machinery to reduce as much as possible the fuel emissions in the environment, during construction on site?	☐	☐	☐	☐
Did you engage pump and motor speed regulators with dynamic configuration?	☐	☐	☐	☐
Did you equip the machinery with intelligent power-off utilities?	☐	☐	☐	☐
Did you optimise the overall dimensions of the engines?	☐	☐	☐	☐
Did you facilitate engine maintenance?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you define accurately the tolerance parameters?	☐	☐	☐	☐
Did you optimise transportation systems and scale down the weight and dimensions of all transportable materials and semi-products?	☐	☐	☐	☐
Did you engage efficient general heating, illumination and ventilation in buildings?	☐	☐	☐	☐
Did you equip products with onsite assembly?	☐	☐	☐	☐
Did you scale down the product weight?	☐	☐	☐	☐
Did you decentralise activities to reduce transportation volumes?	☐	☐	☐	☐
Did you select local material and energy sources?	☐	☐	☐	☐
Did you design for energy-efficient operational stages?	☐	☐	☐	☐
Did you use a fine tuning and a proficient design of the turbine's nozzles and proficient monitoring system in order to decrease the power lost during generation?	☐	☐	☐	☐
Did you design for energy-efficient maintenance?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design systems for consumption of passive energy sources?	☐	☐	☐	☐
Did you design the partially underground powerhouse with roof windows structure that can substitute the side windows?	☐	☐	☐	☐
Did you engage highly efficient energy conversion systems?	☐	☐	☐	☐
Did you choose efficient lamp type according to the specific need?	☐	☐	☐	☐
Did you design/engage highly efficient engines/generators?	☐	☐	☐	☐
Did you design/engage highly efficient power transmission?	☐	☐	☐	☐
Did you use highly caulked materials and technical components?	☐	☐	☐	☐
Did you design for localized energy supply?	☐	☐	☐	☐
Did you use a fine tuning and a proficient design of the turbine's nozzles and proficient monitoring system in order to decrease the power lost during generation?	☐	☐	☐	☐
Did you measure the vicinity to villages or small manufacturing workshops, which would require energy, before choosing the station's location?	☐	☐	☐	☐
Did you scale down the weight of transportable goods?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design energy-saving systems?	☐	☐	☐	☐
Did you engage digital dynamic support systems?	☐	☐	☐	☐
Did you design dynamic energy consumption systems for differentiated operational stages?	☐	☐	☐	☐
Did you engage sensors to adjust consumption during differentiated operational stages?	☐	☐	☐	☐
Did you use sensor of presence or light intensity that can save energy during the changing seasons?	☐	☐	☐	☐
Did you equip machinery with intelligent power-off utilities for safety?	☐	☐	☐	☐
Did you program product's default state at minimal energy consumption?	☐	☐	☐	☐
Did you engage efficient workplace heating, illumination and ventilation?	☐	☐	☐	☐
Did you engage digital tools for communicating with remote working sites?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Minimising Energy Consumption

Powerhouse

	YES	PARTLY	NO	NOT APPLICABLE
Did you select materials with low energy intensity?	☐	☐	☐	☐
Did you research replacement for cement and steel parts that can be constructed using less energy intensive materialsDid you research and used up to date standards for structural design dimensions?	☐	☐	☐	☐
Did you select processing technologies with the lowest energy consumption possible?	☐	☐	☐	☐
Did you engage efficient machinery?	☐	☐	☐	☐
Did you choose suppliers for readymade concrete components that are using new and efficient manufacturing technologies?	☐	☐	☐	☐
Did you use new or well-maintained machinery to reduce as much as possible the fuel emissions in the environment, during construction on site?	☐	☐	☐	☐
Did you engage pump and motor speed regulators with dynamic configuration?	☐	☐	☐	☐
Did you equip the machinery with intelligent power-off utilities?	☐	☐	☐	☐
Did you optimise the overall dimensions of the engines?	☐	☐	☐	☐
Did you facilitate engine maintenance?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you define accurately the tolerance parameters?	☐	☐	☐	☐
Did you optimise transportation systems and scale down the weight and dimensions of all transportable materials and semi-products?	☐	☐	☐	☐
Did you engage efficient general heating, illumination and ventilation in buildings?	☐	☐	☐	☐
Did you equip products with onsite assembly?	☐	☐	☐	☐
Did you scale down the product weight?	☐	☐	☐	☐
Did you decentralise activities to reduce transportation volumes?	☐	☐	☐	☐
Did you select local material and energy sources?	☐	☐	☐	☐
Did you design for energy-efficient operational stages?	☐	☐	☐	☐
Did you use a fine tuning and a proficient design of the turbine's nozzles and proficient monitoring system in order to decrease the power lost during generation?	☐	☐	☐	☐
Did you design for energy-efficient maintenance?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design systems for consumption of passive energy sources?	☐	☐	☐	☐
Did you design the partially underground powerhouse with roof windows structure that can substitute the side windows?	☐	☐	☐	☐
Did you engage highly efficient energy conversion systems?	☐	☐	☐	☐
Did you choose efficient lamp type according to the specific need?	☐	☐	☐	☐
Did you design/engage highly efficient engines/generators?	☐	☐	☐	☐
Did you design/engage highly efficient power transmission?	☐	☐	☐	☐
Did you use highly caulked materials and technical components?	☐	☐	☐	☐
Did you design for localized energy supply?	☐	☐	☐	☐
Did you use a fine tuning and a proficient design of the turbine's nozzles and proficient monitoring system in order to decrease the power lost during generation?	☐	☐	☐	☐
Did you measure the vicinity to villages or small manufacturing workshops, which would require energy, before choosing the station's location?	☐	☐	☐	☐
Did you scale down the weight of transportable goods?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design energy-saving systems?	☐	☐	☐	☐
Did you engage digital dynamic support systems?	☐	☐	☐	☐
Did you design dynamic energy consumption systems for differentiated operational stages?	☐	☐	☐	☐
Did you engage sensors to adjust consumption during differentiated operational stages?	☐	☐	☐	☐
Did you use sensor of presence or light intensity that can save energy during the changing seasons?	☐	☐	☐	☐
Did you equip machinery with intelligent power-off utilities for safety?	☐	☐	☐	☐
Did you program product's default state at minimal energy consumption?	☐	☐	☐	☐
Did you engage efficient workplace heating, illumination and ventilation?	☐	☐	☐	☐
Did you engage digital tools for communicating with remote working sites?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Minimising Energy Consumption

Electromechanic Equipment

	YES	PARTLY	NO	NOT APPLICABLE
Did you select materials with low energy intensity?	☐	☐	☐	☐
Did you research replacement for cement and steel parts that can be constructed using less energy intensive materialsDid you research and used up to date standards for structural design dimensions?	☐	☐	☐	☐
Did you select processing technologies with the lowest energy consumption possible?	☐	☐	☐	☐
Did you engage efficient machinery?	☐	☐	☐	☐
Did you choose suppliers for readymade concrete components that are using new and efficient manufacturing technologies?	☐	☐	☐	☐
Did you use new or well-maintained machinery to reduce as much as possible the fuel emissions in the environment, during construction on site?	☐	☐	☐	☐
Did you engage pump and motor speed regulators with dynamic configuration?	☐	☐	☐	☐
Did you equip the machinery with intelligent power-off utilities?	☐	☐	☐	☐
Did you optimise the overall dimensions of the engines?	☐	☐	☐	☐
Did you facilitate engine maintenance?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you define accurately the tolerance parameters?	☐	☐	☐	☐
Did you optimise transportation systems and scale down the weight and dimensions of all transportable materials and semi-products?	☐	☐	☐	☐
Did you engage efficient general heating, illumination and ventilation in buildings?	☐	☐	☐	☐
Did you equip products with onsite assembly?	☐	☐	☐	☐
Did you scale down the product weight?	☐	☐	☐	☐
Did you decentralise activities to reduce transportation volumes?	☐	☐	☐	☐
Did you select local material and energy sources?	☐	☐	☐	☐
Did you design for energy-efficient operational stages?	☐	☐	☐	☐
Did you use a fine tuning and a proficient design of the turbine's nozzles and proficient monitoring system in order to decrease the power lost during generation?	☐	☐	☐	☐
Did you design for energy-efficient maintenance?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design systems for consumption of passive energy sources?	☐	☐	☐	☐
Did you design the partially underground powerhouse with roof windows structure that can substitute the side windows?	☐	☐	☐	☐
Did you engage highly efficient energy conversion systems?	☐	☐	☐	☐
Did you choose efficient lamp type according to the specific need?	☐	☐	☐	☐
Did you design/engage highly efficient engines/generators?	☐	☐	☐	☐
Did you design/engage highly efficient power transmission?	☐	☐	☐	☐
Did you use highly caulked materials and technical components?	☐	☐	☐	☐
Did you design for localized energy supply?	☐	☐	☐	☐
Did you use a fine tuning and a proficient design of the turbine's nozzles and proficient monitoring system in order to decrease the power lost during generation?	☐	☐	☐	☐
Did you measure the vicinity to villages or small manufacturing workshops, which would require energy, before choosing the station's location?	☐	☐	☐	☐
Did you scale down the weight of transportable goods?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design energy-saving systems?	☐	☐	☐	☐
Did you engage digital dynamic support systems?	☐	☐	☐	☐
Did you design dynamic energy consumption systems for differentiated operational stages?	☐	☐	☐	☐
Did you engage sensors to adjust consumption during differentiated operational stages?	☐	☐	☐	☐
Did you use sensor of presence or light intensity that can save energy during the changing seasons?	☐	☐	☐	☐
Did you equip machinery with intelligent power-off utilities for safety?	☐	☐	☐	☐
Did you program product's default state at minimal energy consumption?	☐	☐	☐	☐
Did you engage efficient workplace heating, illumination and ventilation?	☐	☐	☐	☐
Did you engage digital tools for communicating with remote working sites?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Design for Disassembly

Intake

	YES	PARTLY	NO	NOT APPLICABLE
Did you prioritize the disassembly of toxic and dangerous components or materials?	☐	☐	☐	☐
Did you start with the turbine and the electromechanical equipment, electric transformer, engine, sensors of the turbine, sluices gates, silt basin, the pipeline and then the concrete?	☐	☐	☐	☐
Did you prioritize the disassembly of components or materials with higher economic value?	☐	☐	☐	☐
Did you prioritize the disassembly of more easily damageable components?	☐	☐	☐	☐
Did you engage modular structures?	☐	☐	☐	☐
If readymade concrete parts are in place, did you design those to be easily assembled/ disassembled and provide an assembly scheme to be put on site?	☐	☐	☐	☐
Did you divide the product into easily separable and manipulable sub-assemblies?	☐	☐	☐	☐
Did you separate the casing of the turbine from the wheel with buckets?	☐	☐	☐	☐
Did you minimise overall dimensions of the product?	☐	☐	☐	☐
Did you minimise hierarchically dependent connections between components?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you provide an opposite scheme of disassembly?	☐	☐	☐	☐
Did you minimise different directions in the disassembly route of components and materials?	☐	☐	☐	☐
Did you choose a readymade concrete provider that has a disassembly route?	☐	☐	☐	☐
Did you choose disassembly processors that can process electric components and metal pieces?	☐	☐	☐	☐
Did you increase the linearity of the disassembly route?	☐	☐	☐	☐
Did you engage a sandwich system of disassembly with central joining elements?	☐	☐	☐	☐
Did you easily disassemble the turbine and the powerhouse building with a crane?	☐	☐	☐	☐
Did you avoid difficult-to-handle components?	☐	☐	☐	☐
Did you avoid asymmetrical components, unless required?	☐	☐	☐	☐
Did you design leaning surfaces and grabbing features in compliance with standards?	☐	☐	☐	☐
Did you design anchoring features that are easily attachable to the crane cables for the readymade components?	☐	☐	☐	☐
Did you arrange leaning surfaces around the product's center of gravity?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design for easy centering on the component base?	☐	☐	☐	☐
Did you avoid joining systems that require simultaneous interventions for opening?	☐	☐	☐	☐
Did you minimise the overall number of fasteners?	☐	☐	☐	☐
Did you minimise the overall number of different fastener types by using readymade components for the concrete parts?	☐	☐	☐	☐
Did you avoid difficult-to-handle fasteners?	☐	☐	☐	☐
Did you design accessible and recognizable entrances for dismantling?	☐	☐	☐	☐
Did you use a marking arrow system?	☐	☐	☐	☐
Did you design accessible and controllable dismantling points?	☐	☐	☐	☐
Did you employ two-way snap-fit for the electrical components?	☐	☐	☐	☐
Did you employ joints that are opened with common tools?	☐	☐	☐	☐
Did you employ joints that are opened with special tools, when opening could be dangerous?	☐	☐	☐	☐
Did you design joints made of materials that become reversible only in determined conditions ?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use screws with hexagonal heads?	☐	☐	☐	☐
Did you prefer removable nuts and clips to self-tapping screws?	☐	☐	☐	☐
Did you use screws made of materials compatible with joint components, to avoid their separation before recycling?	☐	☐	☐	☐
Did you avoid rivets on incompatible materials?	☐	☐	☐	☐
Did you avoid additional materials while welding?	☐	☐	☐	☐
Did you use successive coupling for plastic pipes?	☐	☐	☐	☐
Did you avoid gluing with adhesives?	☐	☐	☐	☐
Did you co-design cutting or breaking paths with appropriate separation technologies for incompatible materials separation?	☐	☐	☐	☐
Did you employ joining elements that allow their chemical or physical destruction?	☐	☐	☐	☐
Did you make the breaking points easily accessible and recognizable?	☐	☐	☐	☐
Did you provide the products with information for the beneficiary about the characteristics of crushing separation?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use materials that are easily separable after being crushed?	☐	☐	☐	☐
Did you use additional parts that are easily separable after crushing of materials?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Design for Disassembly

Pipeline

	YES	PARTLY	NO	NOT APPLICABLE
Did you prioritize the disassembly of toxic and dangerous components or materials?	☐	☐	☐	☐
Did you start with the turbine and the electromechanical equipment, electric transformer, engine, sensors of the turbine, sluices gates, silt basin, the pipeline and then the concrete?	☐	☐	☐	☐
Did you prioritize the disassembly of components or materials with higher economic value?	☐	☐	☐	☐
Did you prioritize the disassembly of more easily damageable components?	☐	☐	☐	☐
Did you engage modular structures?	☐	☐	☐	☐
If readymade concrete parts are in place, did you design those to be easily assembled/ disassembled and provide an assembly scheme to be put on site?	☐	☐	☐	☐
Did you divide the product into easily separable and manipulable sub-assemblies?	☐	☐	☐	☐
Did you separate the casing of the turbine from the wheel with buckets?	☐	☐	☐	☐
Did you minimise overall dimensions of the product?	☐	☐	☐	☐
Did you minimise hierarchically dependent connections between components?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you provide an opposite scheme of disassembly?	☐	☐	☐	☐
Did you minimise different directions in the disassembly route of components and materials?	☐	☐	☐	☐
Did you choose a readymade concrete provider that has a disassembly route?	☐	☐	☐	☐
Did you choose disassembly processors that can process electric components and metal pieces?	☐	☐	☐	☐
Did you increase the linearity of the disassembly route?	☐	☐	☐	☐
Did you engage a sandwich system of disassembly with central joining elements?	☐	☐	☐	☐
Did you easily disassemble the turbine and the powerhouse building with a crane?	☐	☐	☐	☐
Did you avoid difficult-to-handle components?	☐	☐	☐	☐
Did you avoid asymmetrical components, unless required?	☐	☐	☐	☐
Did you design leaning surfaces and grabbing features in compliance with standards?	☐	☐	☐	☐
Did you design anchoring features that are easily attachable to the crane cables for the readymade components?	☐	☐	☐	☐
Did you arrange leaning surfaces around the product's center of gravity?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design for easy centering on the component base?	☐	☐	☐	☐
Did you avoid joining systems that require simultaneous interventions for opening?	☐	☐	☐	☐
Did you minimise the overall number of fasteners?	☐	☐	☐	☐
Did you minimise the overall number of different fastener types by using readymade components for the concrete parts?	☐	☐	☐	☐
Did you avoid difficult-to-handle fasteners?	☐	☐	☐	☐
Did you design accessible and recognizable entrances for dismantling?	☐	☐	☐	☐
Did you use a marking arrow system?	☐	☐	☐	☐
Did you design accessible and controllable dismantling points?	☐	☐	☐	☐
Did you employ two-way snap-fit for the electrical components?	☐	☐	☐	☐
Did you employ joints that are opened with common tools?	☐	☐	☐	☐
Did you employ joints that are opened with special tools, when opening could be dangerous?	☐	☐	☐	☐
Did you design joints made of materials that become reversible only in determined conditions ?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use screws with hexagonal heads?	☐	☐	☐	☐
Did you prefer removable nuts and clips to self-tapping screws?	☐	☐	☐	☐
Did you use screws made of materials compatible with joint components, to avoid their separation before recycling?	☐	☐	☐	☐
Did you avoid rivets on incompatible materials?	☐	☐	☐	☐
Did you avoid additional materials while welding?	☐	☐	☐	☐
Did you use successive coupling for plastic pipes?	☐	☐	☐	☐
Did you avoid gluing with adhesives?	☐	☐	☐	☐
Did you co-design cutting or breaking paths with appropriate separation technologies for incompatible materials separation?	☐	☐	☐	☐
Did you employ joining elements that allow their chemical or physical destruction?	☐	☐	☐	☐
Did you make the breaking points easily accessible and recognizable?	☐	☐	☐	☐
Did you provide the products with information for the beneficiary about the characteristics of crushing separation?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use materials that are easily separable after being crushed?	☐	☐	☐	☐
Did you use additional parts that are easily separable after crushing of materials?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Design for Disassembly

Powerhouse

	YES	PARTLY	NO	NOT APPLICABLE
Did you prioritize the disassembly of toxic and dangerous components or materials?	☐	☐	☐	☐
Did you start with the turbine and the electromechanical equipment, electric transformer, engine, sensors of the turbine, sluices gates, silt basin, the pipeline and then the concrete?	☐	☐	☐	☐
Did you prioritize the disassembly of components or materials with higher economic value?	☐	☐	☐	☐
Did you prioritize the disassembly of more easily damageable components?	☐	☐	☐	☐
Did you engage modular structures?	☐	☐	☐	☐
If readymade concrete parts are in place, did you design those to be easily assembled/ disassembled and provide an assembly scheme to be put on site?	☐	☐	☐	☐
Did you divide the product into easily separable and manipulable sub-assemblies?	☐	☐	☐	☐
Did you separate the casing of the turbine from the wheel with buckets?	☐	☐	☐	☐
Did you minimise overall dimensions of the product?	☐	☐	☐	☐
Did you minimise hierarchically dependent connections between components?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you provide an opposite scheme of disassembly?	☐	☐	☐	☐
Did you minimise different directions in the disassembly route of components and materials?	☐	☐	☐	☐
Did you choose a readymade concrete provider that has a disassembly route?	☐	☐	☐	☐
Did you choose disassembly processors that can process electric components and metal pieces?	☐	☐	☐	☐
Did you increase the linearity of the disassembly route?	☐	☐	☐	☐
Did you engage a sandwich system of disassembly with central joining elements?	☐	☐	☐	☐
Did you easily disassemble the turbine and the powerhouse building with a crane?	☐	☐	☐	☐
Did you avoid difficult-to-handle components?	☐	☐	☐	☐
Did you avoid asymmetrical components, unless required?	☐	☐	☐	☐
Did you design leaning surfaces and grabbing features in compliance with standards?	☐	☐	☐	☐
Did you design anchoring features that are easily attachable to the crane cables for the readymade components?	☐	☐	☐	☐
Did you arrange leaning surfaces around the product's center of gravity?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design for easy centering on the component base?	☐	☐	☐	☐
Did you avoid joining systems that require simultaneous interventions for opening?	☐	☐	☐	☐
Did you minimise the overall number of fasteners?	☐	☐	☐	☐
Did you minimise the overall number of different fastener types by using readymade components for the concrete parts?	☐	☐	☐	☐
Did you avoid difficult-to-handle fasteners?	☐	☐	☐	☐
Did you design accessible and recognizable entrances for dismantling?	☐	☐	☐	☐
Did you use a marking arrow system?	☐	☐	☐	☐
Did you design accessible and controllable dismantling points?	☐	☐	☐	☐
Did you employ two-way snap-fit for the electrical components?	☐	☐	☐	☐
Did you employ joints that are opened with common tools?	☐	☐	☐	☐
Did you employ joints that are opened with special tools, when opening could be dangerous?	☐	☐	☐	☐
Did you design joints made of materials that become reversible only in determined conditions ?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use screws with hexagonal heads?	☐	☐	☐	☐
Did you prefer removable nuts and clips to self-tapping screws?	☐	☐	☐	☐
Did you use screws made of materials compatible with joint components, to avoid their separation before recycling?	☐	☐	☐	☐
Did you avoid rivets on incompatible materials?	☐	☐	☐	☐
Did you avoid additional materials while welding?	☐	☐	☐	☐
Did you use successive coupling for plastic pipes?	☐	☐	☐	☐
Did you avoid gluing with adhesives?	☐	☐	☐	☐
Did you co-design cutting or breaking paths with appropriate separation technologies for incompatible materials separation?	☐	☐	☐	☐
Did you employ joining elements that allow their chemical or physical destruction?	☐	☐	☐	☐
Did you make the breaking points easily accessible and recognizable?	☐	☐	☐	☐
Did you provide the products with information for the beneficiary about the characteristics of crushing separation?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use materials that are easily separable after being crushed?	☐	☐	☐	☐
Did you use additional parts that are easily separable after crushing of materials?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

Design for Disassembly

Electromechanic Equipment

	YES	PARTLY	NO	NOT APPLICABLE
Did you prioritize the disassembly of toxic and dangerous components or materials?	☐	☐	☐	☐
Did you start with the turbine and the electromechanical equipment, electric transformer, engine, sensors of the turbine, sluices gates, silt basin, the pipeline and then the concrete?	☐	☐	☐	☐
Did you prioritize the disassembly of components or materials with higher economic value?	☐	☐	☐	☐
Did you prioritize the disassembly of more easily damageable components?	☐	☐	☐	☐
Did you engage modular structures?	☐	☐	☐	☐
If readymade concrete parts are in place, did you design those to be easily assembled/ disassembled and provide an assembly scheme to be put on site?	☐	☐	☐	☐
Did you divide the product into easily separable and manipulable sub-assemblies?	☐	☐	☐	☐
Did you separate the casing of the turbine from the wheel with buckets?	☐	☐	☐	☐
Did you minimise overall dimensions of the product?	☐	☐	☐	☐
Did you minimise hierarchically dependent connections between components?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you provide an opposite scheme of disassembly?	☐	☐	☐	☐
Did you minimise different directions in the disassembly route of components and materials?	☐	☐	☐	☐
Did you choose a readymade concrete provider that has a disassembly route?	☐	☐	☐	☐
Did you choose disassembly processors that can process electric components and metal pieces?	☐	☐	☐	☐
Did you increase the linearity of the disassembly route?	☐	☐	☐	☐
Did you engage a sandwich system of disassembly with central joining elements?	☐	☐	☐	☐
Did you easily disassemble the turbine and the powerhouse building with a crane?	☐	☐	☐	☐
Did you avoid difficult-to-handle components?	☐	☐	☐	☐
Did you avoid asymmetrical components, unless required?	☐	☐	☐	☐
Did you design leaning surfaces and grabbing features in compliance with standards?	☐	☐	☐	☐
Did you design anchoring features that are easily attachable to the crane cables for the readymade components?	☐	☐	☐	☐
Did you arrange leaning surfaces around the product's center of gravity?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you design for easy centering on the component base?	☐	☐	☐	☐
Did you avoid joining systems that require simultaneous interventions for opening?	☐	☐	☐	☐
Did you minimise the overall number of fasteners?	☐	☐	☐	☐
Did you minimise the overall number of different fastener types by using readymade components for the concrete parts?	☐	☐	☐	☐
Did you avoid difficult-to-handle fasteners?	☐	☐	☐	☐
Did you design accessible and recognizable entrances for dismantling?	☐	☐	☐	☐
Did you use a marking arrow system?	☐	☐	☐	☐
Did you design accessible and controllable dismantling points?	☐	☐	☐	☐
Did you employ two-way snap-fit for the electrical components?	☐	☐	☐	☐
Did you employ joints that are opened with common tools?	☐	☐	☐	☐
Did you employ joints that are opened with special tools, when opening could be dangerous?	☐	☐	☐	☐
Did you design joints made of materials that become reversible only in determined conditions ?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use screws with hexagonal heads?	☐	☐	☐	☐
Did you prefer removable nuts and clips to self-tapping screws?	☐	☐	☐	☐
Did you use screws made of materials compatible with joint components, to avoid their separation before recycling?	☐	☐	☐	☐
Did you avoid rivets on incompatible materials?	☐	☐	☐	☐
Did you avoid additional materials while welding?	☐	☐	☐	☐
Did you use successive coupling for plastic pipes?	☐	☐	☐	☐
Did you avoid gluing with adhesives?	☐	☐	☐	☐
Did you co-design cutting or breaking paths with appropriate separation technologies for incompatible materials separation?	☐	☐	☐	☐
Did you employ joining elements that allow their chemical or physical destruction?	☐	☐	☐	☐
Did you make the breaking points easily accessible and recognizable?	☐	☐	☐	☐
Did you provide the products with information for the beneficiary about the characteristics of crushing separation?	☐	☐	☐	☐

	YES	PARTLY	NO	NOT APPLICABLE
Did you use materials that are easily separable after being crushed?	☐	☐	☐	☐
Did you use additional parts that are easily separable after crushing of materials?	☐	☐	☐	☐
NR. OF ASWERS	☐	☐	☐	☐
PERCENTAGE (nr. aplicable checklists/ nr. answers x 100)	☐	☐	☐	☐

ECO-EFFICIENT DESIGN OF

7

part 7 final remark and future steps

9. Future steps

This thesis was concluded with the creation of a Sustainable design Guideline Handbook. This document will be available in copy left, for everyone to access.

This Handbook is intended for designer or companies that want to adopt a LCD approaches or that want to reduce the environmental burden of their products.

The Guideline Handbook contains the seven design priorities and a checklist. After a brief introduction of the LCD and LCA concepts and methodologies, the priorities are explained with the help of graphs. The structure is: priority and component for each of the parts of the SHPS (Intake, Powerhouse, Pipeline, Equipment).

After the description that points the phases or materials with high environmental impact the guidelines follow. And at the end of the book there is a checklist that tries to quantify the design achievements.

The future step for a designer that needs to project a SHPS with lower environmental impact is to redesign the product following the impact reduction design priorities.

As some of the design choice might have unexpected environmental impacts it is advised to perform a second LCA assessment and to calculate new priorities to fully understand the changes.

Only at this point the redesign can be considered finished. Even though, technological advances can develop new strategies or new material or processes that can further the redesign process and consequently reduce more the environmental impact.

10. Final Remarks

Despite of the critics brought to the life cycle assessment methodologies like the complexity and the scientific unreliability, looking at all the life cycles of a product as well as quantifying the environmental impact can shed a light on new design approaches.

The LCA of Hălmăgel power station has some shortcomings like the lack of exact and precise data about all the quantities inventoried as well as all the life cycles. However data from other LCA studies and the SimaPro software have shown that the results are correct. The overall values are slightly bigger than those of the data inside SimaPro software but the belief is that this study might have taken into consideration some phases not present in those studies.

The scope of the assessment was not to compare the results with other projects, instead the study should be considered relevant as a starting point to compare results before and after redesign of the same station. Therefore identifying the component with the highest LCA impact, which is the Rapid Pipeline is pointing out an important design choice as the environmental impact of this component represents 40% of the total, followed by the Equipment, that represents in LCA 33,4% of the total. The LCA component that ranked third is the Powerhouse with 14,65% of the total, followed by the Intake 10,45% of the total.

The rank changes when we start talking about the Strategic Design Priority Identification that shows the priority among the design guidelines.

In the Minimize Material Content which is the strategy with the highest priority the Equipment ranks first with a value of 325,5 points followed by the Pipeline with a value of 217,3 Powerhouse 180,3 and Intake 128,7 points.

The second priority is Optimization of Product Lifetime – Equipment (232,5) – Pipeline (217,3) – Powerhouse (15,7) – Intake (11,5)

The sum for the whole SHPS Optimization of lifespan the Material strategy ranked third – Powerhouse (72,2) – Pipeline (58,7) – (Equipment (46,7) – Intake (41,4). However the individual value of the Minimize toxicity calculated only for the Equipment (128,32) ranks before on a component scale.

Renewable and Bio-Compatible Resources ranks fifth – Powerhouse (14,2) – Intake (12,9) – Pipeline (0,67) and Equipment (0,65).

The last priority has the Minimize Energy strategy considered only for Equipment 1,035 points.

In conclusion the Minimize Material Content strategy has the highest priority showing that the biggest environmental gain can come from using less material, using lighter materials or more performant ones as well as minimizing the sizes of the constructions just to name a few.

A big importance should be given also to Optimization the SHPS components Lifetimes. In this LCA the lifespan of the system was assumed to be 70 years creating the need that some of the components be replaced. One component whose replacement can be avoided by good maintenance and repairs is the pipeline, and as it was just said it represents 40% of the total, not replacing it can already reduce this value to half. If the components need changing, a multiples of 70 years should be scheduled.

Against toxic hazard measurements need to be taken when handling and disposing of the cooling oil used by the turbine in the Minimize Toxicity strategy as well as avoiding toxic processes for material manufacturing.

Because large amount of materials are used for all of the components, the strategy for Optimizing the Lifespan of Materials is important for secondary use, remanufacturing, recycling or energy regain.

Renewable and Bio-Compatible Resources strategy points to use of ecofriendly materials and energy sources. Concrete, steel and plastic are materials are highly energy intensive and are not renewable and those can be replaced by new eco friendlier solutions that are developed constantly in the construction fields.

Minimize Energy strategy refers to adoption of performant lighting systems and installation of light regulating sensors as well as performant electronic components.

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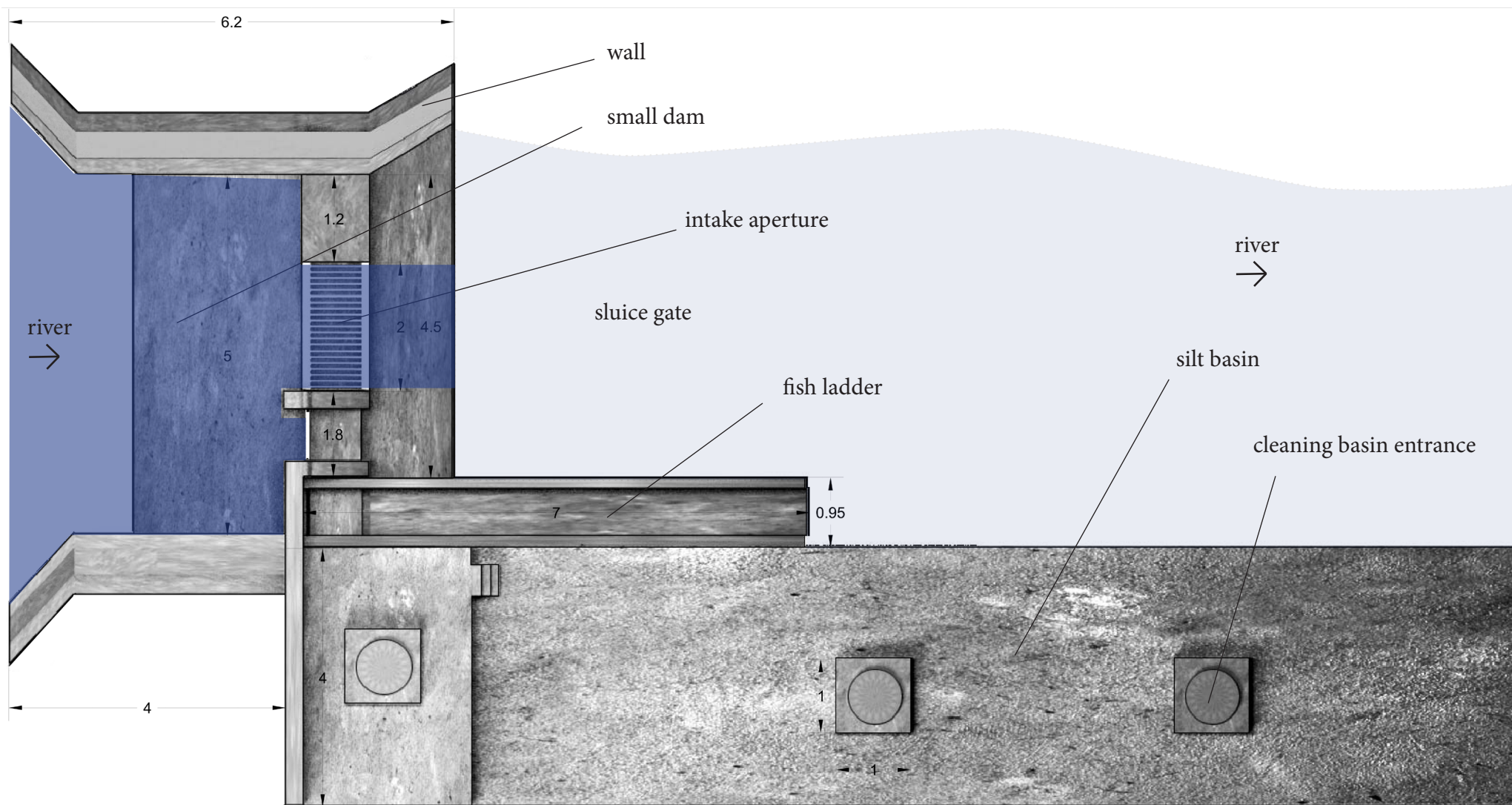
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All the images, graphs and tables not in the list are personally designed and realized by the author.
The same for the annexes.

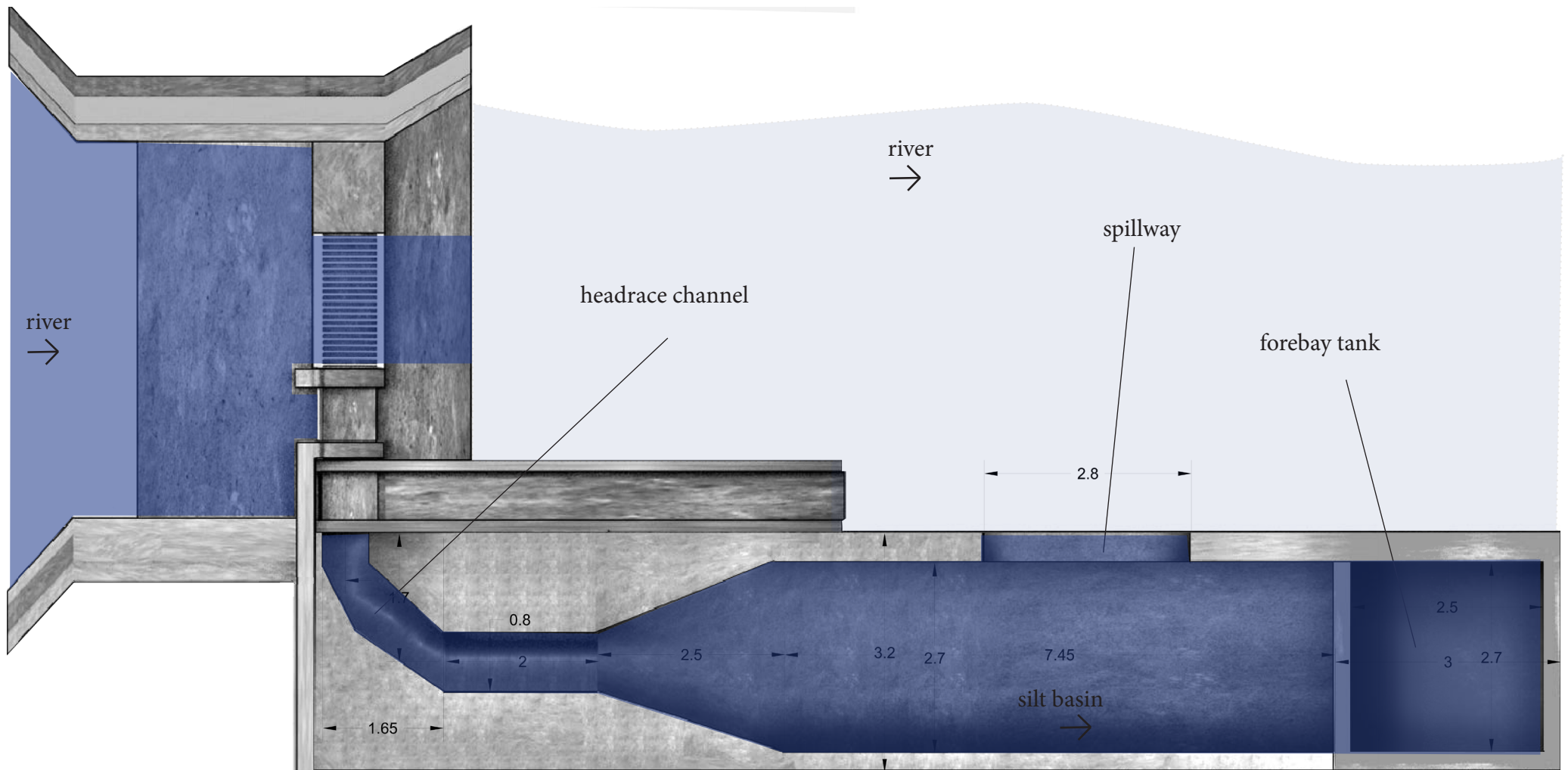


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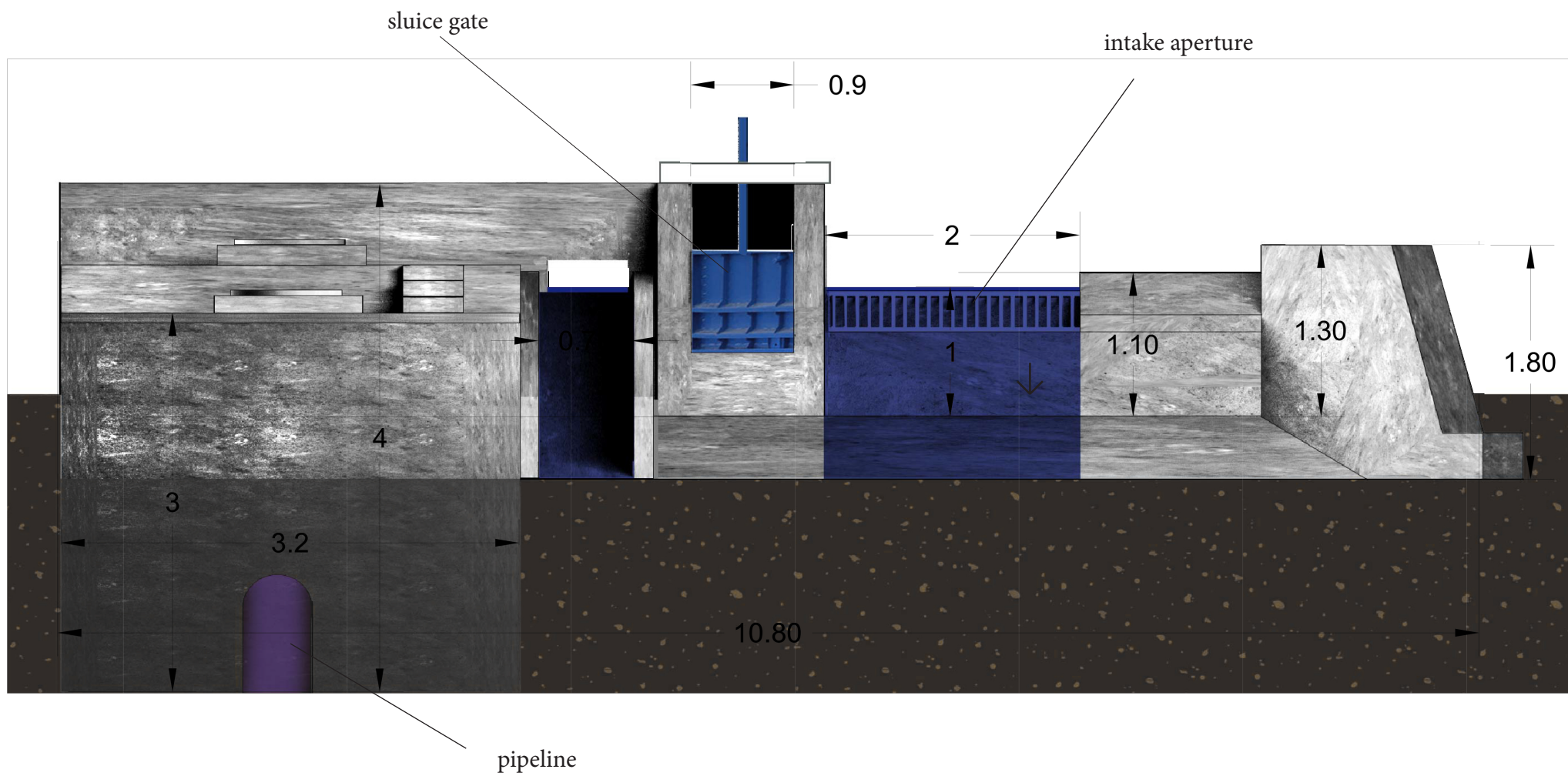
The annexes represent the gross size of the designed system. They are added for understanding the specificity of the station but do not represent highly exact data.



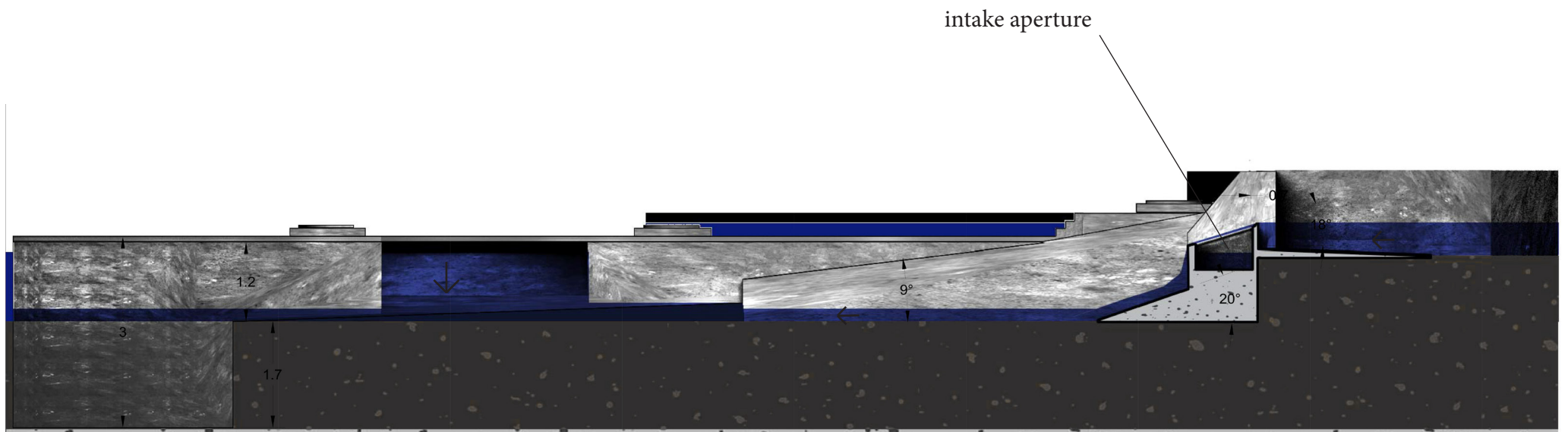
_fig. 13 - Intake system - top view



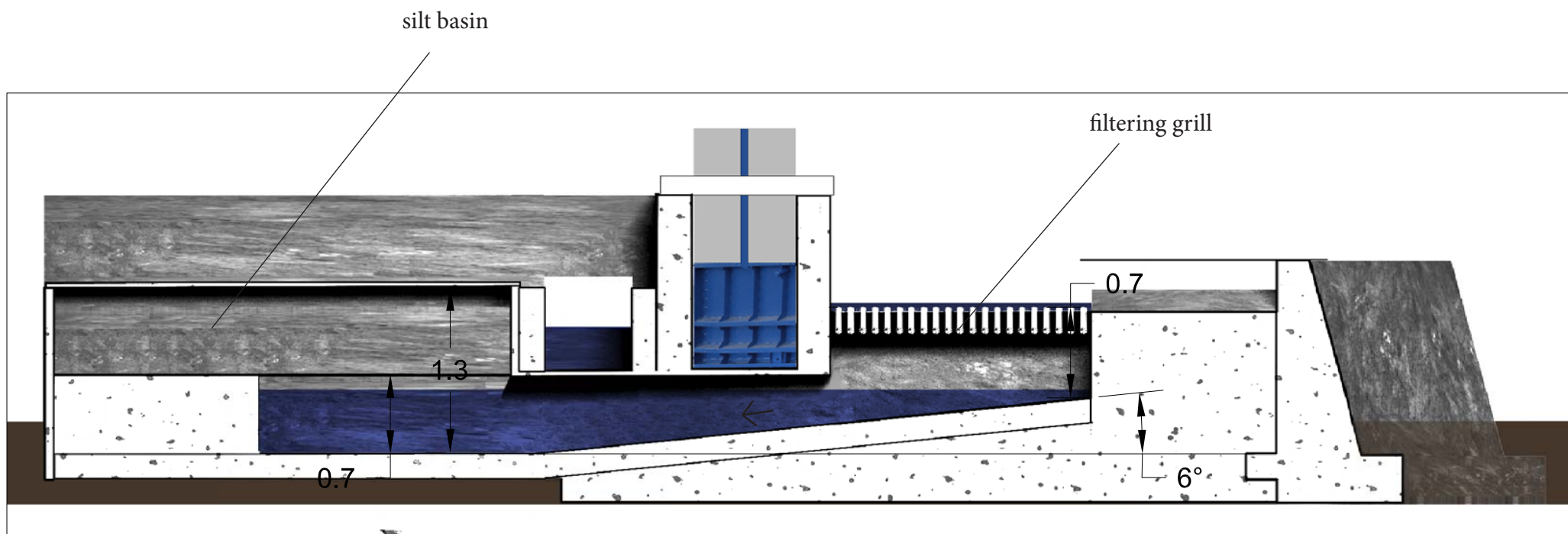
_fig. 14 - Intake system (no lid) - top view



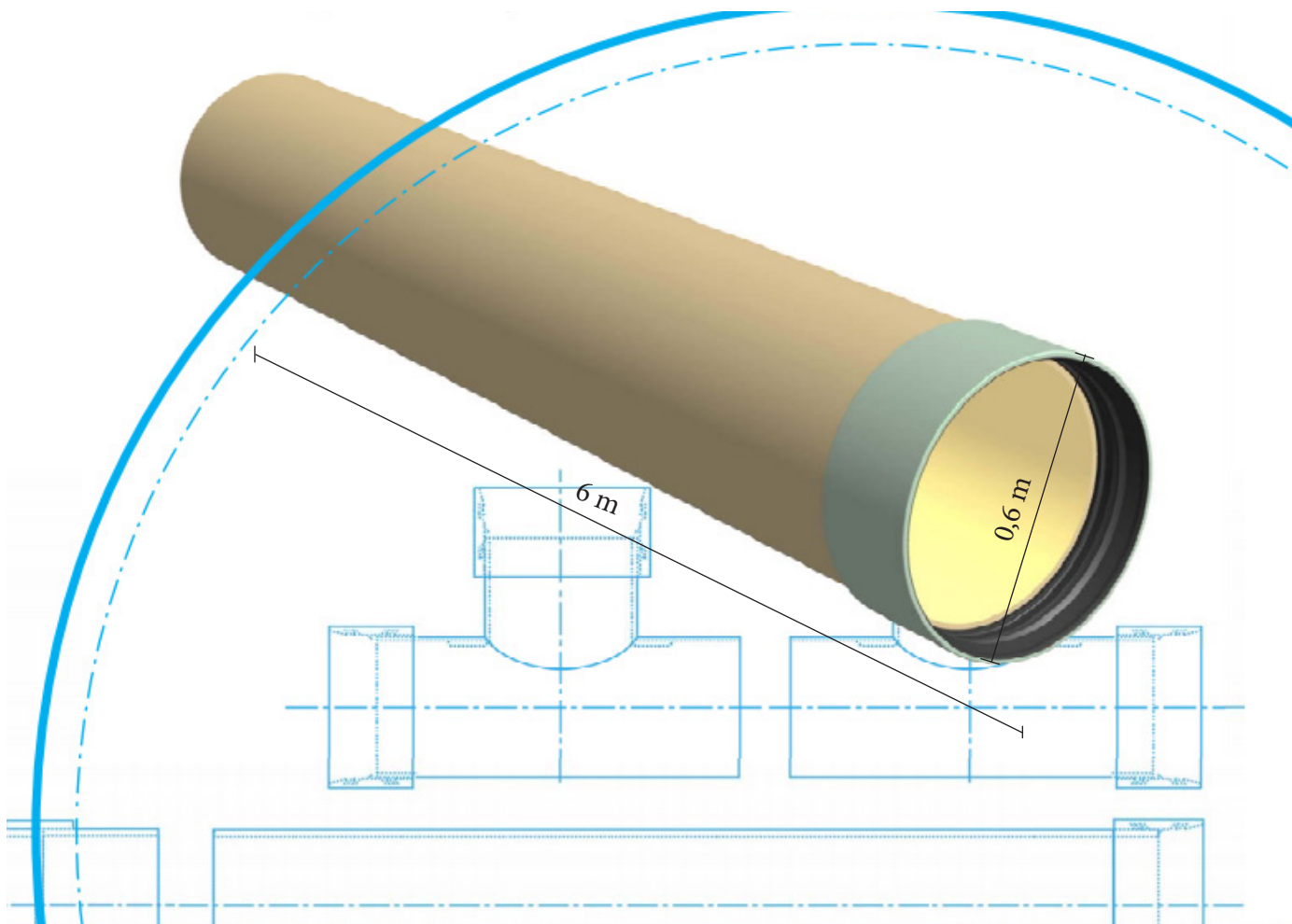
_fig. 15 - Intake system - Front view



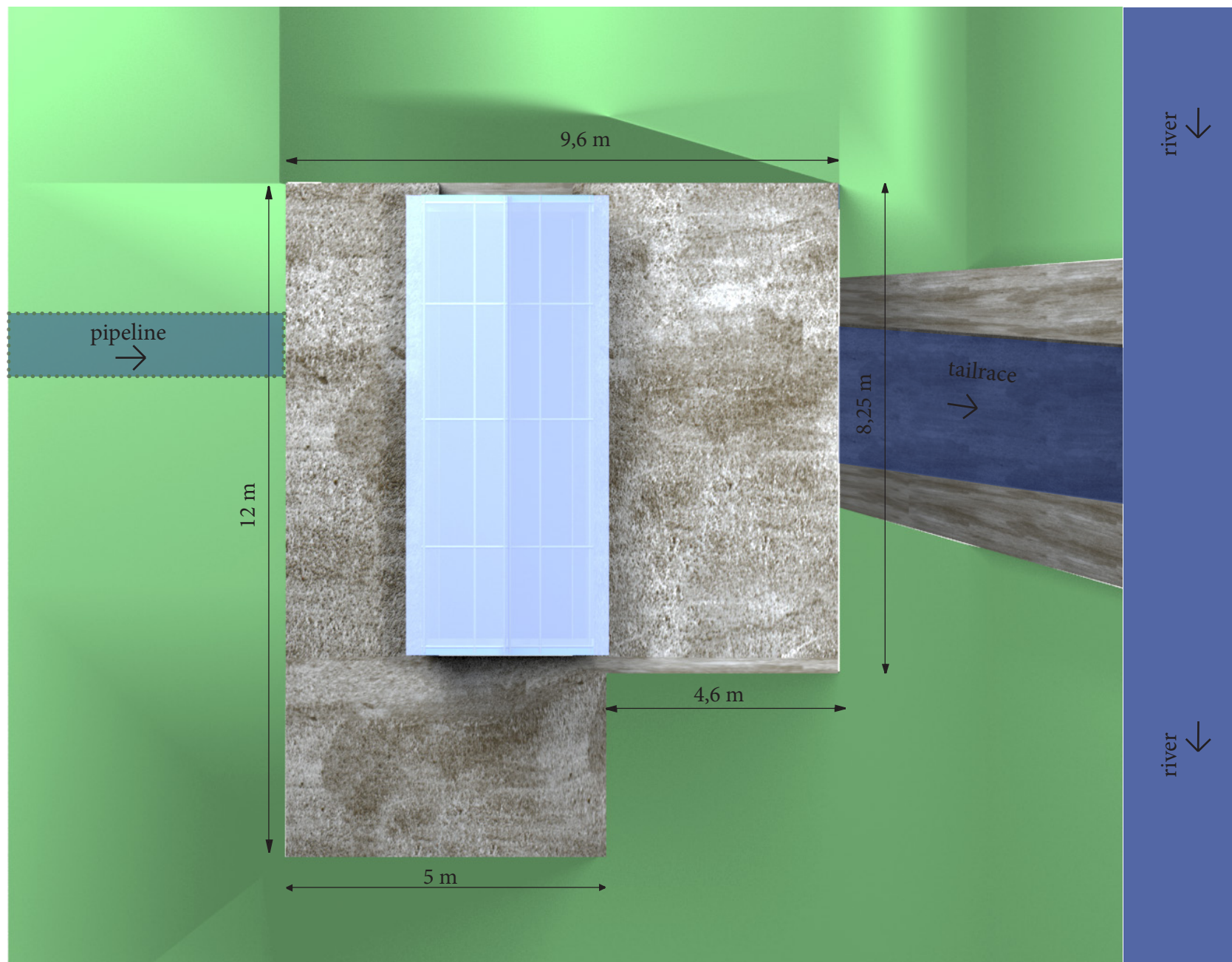
_fig. 16 - Intake system - Lateral section



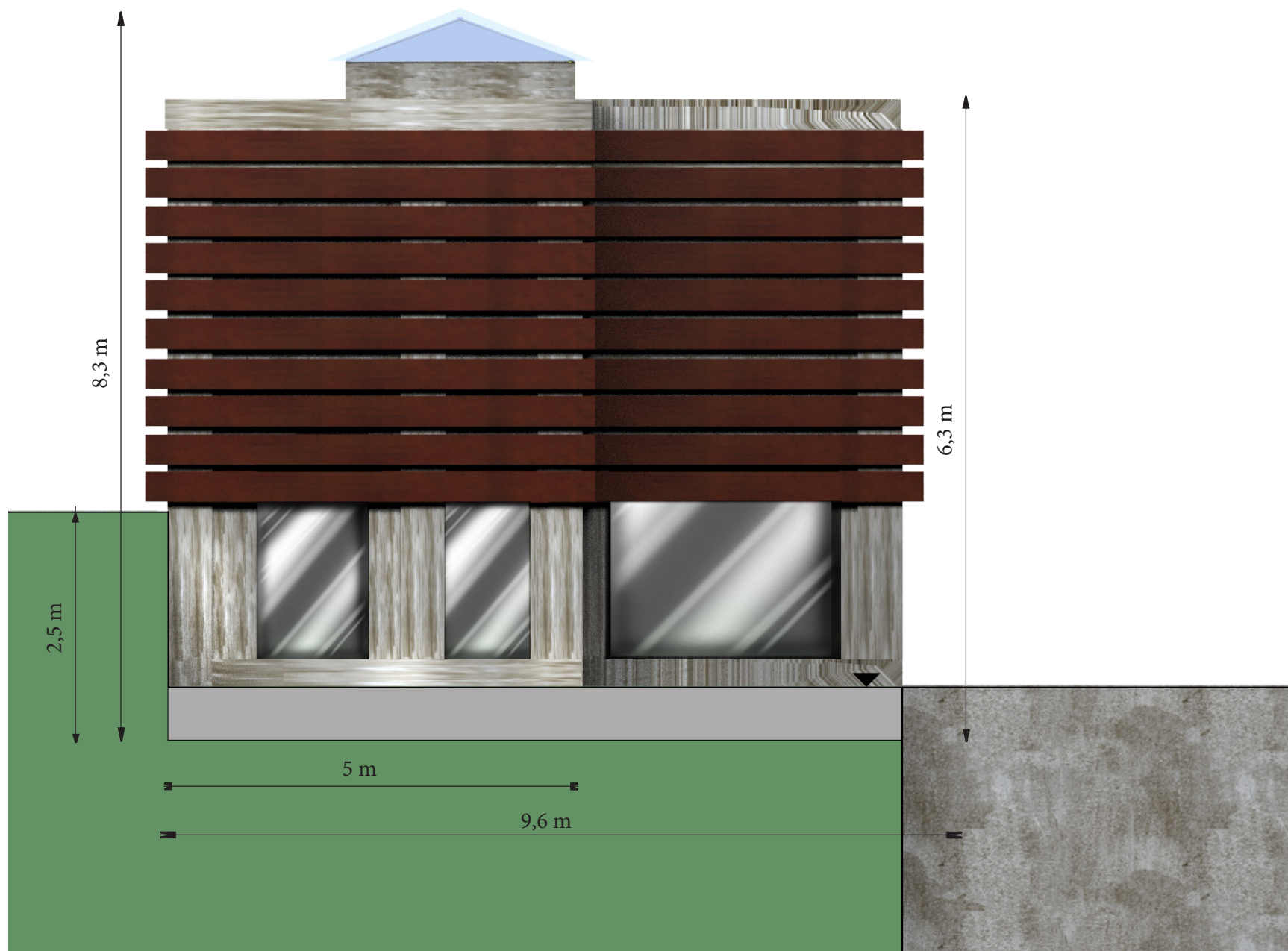
_fig. 17 - Intake system - Frontal section



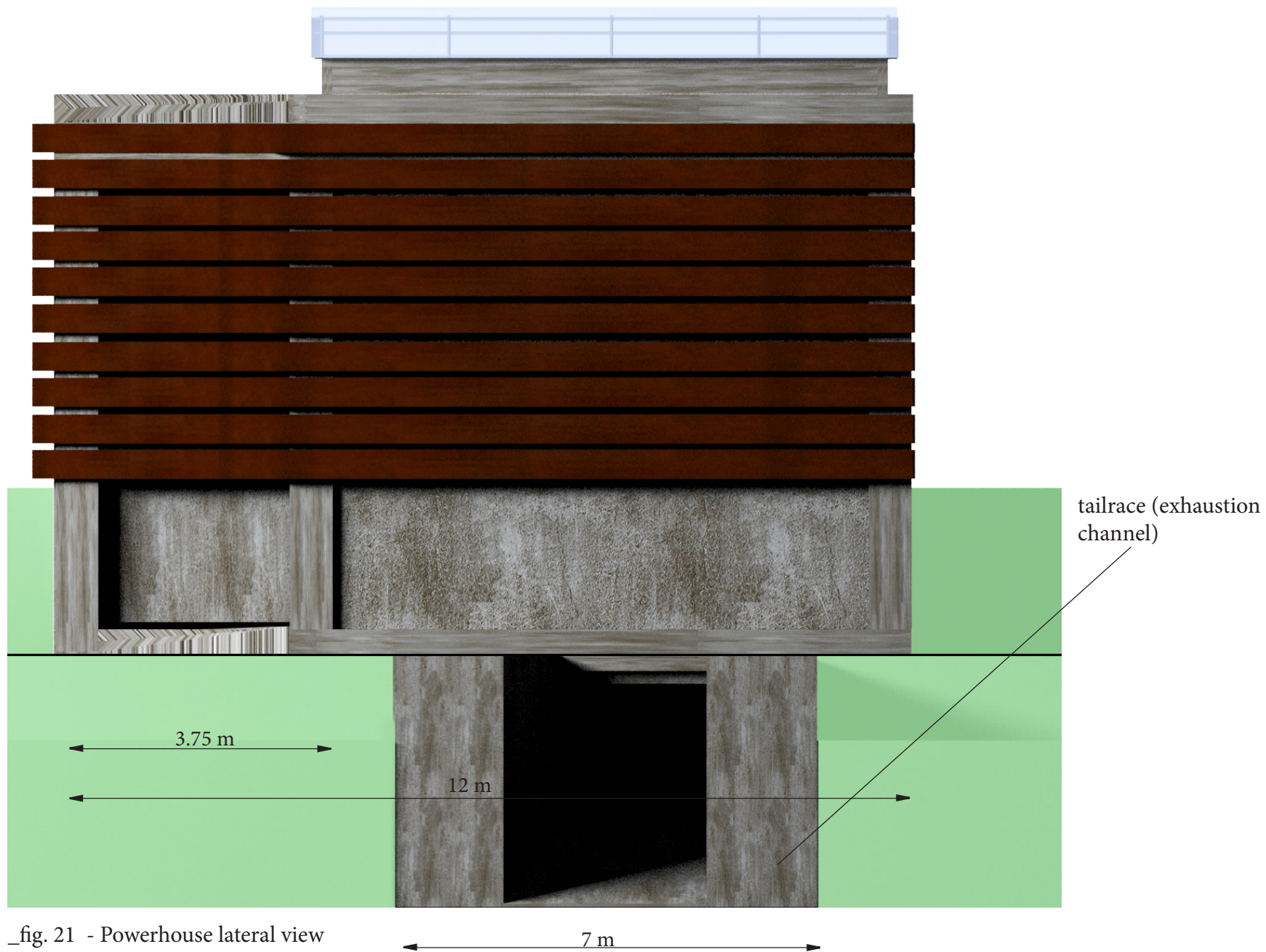
_fig. 18 - Hobas - SN 5000 N/m² Ø 600 mm, lenght 6 meters



_fig. 19 - Powerhouse top view



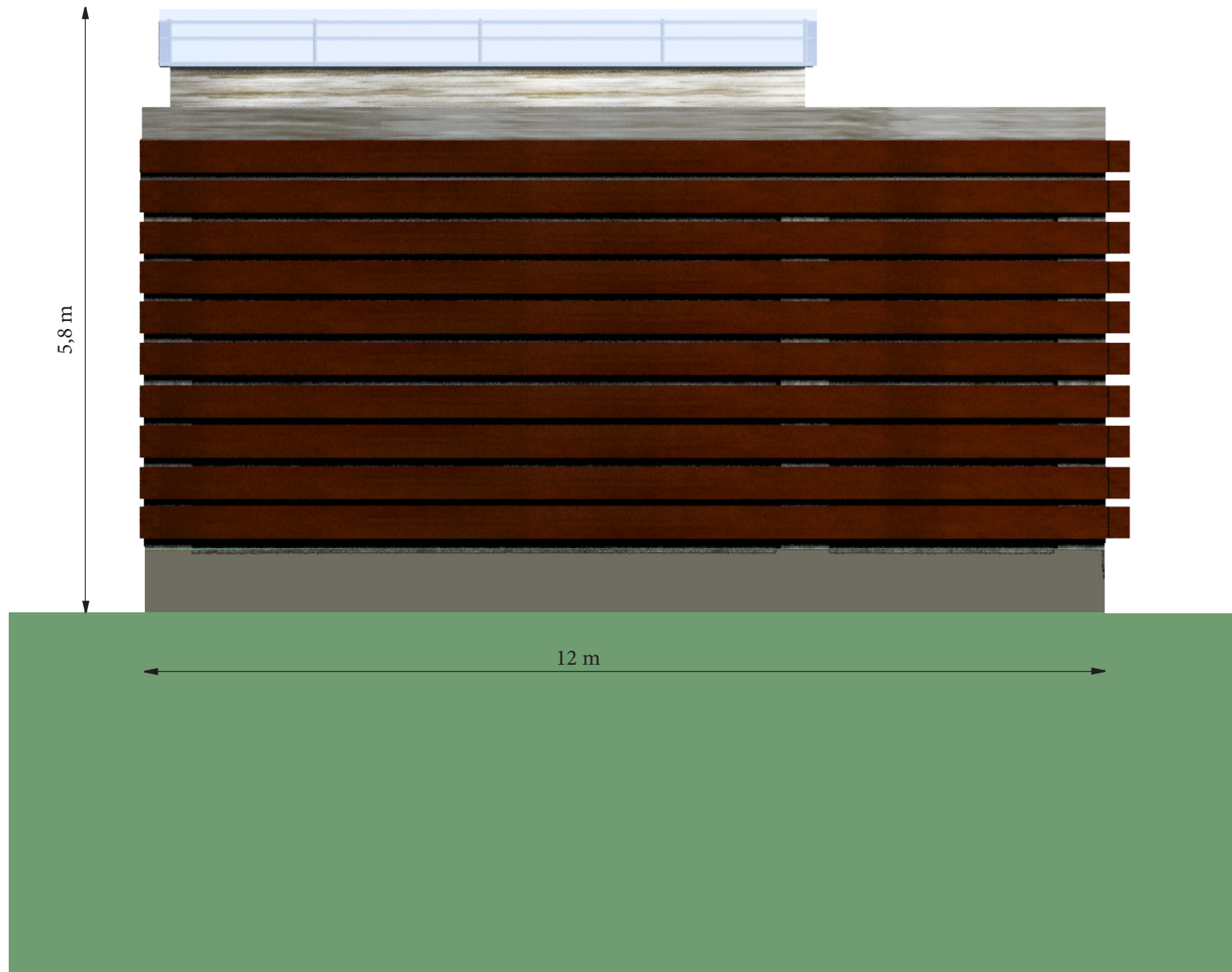
_fig. 20 - Powerhouse frontal view



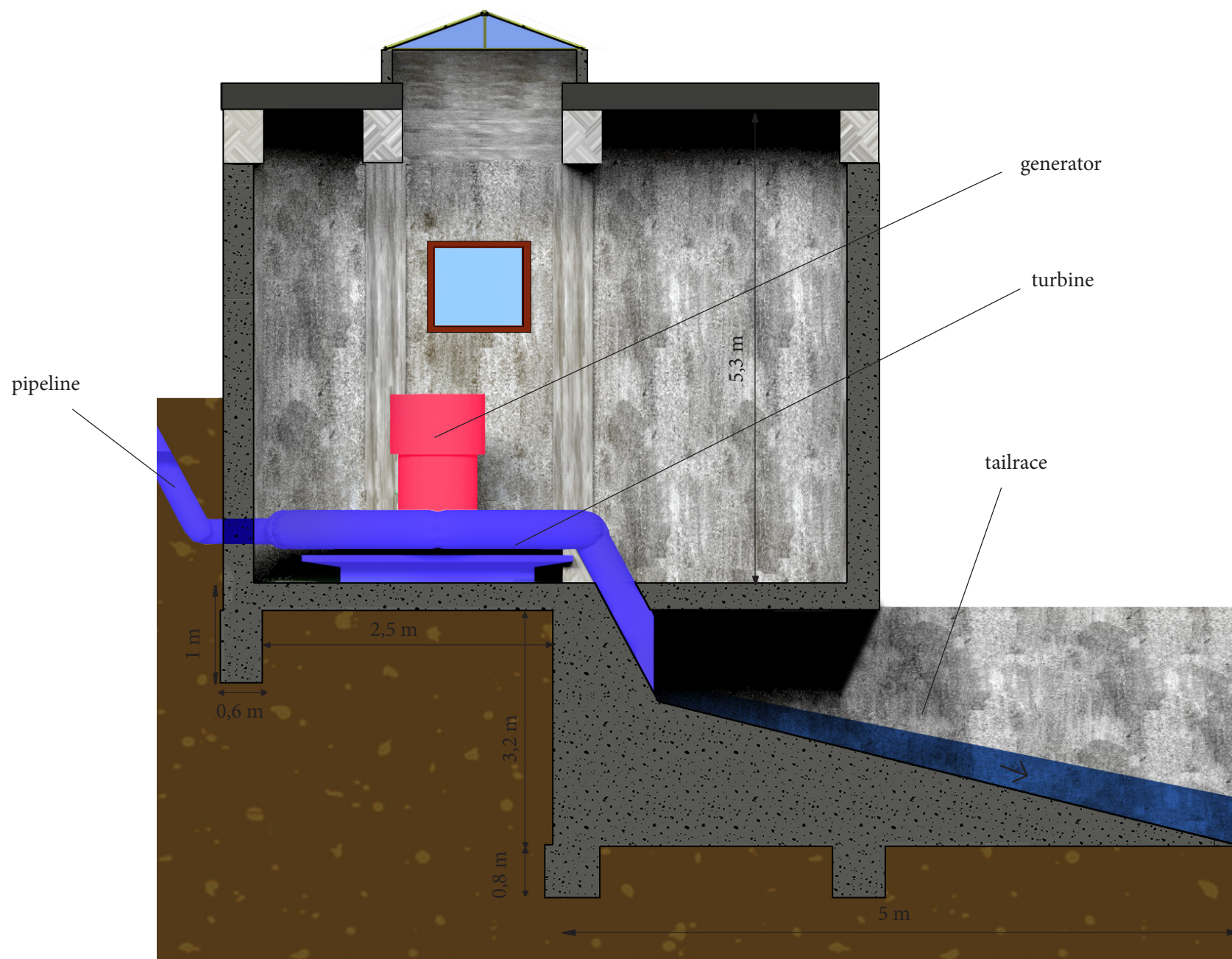
_fig. 21 - Powerhouse lateral view



_fig. 22 - Powerhouse back view



_fig. 23 - Powerhouse lateral view



_fig. 24 - Powerhouse tailrace section

