Sustainability and eco-design

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Last update: July 2018

Abstract

This lecture discusses the implications of PDD in terms of environmental sustainability and gives an overview of the corresponding mitigation measures referred under the umbrella of eco-design—a term defined as the maximisation of the ratio between the product functionality and the associated environmental impacts. In a first section, the lecture recalls the general notions of sustainability and environmental impact and links these general concepts to the design-specific concepts of product life cycle and functional unit. The second section introduces the rationale of eco-design and provides an overview of some eco-design strategies. The last section introduces some of the available tools for eco-design implementation in practice.

Contents

1 Prologue: why this lecture?

A distinctive characteristic of the typical middle-class family—a model the largest part of the fast growing word population longs for—is an overabundance of possessions, stuff and gadgetry [15]. And a rising overabundance of it: the number of energy using products typically found in a household have more than doubled between 1970 and 2000 [16] and may have continue to rise in the meantime [Slide 1]. For certain populations (e.g. US and western countries), this evolution even comes to a point where stuff and unused clutter becomes an overwhelming psychological burden for most middle-class families [2]. A point where consumption becomes counter-productive.

The global overconsumption of stuff already 'overshoots' of the Earth's limited capacity to deliver enough resources and even to deliver a stable living environment [17] [Slide 2]. Neither can the Earth offer enough resources to give everyone access to the current middle-class family model, nor can It do it for the next generations issuing from the people who already access this model. In the ethical debate about resource distribution, the term 'sustainability' speaks for the search of a life-style which can be adopted across humanity and perpetuated to next generations. And there is hope sustainability can be reached, because a lot of things we do is just inefficient [Slide 3][reference needed].

This lecture it is meant to provide you—as a designer—with an overview of the role and potential of design in contributing to sustainability.

2 Products and sustainability

According to the most widely accepted definition, *sustainable development* or *sustainability** "is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [3]. The "ability of future generation to meet their own needs" is generally understood as depending from the preservation of three types of capital: the environmental[1], social[2], and economical capitals[3].

Further efforts to break down this programmatic definition into concrete terms is inevitably bound to political implications and is therefore subject to diverging interpretations. One main topic of disagreement is whether capitals

[1] in other words: the 'nature', the 'natural resources', including living biological stock, usable mineral resources, breathable air and drinkable water, beautiful landscapes, etc.

[2] in other words: human well-being, happiness, and its constituents being eventually, health, education, equality of chances, freedom, etc.

[3] in other words: money and other forms of marketable assets.

are interchangeable, that is, for example, whether a certain amount of social capital can be sacrificed for a bit of environmental capital. In the one hand, proponents of the so-called *weak sustainability* consider the three capitals as interchangeable and of equal importance and seeks for a preservation or growth of their total balance. This school of thought tends to consider the environment from an utilitarian point of view. That is, the environment is 1) the supplier of all the resources we need to satisfy human needs and 2) the repository of all we don't need anymore. Following this idea, the 'function' of natural cycles is to absorb wastes and to turn them into restored resources. Caring about the environment is a matter of ensuring the further fulfillment of human basic needs (e.g. breathe, eat, drink, reproduce) and well-being (to which may contribute things like mediated communication, mechanised transportation, cultural creation, entertainment, comfort, representation). On the other hand, proponents of the so-called *strong sustainability* consider there should be no substitution. This school of thought tends to consider the environment from an idealistic perspective and to speak for nature rights. It assumes that preservation of the social capital is the objective of human activity; those of the economical capital is a mean to achieve it; those of the environmental capital is understood as a condition. Weak sustainability is generally represented as a Venn diagram and strong sustainability as concentric circles [Slide 4]. Adhesion to one or the other school of thought is ultimately a question of *Weltanschauung*, one's world view, their own philosophy.

Without taking position in this debate, we can state that the sustainability of human activities relates to the extent to which they:

- create social value (they are *useful* to someone). Social value is assumed to be positive and is to be maximized.
- contributes to environmental degradation (they have *environmental impacts**). Environmental degradation is assumed to be negative and is to be minimized.
- participate to the creation of economical value added (they can be charged for money). From the point of view of the firm, economical value added is considered as positive and is to be maximized to ensure viability. The weak and strong sustainability disagree on whether economical value added has to be maximized from a macroeconomic point of view.

Consequently, in the context of this lecture, we consider that caring for sustainability consists in maximising social value and minimising the associated environmental impacts while contributing to economical viability. In the following, we further consider that the economical and social aspects of sustainability are already understood and therefore focus on explaining the environmental dimension.

2.1 Environmental impacts

Let's approach the concept of environmental impact with a simple analogy: suppose you want—whatever the reason—to dig a hole in your well-grassed garden [Slide 5]. By doing it, you reduce the available surface to dig another hole in your garden, that is, you consume a specific resource which is the "area of nicely grassed ground". This resource becomes more scarce than it was before. Digging a hole also inevitably creates a heap somewhere else, further reducing the resource "area of nicely grassed ground" of an additional amount (the surface of the heap base).

In this analogy, the hole stands for the *consumption**, the heap stands for the *pollution** and both together stand for the *depletion of a resource** (the garden area). Resource depletion refers to a decrease in the available stock of resources—to the destruction of a bit of what we called earlier the "environmental capital". Environmental impact is the marginal contribution of a process to this depletion due to the direct consumption of resources or through the emission substances leading to its pollution. It is the combination of marginal environmental impacts generated by a large amount of diverse activities (like commuting in London) which generates pollution.

This stated, let's now have a closer look at the kind of resources can be depleted by consumption and what kind of pollution can contribute to this depletion.

2.1.1 Resource consumption, depletion and restoration

Consumption can either take the form of a destruction of the resource or its dispersion to an extent which hinders further use. An example of dispersion is the use of precious metals in semiconductors: extracting the ores, refining the metals, embedding them in products and using these products does not obliterate the chemical elements, it just leads to their geographic dispersion which ultimately makes them unavailable for further industrial use. An example of resource destruction is the combustion of oil-based fuels: the resource disappears as it is transformed into something else (CO_2, among others). Resources ongoing destructive processes may further either be renewable or non-renewable. Destructed renewable resources can be restored, either through natural cycles (like clean freshwater) or through human intervention (like food). In this case, depletion happens when the destruction of resources is quicker than the ability of the restoring mechanism to replenish the stock. The destruction of non-renewable resources can neither be restored by natural cycles nor by human intervention. Once a species is extinguished, once nuclear or fossil fuel is burnt, there is no comeback.

Excessive consumption is already or is about to become a critical issue for a large variety of economic sectors [Slide 6]. The remaining reserves of some precious metals like gallium and arsenic (used in semiconductors), indium and silver (used in photovoltaic panels), as well as gold and silver (used in electronic circuits) may be depleted in 5 to 50 years if consumption and disposal continues at present rate [6]. Those of uranium (used for nuclear energy production) as well as cadmium and nickel (used in batteries) may be depleted within 50 to 100 years (*ibid.*). The depletion of other resources like oil, coal or wild fish is a well-known issue often covered in the media. The depletion of phosphate rock is another less covered ongoing issue threatening agriculture worldwide [5].

2.1.2 Pollution

Pollution is defined as the introduction of physical (e.g. radiation, chemical substances) or biological (e.g. manure, seeds) agents into an ecosystem to an amount it cannot be absorbed, hence leading to its adverse disruption [Slide 7]. Pollution can be either natural (like the disastrous eruption of Mount St. Helens in 1980 and reducing hundreds of square miles to wasteland) or anthropogenic (like the "smog" affecting the health of citizen in urban environments). It can either be accidental (like the Fukushima nuclear disaster) or chronic (like the smog, once again). Its causes can either be isolated (like in the case of the Hinkley groundwater contamination) or dispersed (like the omnipresence of long-lasting waste in oceans). Among the most often considered the anthropogenic, chronic and dispersed pollutions are [Slide 8]:

- eutrophication: excessive growth of algae or plants in a body of water resulting from the excessive intake of nutrients such as nitrates or phosphates.
- acid rains: unusual acidity of rainfalls due to emissions of sulfur dioxide and nitrogen oxyde in the air
- ozone hole: depletion of the stratospheric ozone layer at Earth's poles due to the emission of ozone depleting substances such as CFCs, leading to a reduced share of UV radiation dispersed by the ozone layer.
- smog: noxious smoky fog hitting dense urban areas, composed of airborne particles and chemical compounds generated by combustion and leading to respiratory issues.
- global warming: rise in the average temperature of the Earth's surface resulting from an increased atmospheric greenhouse effect due to the massive airborne release of greenhouse gases such as carbon dioxide and or methane
- light pollution: high concentration of misdirected light at night in densely populated areas which may cause diffuse and chronic adverse effects on human health and disrupts wild life (e.g. bird migration)
- land use: anthropogenic transformation of the natural terrestrial environment into functional spaces, leading to various adverse effects such as reduction of biodiversity, soil erosion, and water quality reduction.

These examples show that there isn't *one* pollution but rather a variety of ways ecosystems can be affected by anthropogenic activities. Different effects may even influence each other and be produced by the same agents, like the ozone depletion and global warming having complex interrelations and both being influenced by CFC emissions. Pollution may also affect complex sets of resources in a way that is not always understood, like global warming not only affecting weather conditions, but fresh water stock, also emmerged land, biological stock etc...

2.1.3 Measuring enivonmental impacts

Unfortunately, there is no global reference of resources that need to be preserved from depletion. One reason is the absence of agreement on what is to be considered as an important resource. Buddhist people would have directly thought about the well-being of bugs and worms in the garden analogy, other wouldn't. Opinions may differ whether the well-being of bugs is important, whether the available garden area is more important than the well-being of bugs, or whether these things are important at all. This also illustrates that there is no consensus on the relative importance of resources. Is it worse to contribute to ozone layer depletion or to the disruption of bee colonies? [Slide 9] All this is the expression of ethical values underpinning different positions in the debate between strong and weak sustainability. Another reason is the partly unequal global distribution of resources, making them differently critical for local populations: some regions have enough fresh water not to care about it, some countries have enough oil not to care about energy. A third reason is the absence of agreement on mechanisms to allocate critical resources, which is an utterly political topic.

There is no global reference of pollutions that need to be mitigated as well. One reason is that some of them are localized, such as smog and light pollution only affecting urban areas. Whether pollution is considered as detrimental also depends on the perceived criticality of the resources involved in the affected ecosystem—and we have seen that there is no global consensus on that. Nevertheless, there are examples of measures to mitigate specific pollutions at global level, such as the United Nations Framework Convention on Climate Change, or the Montreal Protocol on Substances that Deplete the Ozone Layer. A larger number and variety of agreements can be found at regional level, like the legally binding European emission standards for new vehicles or more local levels.

In spite of this lack of consensus, different approaches have been developed to define indicator sets or aggregated indicators of environmental impacts, such as EI99 [4], Impact 2002+ [13], ILCD 2011 or ReCiPe 2008 [10] [Slide 10]. These indicators allow masking the complexity of environmental impacts behind a single or a few summarizing figures. They are useful for practitioners wanting to take environmental impact into account in decision making without being environmental experts or needing to take position on the relative importance of environmental impacts on behalf of their customers. Nonetheless, these indicators cannot account for the whole complexity of eco-systemic mechanisms and remain are based on simplified models and ethical assumptions. Practitioners still need to make a choice between these indicators and apply them, which still requires some expertise.

2.1.4 About irreversibility, or why less is better

Thermodynamic delivers us nice concepts to bypass this difficulty and to find simpler concepts to lean upon. In thermodynamical terms, depletion of resources can be termed as creation of *entropy*. And the second law of thermodynamics tells us an interesting thing about entropy: in a closed system, it inescapably increases.

Let's apply this to the garden analogy. Suppose now you don't need the hole anymore and want to put everything back in place. You can restore the previous situation by putting the heap back in the hole. The result will however only *approximate* the original situation: you will still have a discontinuity in the grass where the hole was and eventually a damaged grass where the heap was. Restoring the soil and grass in *exactly* the same condition would require way more time and energy than what was necessary to dig the hole (e.g. you will eventually need to grow new grass). Because, in thermodynamical terms, what you want to do is to remove from the system the entropy you added by digging the hole. Removing entropy from a closed system requires creating elsewhere more entropy than the amount you want to remove. The domain of water management delivers another illustration of this principle of irreversibility [Slide 11]: mixing freshwater with any kind of liquid pollutant is easy and barely requires energy. But reversing the process, that is, separating the liquids, is difficult and may requires a lot of energy. What thermodynamics says, in other words: the energy required to mess up something is lower than those required to tidy it up.

Another interpretation of the second law of thermodynamics is that creating order somewhere is inescapably bond to creating more disorder somewhere else. The more organized you want the matter to get, the more disorder you have to create somewhere else. An illustration of this is provided by the semiconductor industry: the production of a 2g microchip, which embeds a fairly high organisation of matter requiring high material purity, requires more than 1.7kg of matter [19]. That is, only 1.1% of all matter involved in the production process ends up in the final product, 98.9% turns out to be waste. Creating a platinum ring requires refining approx. 100kg of ores [8], building a car 70t [12], sending an SMS 600g [9]. Creating fancy things creates huge messes.

Understanding environmental impact as entropy amounts to say that every activity has an environmental impact, which is irreversible. Trying to restore some resources (to "recycle" them) would only make the whole set of resources worse. Consequently, the best way to avoid environmental impact is to reduce activity. Less is better. In other words, the more social value is created out of the minimum activity, the better. Sustainability is about reducing waste, understood in the sense of the consumption of a resource which is not bound to human satisfaction.

Take-aways of this subsection:

- *The environmental issue considered in sustainability is* resource depletion*
- *Resources can either be depleted by* consumption* *or by* pollution*
- *Humans decide upon the importance of resources, and humans don't always agree*
- *The* environmental impact* *of a process is its marginal contribution to resource depletion*
- *Every activity has an environmental impact, even resource restoration activities*
- *Less is better*

Exercise 1. In groups of 4 people, discuss which environmental impacts you consider as important, how your views may fit with your future job sheet and the local conditions you are living in. Try to mix nationalities by constituting the groups, this will increase the chances to have conflicting opinions and enhance discussion.

2.2 Eco-efficiency of products

Talking about products, where are the environmental impacts coming from? When my TV is off, it does not do anything harmful for anybody, it is just an inert object. That is, the mere existence of products does not create environmental impacts. Rather, products are middle things between social needs (watching TV) and large and complex networks of activities caused by the realisation of these needs: the TV needed to be fabricated so I can have it, because I have it I can plug in to the mains and turn it on, because it will inevitably become a waste product it will need to be processed or will come back to the environment and may leak harmful substances. As we said earlier: each activity has environmental impacts. The environmental impacts associated with products sums up to those of all activities which contributed to the delivery of its specific functionality. The set of all these activities is called the *product life cycle**. The specific functionality is called the *functional unit**. The ratio between the sum of all impacts created within the product life cycle and its functional unit is called the *eco-efficiency**. Improving the sustainability of a product amounts to improve its eco-efficiency, which requires analyzing both the product life cycle and the functional unit.

2.2.1 Product life cycle

The concept of product life cycle is generally represented as a circle of chronological stages [Slide 12][4]. Typical stages are:

[4] not to be mistaken with the product life cycle used in innovation management

- Raw materials extraction: resources are taken from their natural state, eventually refined and transformed into semi-manufactured products (e.g. bauxite is excavated, processed to produce alumina, smelted to product raw metal aluminium blocks)
- Manufacturing: semi-finished products are turned into functional components with the help of diverse processes (milling, casting, etc.), which are in turn assembled into finished products and packaged for distribution
- Transport and distribution: products are transported from point of production to point of use, eventually involving diverse intermediaries (retailers, warehouses, etc.)
- Use: products deliver their functionality for the end-user, eventually in combination with other products or consumables (ink cartridges and electricity), leading to product fatigue, eventually requiring maintenance, reparation, and overhaul
- End-of-life: discarded products can be repaired, remanufactured, their materials recycled, hence avoiding the need to extract raw materials for future product generations, or sent to landfill.

This representation is simplistic in the sense it suggests that a product life cycle is either a linear process with a single entry point (raw material extraction) and end point (landfill) or a perfectly circular process. In reality, the product life cycle is rather a complex network of interconnected activities taking inputs from different entry points and producing different products as well as more or less wished by-products [Slide 13]. Each of these activities involve what are called *elementary* and *non-elementary flows**. Elementary flows are either direct inputs from natural resources (e.g. O_2 intake in combustion) or direct outputs to the environment (e.g. consequent NO_x emission back in the air). Non-elementary flows are anthropogenically produced things, i.e. which are the product of human intervention (e.g. diesel, TV). The environmental impact of a product is the sum of all elementary flows of all processes involved in its life cycle. The example of all non-elementary flows involved in the production of bread shows how complicated life cycles can be even for simple products [Slide 14] [1].

2.2.2 Functional unit

The functional unit is a measure of the amount of functionality delivered by a product. This amount is defined in both qualitative and quantitative terms: *what* is delivered by the product and *how much* of it it can deliver. For example, the functional unit of a pen is not only given by its specific function—which is to draw a visible line on a predefined range of materials—but also by the total length it can draw (e.g. 2km) [Slide 15].

The quantitative part of the functional unit is important because it delivers the only reference allowing to compare the eco-efficiency of products objectively.

If two pens deliver the same functional quality (same line characteristics such as darkness and regularity), have the same environmental impacts, but one of them can draw half the length of the other, then it is clear which of them is the most eco-efficient. It is more difficult—and often does not make any sense—to compare the environmental impacts of two products having diverging functions. What if two pens deliver lines of different thicknesses? What creates the most usage value: a car or a cell phone?

The extent to which the potential quantity of functionality a product can deliver is actually realised depends on usage patterns. This encompasses on the one side the appropriateness of the usage but also on the willingness of the user to *exhaust* the potential of a product. A typical example of this phenomenon is the cell phone: there is a high probability that you have one of them sleeping in one of your drawers at home [11] [Slide 16]. These products can still deliver their functionality, but they have become obsolete, either for structural reasons (switch from 3G to 4G) or as a result of changing fashion (new iPhone coming out), among other possible reasons. Therefore, it is not only interesting to have a look at the potential quantity of functionality delivered by a product, but also at the extent to which users turn this potential into reality.

2.2.3 The role of design in product eco-efficiency

There is a word of saying that 80% of the costs of a product are engaged by its design, the rest being the influenced by the later intervention of other stakeholders of the product life cycle, like the manufacturer and the user [Slide 17]. Another common place is that the cost of changes increase with time along the product development process. The same applies to the environmental impacts. This is due to the fact that the essence of design is to make *prescriptive* decisions. When you decide a product, you decide how the product should be manufactured (because you define materials, shapes, and assembly principles) and used. You therefore decide upon the cost and the environmental impacts of manufacturing and use. Stakeholders of the product life cycle still have a certain degree of freedom, yet constrained by your decisions. Similarly, decisions taken at the early design stages constraints the degrees of freedom at later stages. Hence, the best time to think about eco-efficiency is in the early design stages.

Take-aways of this subsection:

- *The sustainability of a product is given by its* eco-efficiency*
- *Eco-efficiency is the ratio between two quantities: impact and function*
- *The quantity of impacts is given by the sum of all* elementary flows* *involved in the* product life cycle*
- *The quantity of function is given by the* functional unit*
- *You can only compare the eco-efficiency of products having the same function*

- *The earlier you think about sustainability in the product development process, the better.*

Exercise 2. Try to define in which terms the eco-efficiency of a car could be defined. How does the product life cycle looks like? What are the major elementary flows? What is the functional unit of a car? Where could be impacts avoided or functionality gained?

3 Eco-design

There is no magical formula to increase the eco-efficiency of products; no systematic method leading invariably to positive results. The essence of design is to develop solutions for open, complex and ill-defined problems. And for those problems, there is generally no systematic method designers can be provided with in order to derive optimal solutions.

Nonetheless, like any other design parameter, eco-efficiency can be approached through a simple rational process in four steps:

- Setting up objectives: what do I want to do and what are my motivations for that?
- Assessing the initial situation: how far am I from my objectives?
- Looking for solutions: what can I do to reach my objectives?
- Checking progress: did the action improved the initial situation?

3.1 Setting up objectives

Successful integration of eco-efficiency as a product requirement in design requires identifying an underlying motivation (why should we do that?) and a clear set of quantified objectives (what do we aim for). In the first subsection, we review the different possible motivations for a company to engage into eco-design. In the second section, we review the different schemes a company can lean upon to identify sound objectives.

3.1.1 Motivations for eco-design

There is a wide range of reasons why a company may have interest in engaging in eco-design. Among these:

- External factors:
  - Legislation. While environmental regulation generally focus on companies and factories, some of them, especially in the EU, focus on products. This is the case of the EU directive 2009/125/EC called

"ErP" (Energy-related Products), also known as the "European ecodesign directive". This directive sets targets for in-use energy consumption for of energy-using products (like home appliances such as fridges) as well as energy-related performance targets for products having influence on energy consumption (like tyres) [Slide 18]. Electric and electronic products are also indirectly targeted by the EU directive 2012/19/EU called "WEEE" (Waste Electrical and Electronic Equipment). This directive requires producers of electric and electronic product to participate in the establishment of recycling efforts. While this directive does not directly set requirements to products, it creates incentives for producers to manufacture products which are easy to recycle. Compliance with these directives are required for the product to carry the CE marking.

  - Societal pressure. As eco-efficiency is increasingly being acknowledged by the general public as a valuable product feature, demand for explicitly labeled 'eco-friendly' products increases and those for products with negative environmental image decreases. Today's marketing teams have all in mind the story of large companies like Nike or Gap whose questionable behavior (e.g. bad working conditions, child labor) have been publicly exposed in works like No Logo from Naomi Klein in the 90's, leading to negative customer reactions [Slide 19]. Today, the reputation of a large company is constantly kept under scrutiny, leaving companies little space for neglecting their social responsibility. At the same time, compliance with sustainable practice became a competitive argument. This is shown by the emergence of a large variety of product labels related to sustainability we will look at in more detail in the next section (3.1.2).

- Internal factors:

  - Cost reduction: As we stated in the previous section: less is better. Eco-design is about reducing waste, that is, the consumption of a resource which is not bound to human satisfaction. And if it is not bound to human satisfaction, there is a high probability you won't be able to charge for it. And if you can't charge for it, it is a cost for you. Eco-design can be a strategy to hunt unnecessary costs and to increase the economic viability of a company [Slide 20]. In this sense, eco-design is close to management approaches like lean manufacturing which are targeted at the systematic identification and elimination of unnecessary efforts.
  - Internal momentum: eco-design can participate to the general effort of a company to establish a corporate culture [Slide 21]. Sustainability conveys positive value, which can act as a motivating factor for employees and support constructive mind sets. Because eco-design requires the involvement of all departments of a company, the establishment of an organisational structure to support eco-design can

lead to more communication between departments and lead to positive side effects such as the early identification of mistakes and misunderstandings.

While external factors give the impression that sustainability is an additional constraint burdening companies, the internal factors show that engaging in eco-design can turn into net benefits. Eco-designed products are not necessarily more expensive, contrarily to the general belief.

3.1.2 Where to search for help to define eco-design objectives?

Section 2 and especially 2.1.3 depicted a rather puzzling picture of sustainability as it stated that there is no global reference of environmental impacts which have to be cared for. Wile there is no generally applicable reference, there may be standards applying to specific geographic regions or to specific product branches. These standards discharge companies of the burden to define by themselves which environmental impacts they need to consider, which volume of impact is acceptable and how to measure it. They set criteria which are relevant for a given regional context or product, and eventually provide compliance thresholds. Let's have a look at some examples of these:

- Regulatory requirements. The EU directive 2011/65/EU"RoHS" (Restriction of Hazardous Substances) restricts the use of ten especially noxious substances in electrical and electronic products, including lead, mercury, hexavalent chromium and specific flame retardants like phthalates. This directive provides a clear guidance, as it sets the list of products affected by these restriction, the list of substance which are restricted as well as the maximal allowed thresholds.

- Voluntary governmental ecolabels. The EU-Ecolabel is a voluntary label provided by the European Commission. It states a list of eco-efficiency-related product criteria for a large range of products categories such as televisions, floor coverings, paper, toilets, among others. For example, the criteria list for the category "imaging equipment" sets thresholds for indoor air emissions, requires printers to offer printing more than one page on one sheet of paper and OEMs to provide a warranty of minimum 5 years, among others [Slide 22]. If your product does not fit in one of the provided categories, you can approach the Ecolabelling Board to participate in a standardisation process to define new criteria for your product.

- Branch specific ecolabels. EPEAT (Electronic Product Environmental Assessment Tool) is a US and non-profit initiative delivering an eco-label for B2B electronic products. Specific criteria for each product category are based on international standards, like the IEEE 1680.1™ – 2018 Standard for Environmental and Social Responsibility Assessment of Computers and Displays. Based on a point system, it delivers three levels of compliance: bronze, silver and gold.

- Branch and impact specific ecolabels. Energy star is a Us government-led voluntary program to promote energy efficiency. It delivers the a label to products whose energy consumption is lower than a maximal allowed value for their product product category. This maximal value is given as a function of the product functions. For example, for monitors, the higher the resolution and the area of a monitor are, the higher the energy allowance is. The complete formula for defining the maximal allowed energy consumption of a monitor can be seen here.

The three first types of standards are multi-criteria and cover all relevant impacts of a product category involved in the whole product lifecycle. These criteria are developed in standardisation processes involving governmental bodies, companies and NGOs, and are backed on detailed environmental studies. They are therefore a good starting point to have an idea of the relevant environmental impacts of a product. The last type of standards focus on one specific environmental impact, which man not always be the most relevant one for a given product category. The corresponding criteria should therefore not considered as a proxy for the total environmental impact of a product.

There are a lot of ecolabels [Slide 23] and there may be different online databases referencing them, like this one. Browsing the criteria of the labels applying to a product category of interest is a good starting point for an eco-design initiative. In case the product isn't covered by any label, it is still possible to perform an environmental assessment, which is the topic of the next section.

Take-aways of this subsection:

- *Eco is not more expensive: there are good reasons for a company to involve in eco-design*
- *Legislation and eco-labels are good sources of information for jumping in eco-design*

Exercise 3. Make an internet research to find out which environmental standards would apply for to a fridge. Can you think of any way to outperform these standards?

3.2 Assessing the initial situation

This stage is about identifying the environmental *hotspots** of a product, that is, which activities of the product life cycle deliver the largest share of all the environmental impacts of the product and are consequently to be focused on in priority. Insights may have already been gained from standards in the previous stage 3.1.2, since product criteria are generally set to cover the environmental hotspots. However, more detailed and product-specific insights may be delivered by the direct application of *environmental assessment** methods. The queen of all environmental assessment methods is *LCA** (life cycle assessment) because of its rigour and precision. LCA is however an overly time consuming method requiring significant expertise. Environmental assessment can be approached through streamlined methods, like the MECO matrix.

3.2.1 Life Cycle Assessment (LCA)

Life cycle assessment is an internationally recognized method whose principles are recorded in the standard ISO 14040. It basically implies four steps:

1. defining the boundaries of the system, that is, what belongs to the product life cycle and what can be left out. In practice, all economic activities are interconnected, so that it is not possible to make a clear cut between what contributes to the delivery of a product and what does not play a role. For example, to dig the hole in your garden, you need a spade. A certain percentage of the environmental impacts of the spade can be allocated to the hole, because you bought the spade to dig holes in general and *this* hole in particular. And to make the spade, you needed a machine. A certain percentage of the environmental impact of the machine can be allocated to the spade and to the hole, because the reason to be of this machine was partly to produce a spade so you can dig a hole. This causal propagation can be infinitely extended like a fractal picture [Slide 24], but would not lead to any additional useful insights. The objective of this step is to find where to stop it.

2. performing an *inventory* of all elementary flows involved in all activities of the product life cycle. All inputs and emissions are identified by a type of substance and a quantity (e.g. 200g of NO_X) and are recorded in a large spreadsheet [Slide 25]. Quantities of the same substances are added up.

3. computing the impact associated with these inputs and emissions using environmental indicators (some of which have been introduced in section 2.1.3). These indicators associate quantified specific environmental effects to the substances identified in the previous stem. For example, the impact of a substance regarding climate change is given by the Global Warming Potential (GWP). The global warming potential of CO_2 is 1 and those of SF_6 is 22,800. If you have in your inventory emissions of 200g of CO_2 and 2g of SF_6, you get a total GWP of 200x1 + 2x22,800 = 23,000. This can be made for different environmental indicators [Slide 26], whose values can be eventually summed up to generate an unique environmental impact value.

4. interpreting the result and identify the hotspots. Displaying the results in flow diagrams [Slide 27] or Sankey diagrams can help in finding which processes in the whole life cycle are leading leading to the largest part of environmental impacts.

The major drawback of life cycle assessment is that it requires information which is only available when a product is fully defined. As a consequence, it cannot be used in early design stages, where all possibilities are still open.

Nonetheless, in most cases, a new product is either the redesign of an already existing product or a combination of existing technologies. It is therefore possible to base on the LCA of an existing product in order to define which hotspots are to be addressed in the design of a new generation of this product.

3.2.2 MECO matrix

LCA remains a time-consuming tool reserved for experts and does not fit with the time line of early design stages. An alternative to LCA is to use qualitative environmental assessment tools such as the *MECO matrix**. MECO stands for Materials, Energy, Chemicals and Other. It takes the form of a 5x4 matrix where the columns are the 5 life cycle phases ‘materials’, ‘manufacture’, ‘distribution’, ‘use’ and ‘disposal’, and the rows are the 4 MECO environmental aspects, that is, ‘materials’, ‘energy’, ‘chemicals’ and ‘others’ [Slide 28]. This matrix is meant to be filled by thinking about each of the environmental aspects across each phase of the product life cycle.

Because it is qualitative, this method is particularly adapted for early design stages where no quantitative information is available on the product. Because it only requires a single sheet of paper, it is particularly adapted for group discussions and quick decision making. However, as it is a qualitative approach it is more subjective and less systematic than LCA, so it may lead to some important issues being overlook.

Take-aways of this subsection:

- *Environmental assessment helps identifying* hotspots* *to prioritize in an eco-design project*
- LCA* *is the most rigourous environmental assessment method but is very time consuming*
- *In early design stages, LCA can be substituted to streamlined assessment methods like the* MECO matrix*

Exercise 4. In groups of 4, on a white board or a sufficiently large sheet of paper, draw the MECO matrix and try to fill it out for the product ’smart phone’

3.3 Looking for solutions

Once the environmental hotspots of the product are known, it is time to look for alternative designs potentially offering an increased functionality/impact ratio. For this, you can either rely on *eco-design guidelines** or on *eco-ideation mechanisms**. The earlier are already existing design principles you can apply to your product. The latter are creativity triggers to find your own original solutions.

3.3.1 Eco-design guidelines

In the absence of magic formula to design sustainable products, guidance can be given to designers in the form of guidelines, i.e. strategies, or "rules of thumb", which have proven to lead towards satisfactory solutions but which are not guaranteed to be optimal. Academia has produced large sets of these rules of thumb by analyzing existing designs. At a rather abstract level, we can mention the "10 golden rules" of eco-design by Luttropp and Lagerstedt [14], providing 10 rough strategies an eco-design approach can engage in. At a rather concrete level, we can mention the extensive eco-design guidelines compilation of Telenko et al. [18]. The latter are categorized by environmental aspect in the product life cycle, and are therefore useful to target a specific hotspot [Slide 29]. <talk about ECODESIGN PILOT>

In the following paragraph, we introduce some examples of strategies to address specific hotspots.

Design for multiple life cycles Design for material recovery is particularly relevant for products whose major environmental impacts lie in the raw material extraction phase or whose content may be harmful once released into the environment at end-of-life. There are three options for material recovery at end-of-life:

1. Reuse. After eventual repair or refitting, the disposed product can be reused by another user. Eventually, the product can be dismantled and its parts reused for alternative purposes. This is then called 'upcycling'.

2. Remanufacturing. Disposed products of a same model are collected and dismantled to separate parts. Parts are tested and sorted. Those which are still fully functional are reintroduced in the production process. The others undergo an alternative end-of-life route.

3. Recycling. Mixed disposed products are collected and dismantled or shredded to separate materials. Materials are sorted and introduced in a recycling process. In most cases, recycling amounts to 'downcycling' in the sense that the recycled material has not exactly the same properties than the original material (e.g. polymers in plastics get shorter).

These recovery methods are sorted in the order of increasing additional impact/entropy and decreasing preservation of the value added [Slide 30]. Recycling amounts to destructing the geometrical shape of a product and turning it to another half-finished product (e.g. plastic pellets). Both the destruction of the value added by forming processes and the application of a new forming process create impacts. Recycling only makes sense when these additional impacts are lower than those of forming products out of virgin material. Remanufacturing intends to use parts *as is*, that is, to keep the value added in the part geometry. Therefore, it potentially leads to lower impacts and should be preferred to recycling. Reuse potentially leads to even lower processing and should be preferred to remanufacturing.

Here are some examples of design for remanufacturing guidelines [more info link]:

- Modularize the product to group parts depending on their own life cycle.
  - Group parts per amount of value added. That is, group low value parts together and high value parts together. This will reduce the number of required processes to dismantle high value parts.
  - Localize wear functions on easily detachable parts [Slide 31]. This will reduce the volume of material which will need replacement in the remanufacturing process.
- Make the disassembly process easier, that is, reduce the level of intervention required to extract the parts to be reintroduced in the production process.
  - Use easily reversible joinings. For example, prefer nuts and bolts to snap fits.
  - Reduce the variety of joinings techniques. The higher the number of different joining techniques, the higher the number of different disassembly processes is required, the more expensive disassmbly is.
  - Reduce the variety of directions of the joining techniques. Making the entry point for disassembly on one unique side of the product avoids the need to turn the product in the disassembly process and reduces the disassembly time

Here are some examples of design for recycling guidelines [more info link]:

- Choose materials which can be recycled. There is not necessarily a recycling process available for each material. Composite materials for example are difficult to recycle because there is no inexpensive way of either separating the constituents of the composites or reshaping composites for another usage.
  - Choose materials for which the existing recycling process is actually performed by some companies. That a process is available in theory does not mean it is actually performed by someone; some recycling processes may be at a protoype stage.
  - Choose materials which can be sold after recycling, that is, there is a market for that material. It may be technically possible to recycle a product but there may not be any market for buying the recycling material.
- Make materials separable if they are not compatible. Recycling requires separating materials which cannot be recycled together. Separation includes detachment and sorting.
  - Choose materials which can be sorted by conventional separating processes (e.g. float-sink [Slide 32] or air separation for plastics, magnetic or induction separation for metals, among other techniques)

  - Avoid irreversible joining processes wuch as over-moulding. Even in shredding, overmoulding does not allow for separation of materials, whatever their size [Slide 33].

- Avoid the use of incompatible materials, that is, materials that disturbs the recycling process of another material [Slide 34].

Design for energy efficiency Design for energy efficiency is relevant for... The energy efficiency of industrial products depends on three factors: the theoretical minimum required to deliver the function, the intrinsic losses of the product and the user-induced losses [7] [Slide 35].

3.3.2 eco-innovation mechanisms

<input Benjamin>

3.4 Checking progress: iterating LCA

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