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FUTURE ILLUMINATION SYSTEMS AND THE CLIMATE CHANGE CHALLENGE - THE CASE OF DANISH OFFICE LIGHTING

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ABSTRACT

Higher eco-design requirements from the EU Directives and higher lighting standard requirements for working places open a new and challenging chapter of development for the illumination systems of the future. Electricity consumption due to illumination in offices in Europe will continue to rise due to the increasing number of offices and due to the new illumination standards. The total annual primary energy consumption of the European office lighting stock in 2005 was 281 PJ, of which 271.73 PJ was due to electricity use. It is estimated that office lighting generates 519 kton of non-hazardous (or landfill) waste and 7.2 kton hazardous (or incinerated) waste; 12.5 Mt CO_2-eq. greenhouse gas emissions; 73 kt SO_2-eq. acidifying gasses. It emits heavy metals in an amount of 5.7 ton Ni-eq. to air and 2.7 ton Hg to water.

This paper discusses the question: What kind of considerations should the photonic industry take into account when designing future low-carbon illumination systems to efficiently reduce the CO_2 emissions, when evaluating the possibilities for the future?

Keywords: Illumination, Life cycle approach, product-service systems, electricity consumption, low-carbon technologies and eco-innovation.

1. INTRODUCTION

Electricity consumption in the office sector is expected to increase about 85% from 2005 to 2020, and so will the emissions of CO_2 and other environmental impacts as they are related directly to the production of electricity. The achievements that are anticipated by implementing the best available technology - as suggested by the European Preparatory Study for eco-design requirements - will only reduce about 20% of that increment (Van Tichelen, B., et al, 2007).

Furthermore, the best available technology suggested to bring this reduction into reality is based on fluorescent lamps. Yet, the goal of reducing 20% of the CO_2 emissions by 2020 compared to 2005 levels are far from being reached within this sector. On one hand, increased energy efficiency can only contribute partially to meet the challenge and the goals suggested. On the other hand, Denmark has set as further goals that the share of renewable energy must be increased to at least 30% of the energy consumption by 2025 and that the energy consumption must not rise. Achieving these goals require the introduction of technologies that both are practical to include in connection with renewable energy and can make further energy savings possible.

Developing technologies that can contribute to the reduction of CO_2 emissions is a complex problem that has to be addressed from many angles. If we see the problem from a systemic point of view, we have to consider that providing an illumination service both comprehend the technological devises, we are using to provide that service, as well as we have to consider the way in which we are producing electricity. Furthermore, we have to consider the regimen and practices in this sector.

Unfortunately, getting rid of the incandescent lamps does not necessarily mean that we are going to solve the Green House Gas emissions from the illumination sector at once. To efficiently reduce the illumination ecological foot print requires that we determine where the most serious impacts are created and what kind of collateral impacts should be taken into account. Thus, we need to find systems that can both have a bigger potential of luminous efficacy than the fluorescent lamps in the future and as much as possible be able to reduce the consumption of fossil fuels, materials and chemicals.

However, even if we are good at finding the technological solutions, environmental innovations have the risk of not being competitive enough in relation to conventional technologies. The lack of competiveness might derive from weaknesses in the research, development and also from the commercialization phases.

2. METHODS

From the environmental point of view, we look at the entire life cycle of the possibilities or alternatives and assess, where the improvement potentials are. To do this, we used the Life Cycle Assessment results from the European Preparatory Studies for eco-design requirements in the office lighting sector. In this study, the selected alternatives were assessed in relation to energy consumption and their life time. Just recently OSRAM (November 2009) released a LCA comparing incandescent lamps vs. CFLs and LEDs. The results of this assessment are also taken into our analysis in order to see the environmental issues that need to be taken into consideration, if LEDs are considered as a feasible alternative. This is done with the intention to set the boundaries around the problematic areas and to identify where in the life cycle of the service strategic changes might be done. In other words, we aim to establish, where the best improvement potentials are to be found for further developing the illumination of the future.

Cases for the analyses:

In order to make a feasibility analysis (finding the possibilities and directions for new technologies), we use some relevant examples or alternatives:

As a base line, we consider an illumination system based on Tri-phosphate fluorescent lamps. We consider this system, since it was suggested as the best available technology as a result of the Preparatory Studies for Eco-design Requirements of EuPs (Van Tichelen, B., et al, 2007).

We consider a system based on white Light Emitting Diodes (LEDs). LEDs were considered as best not yet available technology in the same studies, due to the number of lumen/W in the year 2006 (only 30 L/W). Today, however, only three years after, LEDs have reached an efficiency of at least 90 L/W.

To further achieve some energy savings in combination with LEDs, we consider optical solar lighting systems.

The main objective with this article is to establish a framework that allows us to design a new illumination system with a minor ecological footprint than the one offered by the current best available technology.

In order to find new technological alternatives, we formed a working group with professional designers from Designskolen Kolding, engineers from the Technical University of Denmark (DTU-Fotonik, Department of Photonics Engineering), envirironmental planers form Roskilde University and representatives of professional installation competences IBSEN ApS.

3. THEORETICAL CONSIDERATIONS

One of the first motivations to start this research was that currently Europe uses too much energy for illumination, and even banning the incandescent lamp, the electricity consumption will still rise. The other consideration is that we cannot continue increasing the consumption of electricity, because the levels of CO_2 are already surpassing the limits of a sustainable ecological footprint. When referring to a sustainable foot print, we are referring to the energy sources available to produce energy (fossil fuels) and the impact on the resources necessary to absorb their emissions and also to the materials and chemicals' impact on the environment (Wackernagel. M., 2005).

The rising electricity consumption is very problematic, since it is mainly based on fossil fuels, and, therefore, the production of CO_2 will increase as the consumption grows. For the same reason, we also have to consider that what we want is to reduce the CO_2 emissions at the same time as we increase the levels of services. Thus, what it is necessary to find out is how to maintain or even improve the service of illumination using less energy – and do this as much as possible free of the use of fossil fuels. Consequently, it is very important to find alternative technologies in the area of illumination that may cope with these conditions. According to the European Assessment for Energy using products (EuP) for the illumination sector, the best available technology today for the office sector is the tri-phosphate fluorescent lamp using electronic ballast. Even implementing this technology (which is considered as the best available technology) the consumption of electricity compared to what was used in 1990, will be using 25% more energy and producing 66% more emissions of persistent organic pollutants in 2020, while emitting almost 30% more CO_2 than in 1990 (Van Tichelen,P., et al., April, 2007). (Note that the different percent values are due to a changed relative distribution between the sources of power used in the electricity production).

Life cycle approach

I order to find an environmental solution to this problem in this sector, we need to find out in which process of the life cycle of the illumination technologies the biggest environmental impact occurs, and what kind of process should be improved to reduce those impacts.

Thus it is important to analyze this problem from a life cycle perspective, considering all the stages of the illumination service life cycle and not only the life cycle of the lamp. To achieve this objective, we need to make use of a tool that can detect and measure the main impacts caused by providing this service. A life cycle assessment is practical for this purpose, since it is both an approach and a tool to make a systemic analysis. Taking a systemic approach, The aim should be to find the direction in which the service might be improved on the material basis.

Efficiency

Efficiency has to be seen from three perspectives. In general, efficiency is considered as the amount of inputs in relation to the outputs. In relation to illumination systems, what it is important then is electricity, which is one of the inputs at which we will focus. Even if the system can convert 100% of electricity to light, it does not mean that all that light can be appreciated by the human eye. Here then, it is important to consider different types of efficiency (see Figure 1). Schubert defines three different kinds of efficiency: Internal quantum efficiency, the external quantum efficiency and the power efficiency

Even if we inside a given component can produce a certain number of photons, it is not sure that we can get them all out of the device. To know how much the output really is, we need to look at the external quantum efficiency, which measures how effective the process is, for example comparing the number of electrons that come into the system and the number of photons that one actually gets out of the device.

The third category: power efficiency, tells us how much electric power was needed to produce a given amount of optical power. This is useful to see, how much electric power was lost in the process, and finally, how much electric power one needs in order to produce one photon. (Schubert F., 2007: 86 and 87)

Though, it is important to know how much optical power one can get, it is also important to know how much a human eye can see from that light, since the human eye only can perceive certain frequencies of the light. The luminux flux tells us how much visible light the human eye can really see. Thus, in order to measure how efficient a given source is to produce light that the human eye can see, we need to measure it in terms of luminous efficacy (Schubert F., 2007:284-285)

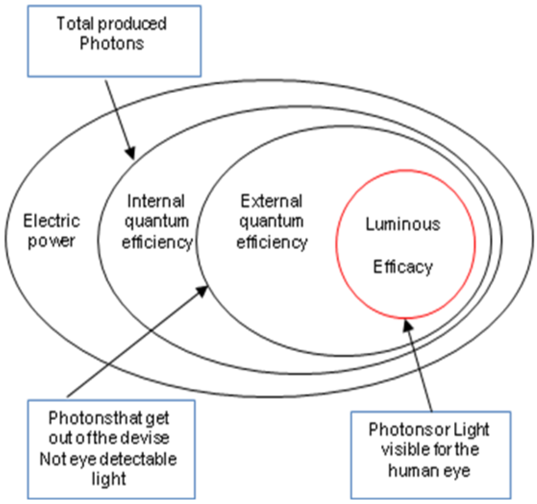

Figure 1: Different types of efficiency for illuminating devices.

What is interesting for our project then, is to analyze, how much electricity we use per photon (External quantum efficiency) with a high luminous efficacy (so the users can see the light, experience it as beeing pleasant, or in other words have a better service of illumination, red circle). This comparison is what Schubert (2007:284-285) calls Luminous efficacy. Thus, from the technology point of view, we will look at the most relevant alternatives with potential to further increase luminous efficacy.

Possibilities: beside the environmental point of view one should also consider, technological, social, and economic perspectives.

Technological possibilities

On one hand, one of the main constraints is the energy efficiency on which the CO_2 emissions depend. From this stand point, what it is important then is to determine, which of the technologies have more potential to improve the luminous efficacy. Here, the focus should be to reduce the energy consumption and losses, while we deliver the service. Thus, we have to consider that in order to have illumination, one part of the problem relies on the electronic devices performance, but the other part is how the electricity is produced.

As we already mentioned, from the environmental point of view, one needs to look at the entire life cycle of the possibilities or alternatives and assess where the improvement potentials are. By using this approach it becomes possible to analyze the selected alternatives in relation to energy consumption, material and resource consumption and the life time of separated products that form part of the whole illumination service.

The illumination service is an intersection of many outputs: illumination devises, cables, sensors luminaries, and electricity (See Figure 2)

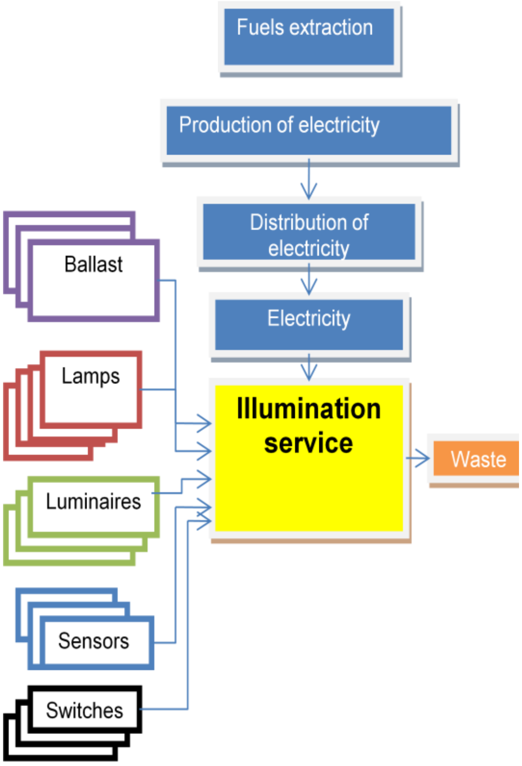

Figure 2: Illumination systems.

It is not only important to consider the service of illumination as exclusively the one provided by the lamp (the horizontal direction) it is also important to remember that the electricity is an essential part to provide the illumination service (vertical direction).

In relation to the lamps, we are critical to the suggestion that fluorescent lamps are the right solution due to the limitation from the RHoS and WEEE directives, since their luminous efficacy depends on the mercury content. As a matter of fact, these two directives will set a limit for fluorescent lamps efficacy development. However, LEDs are still in a stage, where further development can be achieved in questions of efficacy. Nevertheless, the task is not easy and many other aspects have to be addressed such as materials, resources or chemicals consumed. Therefore, when reducing CO_2 emissions, the other aspects need to be taken into account, so we achieve an overall reduction of CO_2.

Consumer acceptance and cost

On the other hand, even if we find some innovations that comply with the necessary environmental improvements, there are still two issues that need to be considered, since is not always for sure that those innovations will be accepted by the consumer and that they will reach the market. We, therefore, need to consider what will be the mechanisms that can help us in that process. To do this is not an easy task, since the other problem to consider is that the stake holders in this sector have a number of habits and long traditions of using systems based on fossil fuel and that environmental technologies are not always seen as sufficiently “profitable” compared to conventional technologies. Therefore, we need to identify the main possibilities for a strategic implementation also from a socio-economic angle.

The life cycle analysis can provide us here with the material status of the available technologies.

However, environmental improvements have not always the sufficient driving power to make stakeholders switch to the new technologies, since the patterns of production and consumption are very much constrained in the pre-established relationships between producers and stakeholders roles in our current society

Thus, what we need to consider here, is what kind of business opportunities have the future illumination systems with a minor ecological footprint to substitute conventional technologies. When looking at the material dimension, practitioners of the LCA suggest taking as a base of comparison the service provided by the product, hereby defining a functional unit (see Table 1).The aim is to quantify the product or service with respect to volume and time, looking for possibilities of change on the product, in this case the lamp. However, this definition is still product-oriented. From this, one derives solutions that mainly focus on the materials and energy. Having the focus on either the life cycle of the lamp or in the life cycle of the electricity.

The functional unit according to Wenzel and Caspersen, (1999) should be defined considering both, the obligatory properties and the positioning properties. However, when it comes to the real life practice, the obligatory properties are the ones that define the functional unit since, as the definition of ISO points out, it has to be quantified. The functional unit is defined as the quantifying performance of a product system for use as a reference unit, (ISO 14044, 2006).

Obligatory properties	Positioning properties
Supplying 500 lumens to a working area in typical Danish office	- Not blinding effect - Avoiding overheat - Optimal spectral composition of light for a working space (colour of light) - Esthetical component of the room - Flexibility possibilities (regulation of intensity) *-Reducing CO_2 emissions* *- Indication of "green responsibility"*

Table 1: Functional unit. Adapted from Wenzel and Caspersen (1999).

When analyzing the possibilities for future illumination systems, it is important taking into account parameters such as efficiency but also parameters such as colour temperature, spectral composition and noise (non oscillating light) from the new alternatives. It can be argued, that it is also possible to quantify these, however, our point here is, that they are properties that are in relation to consumer's preferences and depend of the consumer's perceptions. These being subject-related, it is very difficult to quantify these as material bases, and they are often left aside of the analysis. In Table 1, we differentiate the Obligatory properties from the Positioning properties of an illumination system.

One way of providing more focus on the new positioning properties and one way of considering with the same weight the relevant illumination devises in conjunction with the electricity consumption and production is using the concept of Product-Service Systems suggested by UNEP (2000). A Product-Service systems, can be defined as the result of an innovation strategy, shifting the business focus from the design and selling physical products only, to selling a system of products and services, which are jointly capable of fulfilling specific client demands. (UNEP, 2000:4) While the responsibility under a Life cycle perspective lays on the design phase or on the production phase, the Product-Service Systems perspective seeks to distribute the responsibility through the entire production chain given an equal weight to the consumption phase.

In this way, the focus is not on selling separate products, but "selling the utility, through a mix of products and services, while fulfilling at the same client demands with less environmental impact" (UNEP, 2000: 3).

In order to narrow down to our study object, we will see to what extent LEDs and perhaps an addition of solar optical fibre illumination can contribute to enhance the possibilities of providing an integrated functional solution to meet the client demands.

Efficiently reducing ecological footprint: In our research it is considered with a twofold perspective. On one side we look at this from a footprint perspective: fewer hazardous materials and less resource consumption. With resource consumption beside materials, we also refer in high degree to the reduction of fossil fuels. On the other side, they have to be cost-competitive and provide a competitive service. This from an eco-innovation perspective can be achieved with the process of optimization of resources and thereby reducing the costs (Lovins, 2008).

According to Huber (2003) it is important to consider other parameters than technological ones to provide realistic solutions. Thus, from the socioeconomic side, one of the parameters in the past to select Edison's lamps was the number of watts that the lamps used. As a matter of fact, it is not about buying watts, what it is about is buying a certain number of lumens, with a very high quality and colour of light defined by the consumer side. History has shown us that even when florescent lamps have been accessible for a long time, they had a very hard time in getting accepted by the consumer, and still there are many consumers that do not like this technology. Therefore, it is not only a question of researching and finding new ways of illumination for our surroundings, but it is important to consider, what will it take for the consumers to adopt or accept the new technologies focusing in an new definition of the final service utility. Therefore, some of our main considerations, when it comes to social and economic parts are: the service and how do we provide that service, so we can design or re-design the future alternatives.

One of the interesting possibilities to consider with respect to future office illumination systems is the fact that most office spaces are used during daytime, which means that there actually often are plenty of daylight outside. It is actually many times so much that the office space has to be shielded behind curtains in order to allow for the working tasks to be performed. This points to the possibility that one could aim to apply some kind of solar collector, which either could produce electricity for use inside the offices, or one could use fiber illumination systems to move the sunlight into darker areas of the office buildings. With regard to the first, it is relevant to have in mind that photo-voltaic collectors and modern LED based illumination preferably could work on a separate low-voltage system.

Concerning the fiber illumination systems, it is highly relevant to point to the challenges that the fibers cannot be installed just in the same manner as normal electric wires (the fibers may not be bend so hard as electric cables). Furthermore, the fiber loss has to be considered. In order to illustrate this, we have performed a characterisation of a commercially available fiber illumination system including 20 meter long (polymer) fiber bundles to transport the collected sunlight.

Measurements were performed outside during sunny summer days in Denmark. Results are illustrated in the chromaticity diagram, shown in Figure 3, where the reference point (Ref) corresponds to the light coming from the sun and the point Test corresponds to the light coming from the fiber bundle output. The chromatic distance (DC) of the light coming from the fibers is 31.10-3, which is far above the limit of 5.4.10-3 given by the International Commission on Illumination (CIE). This observed “decolouration” is one of the challenges that future fiber illumination systems have to find solutions to.

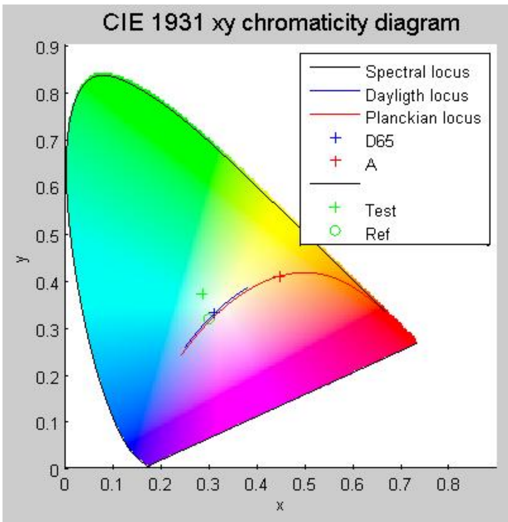

Figure 3: Chromaticity diagram measured on a commercially available fiber illumination system.

Other of the parameters for a selection of lamps beside the qualitative ones is the price. Considering the whole system one should consider then the entire price of the service and not only the price of the bulb. Therefore, technologies that present the highest potential of energy saving will have to be economically viable in the entire life cycle. Thus, we will consider the concept of total economy, which is related also to a systemic approach, since it considers not only the price of the lamp, but also the price of the whole service along the entire life cycle.

Regimens and practices

When talking about regimes and practices, one of the basic issues is the way in which the people will accept the new technology or the new service. Here it is, according to Rogers (2003), important to predict the reactions of people to an innovation. Not only making a differentiation of type of adopters, but also considering beliefs and past experiences of potential adopters. One of those experiences in relation to illumination devises, have been the colour of the light and the intensity of the light, and, therefore, setting LEDs on the market with lower performance than expected by consumers might give the consumers a negative experience, and the reaction will be not to trust those devises anymore (or at least for a very long time). Therefore, it is important to find out what can make the innovations in the new service or devises more acceptable for the consumers, and how to ensure a proper diffusion of the innovation.

We further consider that innovation is an iterative process, where it is necessary sometimes to take the already existing knowledge and technology as stand point and look for further improvement both based on what we know and/or in something completely new (Andersen P.D., et al, 2006). For example with LEDs, one can see that the technology have been there for some time - especially for the car industry and decoration purposes. However, it is just recently that their development in direction towards, TVs., Computer screens and general illumination systems have taken place, especially with the white LEDs - the last one being just a few years old. Therefore, one has to consider that LEDs for general illumination are still in the first or perhaps second stage of their technological development curve (see Figure 4), which represent still big opportunities for further applications.

The support refers to the political and regulations framework that can make it possible for the innovations to reach the market. Here, it is important to consider all the phases in the research and development of the innovation curve (see Figure 4), in the implementation of new ideas, or in its commercialization. Different to the linear and traditional approach of innovation, where research is only thought in connection with completely new ideas or in the beginning of the invention; We consider that, research should be pursued in all the phases and, therefore, differentiated forms of support should be pursued for each of the phases.

It is important to consider as well, that the implementation of new technologies will require adequate relationships and conditions that facilitate their fast and broad dissemination. To each of the phases of the diffusion of innovation different institutions are attached. Finding the corresponding institution network can enhance the possibilities to make the diffusion more effective (Kjær T., and Andersen J., 1993). Therefore, it is important to find out what the current Danish scientific and research base is for the illumination sector (research and development institutions as well as sector networks).

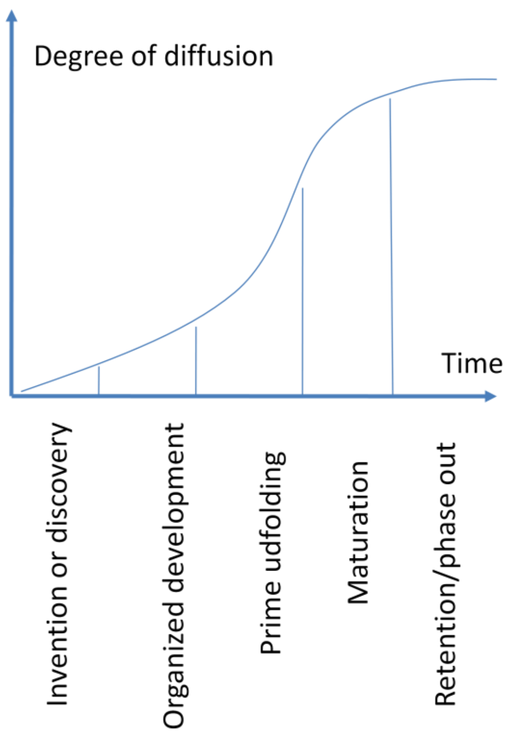

Figure 4: Innovation phases or innovation life cycle (Huber 2003). One can say that white LEDs are still in the stage of organized development or prime unfolding phase.

Though getting the product to the market is traditionally a process thought of as an exclusive job for the industry, environmental-innovation theories (Andersen et al., 2006) suggest that research, development and demonstration is not enough to support completely new technologies to a competitive level in the commercial market. Therefore, market oriented policy instruments should support this phase. The reason for improving the policy instruments for environmental technologies is, (different to other technologies), that environmental technologies are highly capital-intensive and this makes investment to seem less attractive for the venture capitals. Extending the span of life of the products (for example) will mean investments with long time horizons even less attractive. Nevertheless, it could be a good “business” for the governments. Though the investment return is not measured in money, it could be capitalized in cleaner environment and security of energy supply (Andersen et al., 2006: 25), which are very important in order to reach the climate goals and energy sufficiency. Furthermore, besides solving the climate and energy problems, there is also the potential to create jobs and development in the region, spreading the benefits to all other sectors functioning as engine of economic development. Thus, finding the policy instruments necessary to support the environmental innovations still can represent a win-win situation for the governments, since this support could attract more venture capital into the region strengthening the entire cluster competition.

CONCLUSIONS

One important point when designing low-carbon technologies with a minor ecological footprint is considering the best available technologies in terms of a life cycle perspective. This in relation to the photonic sector can be supported by regulations and studies made by the Eco-design directives or from relevant lifecycle assessments.

It is important as well to rethink the functional unit both in its product-oriented dimension (material dimension), but giving the same weight other relevant intersecting products that together provide the final utility. This perspective may allow seeing the possibilities that might not be directly measurable but are intrinsic to the new function(s) in the technological development of low carbon technologies and their potential business opportunities.

It is highly important to consider the consumer demands focusing in the right sector to be able to deliver a competitive service both in terms of quality and price.

The high level of competitiveness on the market will be the same if compared with conventional technologies. Therefore, when designing eco-innovations one has to be able to identify the potential market or policy instruments that can support the innovation through all the innovation phases until the product or service can reach the market.

The success of such strategy is complex and requires a close cooperation from trans-disciplinary fields, but if this point is achieved it could be one of the possibilities in itself.

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