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Beyond unsustainable eco-innovation: The role of narratives in the evolution of the lighting sector

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ABSTRACT

The discourse of Sustainable Development has reinvigorated the idea that technological innovations are inescapable to sustain economic development and simultaneously achieve environmental sustainability. In this paper, we propose a framework to describe six possible combinations of innovation and demand/consumption levels that constitute in turn six *narratives of sustainability*. We argue that the present global trend is set out for a dominant narrative, what we call 'Green Growth', which is rooted in the idea that economic growth – and thus technological change – is a prerequisite for environmental sustainability. By way of example, we use the case of the lighting industry to show that this narrative cannot assure an absolute reduction of the present levels of energy consumption. We therefore propose to embrace a different narrative of sustainability that encourages at the same time the development of eco-efficient technologies and the reduction of demand/consumption. This alternative narrative is linked to the development of the concept of '*useful light*' and to a paradigm change in which the lighting sector is no longer framed around the electric bulb. This transition would require a new class of Lighting Service Companies (LISCO) and of new functional business models based on the sale of 'useful light'.

1. Introduction

Since the 1970s, the discourse of environmental sustainability has gained a central role in the international public debate and political agendas. From the rise of environmentalism, conservation of the ecosystems and development of the human economies have been seen as two irreconcilable enterprises. Economic growth entailed environmental degradation and environmental conservation constituted an unacceptable constrain for business (Porter and Van Der Linde, 1995; Kemp and Andersen, 2004).

A number of scholars even questioned the concept of limitless growth of the economic sphere in a planet with finite resources (Boulding, 1966; Georgescu-Roegen, 1971; Daly, 1973; Meadows and Randers, 2006). This position was fiercely opposed by those who argued that the limits to growth could be overcome by the endless potential of innovation and technology (Sandbach, 1978; Mol and Spaargaren, 2000; Bardi, 2011). The well-known concept of 'sustainable development' (Brundtland, 1987) became an important milestone in the effort to overcome this impasse between economy, technology and environment. Brundtland's report introduced the idea that economic growth is limited by the present state of technology and therefore it is possible to stretch these limits on the condition that technology seamlessly evolves. One of the consequences of Brundtland's perspective was that the discourses of technical change and innovation became hybridised with elements that come from the discourse of sustainability (Freeman, 1996). In the after-Brundtland world, a new conceptualisation of innovation based on the idea of eco-efficiency – i.e. the process of minimizing energy, raw material and

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pollutants per unit of production – gained popularity as a way to integrate environmental and economic goals (Carrillo-Hermosilla et al., 2009) among an increasing number of scholars and practitioners (Adams et al., 2012). The eco-efficiency discourse is based on the '*decoupling argument*' i.e. the possibility provided by technological innovations to diminish the amount of materials, energy and waste per unit of GDP (Jackson, 2009). Economic growth and environmental sustainability are compatible as long as decouple effects counterbalance the increase in consumption of services and goods. This approach has been stretched up to the idea that economic growth is not only *compatible* with environmental sustainability, but it is also an indispensable *incentive* to it. Only economic growth, indeed, creates the conditions in the market that fuel the development of new greener technologies (Beckerman, 1992; World Bank, 1992).

Other studies have questioned the eco-efficiency approach to sustainability by highlighting the intrinsic link between economic growth and material consumption (Jackson, 2009). For example, the literature focused on the study of the 'rebound effect' demonstrated that the increase of the efficiency of extraction and utilization of natural resources may lead to an increase in their consumption (Birol and Keppler, 2000; Alcott, 2005; Herring, 2006; Polimeni et al., 2008; Saunders and Tsao, 2012).

This paper applies the method of Discourse Analysis, which only recently has been operationalized with reference to sustainability and environmental politics (Hajer and Versteeg, 2005), to make two major contributions. First, we propose a conceptual map that positions and operationalizes a number of alternative narratives of sustainability and innovation in order to show that the focus on eco-efficiency is only one of the possible interpretations of the relationships between human economies and the surrounding *natural environment*. Second, we apply this map to the evolution of the lighting sector to show how different narratives may lead to the transformation of the sector by changing the action of the main players in the industry and their business models.

Two conclusions follow. First, the eco-efficiency perspective may ease the purse for environmental sustainability but it is neither needed nor sufficient; therefore demand-side measures are required. Second and consequent, business models that follow the eco-efficiency perspective, like the sale of more efficient lighting bulbs in the lighting sector, may be inadequate to achieve environmental sustainability because they discourage demand-side measures. We therefore suggest an alternative model that we define as *Lighting Service Company* (LISCO) that integrates measures designed to combine eco-efficiency with the reduction of energy consumption.

The article is organised as follows: section one introduces Discourse Analysis and indulges in a brief description of the notion of *frame* and *narrative* to characterize the discourse of sustainability and eco-innovation. The section ends with the introduction of a map that shows how multiple discourses can be debated along two key factors: demand/consumption and innovation. Section two illustrates the case study of the lighting industry focusing on past and current dynamics. Section three analyses the narratives of sustainability of the lighting industry indicating the dominant trajectory, the alternative proposed one, and the frictions that potentially might hamper the transition towards countervailing narratives in the sector. Section four concludes by discussing the limitations of the present work and suggesting future lines of research.

2. The construction of the narratives of sustainability

The study of *language-in-use*, also widely known as Discourse Analysis, has become increasingly popular among those scholars interested in researching the intersection between science, technology, society and politics (Nicolini, 2012). More recently, the study of logics and the role of language in environmental politics have gained a relevant position in the Science & Technology Studies (STS) debate (Hajer and Versteeg, 2005; Feindt and Oels, 2005; Dryzek, 2013). This section introduces the notion of discourse, frames, and narrative that, we argue, are crucial to understand the origin and the evolution of the modern concepts of environmental sustainability and eco-innovation.

2.1. Discourse, frames and narratives

The word *discourse* in the common language refers to the mundane use of language in social interaction. The word usually describes an articulate discussion or treatment of a subject in the form of speech or writing. At the same time, the term discourse also refers to the ways in which people integrate linguistic and non-linguistic features '*to enact or recognize certain identity […] give the material world certain meaning, distribute social goods in a certain way, privilege certain symbols systems and ways of knowing over others*' (Gee, 2011, p. 13). This second meaning has been developed and analysed by several disciplines including linguistics, psychology, politics and history among other social sciences (van Dijk, 1985; Gee, 2011). The importance of this kind of analysis has gained momentum during the last five decades since an increasing number of '*researchers developed the idea that discourse is, first and foremost, a form of action, a way of making things happen in the world, and not a mere way of representing it*' (Nicolini, 2012, p. 189). As a form of social practice, discourse always belongs to social groups, cultures and institutions (van Leeuwen, 2008). So when one enacts a specific kind of discursive practice one also sustains specific social group(s), culture(s) and institution(s) (Gee, 2011).

The practical implications of discursive practices are evident in the allocation and distribution of social goods, such as sustainability, defined as all the goods (e.g. products, services, values, relationships) that people value. For instance, Hajer and Versteeg (2005) highlight that the discourse analysis applied to environmental politics has contributed to the debate of environmental sustainability adding three crucial dimensions. First, discourse analysis showed that the notion of Nature and Environment is not objective categories but socially constructed and historically situated concepts (Morton, 2012). Second, the various discourses of sustainability limit the range of policy options, thus serve '*as precursors of policy outcomes*' (Morton, 2012, p. 179). Third, the analysis of discourse provided a solid basis to understand the strategies deployed by powerful actors engaged in environmental disputes to override competing countervailing discourses that potentially might jeopardize their hegemonic positions (Hajer and Versteeg, 2011; Stevenson and Dryzek, 2012; Hajer and Strengers, 2012).

One of the characteristics of the discursive practices is the capacity to create, promote and diffuse cognitive frameworks, mental models that influence action in the real world (van Dijk, 1995). In the description of those dynamics the concepts of 'framing' and 'narrative' occupy a relevant position. The process of framing is a process of simplification of reality (Goffman, 1986 [1974] p. 40–45) carried by specific actors and shaped by their particular institutional, political and life settings (Carragee and Roefs, 2004). The interpretation of reality always follows a specific logic (Tannen, 1993) and includes subjective and values judgements (Entman, 1993; Leach et al., 2010). According to Entman (1993), the interpretative process takes place in four steps: frames 'define problems' (i.e. define who or what is doing what, who is damaged or benefited, usually measured in terms of social goods or cultural values), 'diagnose causes' (i.e. identify the source(s) of the problem), 'make moral judgements' (i.e. define what is 'just' to do and what is not) and 'suggest remedies' (i.e. propose action). Frames highlight some aspects of reality whilst obscuring other elements. Frames are represented by narratives that are 'simple' stories that start by defining a problem, elaborate their consequences and end by outlining solutions (Roe, 1994). Since narratives represent frames, they imply a number of practices that involve value judgements about what or who is excluded and included and what issues, questions and solutions are prioritized.

2.1.1. The discourses of environmental sustainability and eco-innovation

As Hajer and Versteeg (2005) suggest, Discourse Analysis can be fruitfully applied to the study of environmental politics. Furthermore, we suggest that, such an analysis can provide useful insights to analyse the interaction between the discourse of technological innovation, and that of environmental sustainability. One of the reasons that justify such an enterprise is the recent hybridization of the discourse of technological modernization with elements that originated within the discourse of environmental sustainability. An emblematic example is the increasing popularity of adjectives as 'eco', 'environmental', 'green' or 'sustainable' in connection with innovation (Rennings, 2000; Hellström, 2007; Pansera, 2012; Schiederig et al., 2012). This trend has intersected with natural science and engineering (Hueting and Reijnders, 1998), innovation studies (Freeman, 1996), and entrepreneurship studies (Porter and Van Der Linde, 1995).

The practical outcome of this process of hybridization of sustainability and innovation is a formulation of eco-innovation articulated in three levels (Carrillo-Hermosilla et al., 2009, 2010): (i) add-on and/or end of pipe solutions i.e. incremental improvements of pre-existing technologies that reduce the environmental impact; (ii) sub-system changes i.e. eco-efficiency improvements operated within well-established technological paradigms (paradigm meant as in Dosi (1982)); (iii) eco-effectiveness or systemic changes i.e. new technological paradigms that lead to drastic eco-efficiency leaps i.e. closed-loop systems and cradle-to-cradle design.

Despite the sophistication achieved by the discourse of eco-innovation, in the realm of practices the concept remains often framed in terms of mere eco-efficiency (Hellström, 2007; Jänicke, 2008; Pansera, 2012). This is because, we argue that, the notion of sustainability on which the discourse of eco-innovation is rooted is still the contested field of competing frames (Castro, 2004; Hopwood et al., 2005; Scoones, 2007). Here, for simplicity, we distinguish between two major conceptual framings within the broader discourse of environmental sustainability: *weak* and *strong* sustainability. Weak sustainability considers human and natural capitals as interchangeable. An economy is *weakly* sustainable '*if the ratio of savings to income (which allows investment) is larger than the sum of the ratios of depreciation of human-made capital and "natural capital"*' (Martinez-Alier, 1995). On the contrary, strong sustainability implies the conservation of a critical natural capital e.g. wet land, fishery stocks, and forests (Costanza and Daly, 1987; Daly, 1987; Daly and Farley, 2007). These two framings lead to at least two relevant questions about sustainability: *To what extend is it possible to improve the efficiency of the conversion of natural capital into human-made capital? Is it reasonable after all to consider natural and human-made capital interchangeable?*

Following these questions, we argue that the present discourses of innovation as a way to address the environmental issues produced by industrialization (i.e. the discourse of ecological modernization (Jänicke, 2008)) are mainly framed within two major positions: one is based on the idea that innovation, framed especially as eco-efficiency, can create the conditions that allow both economic growth and the conservation of the natural environment; the other is based on the idea that to achieve environmental sustainability, measures to control the demand are needed.

In order to analyse the dynamics and the potential evolution of the discourses of sustainability and innovation along the two conceptual keys of innovation and demand/consumption, we propose a framework (see Fig. 1) to identify six possible narratives that are explained in the next section.

2.2. Six narratives, six pathways

In Fig. 1 we plot the dynamics of innovation vis-à-vis the evolution of demand. In the chart innovation can assume essentially three forms: a *non-eco* form in which eco-efficiency is not contemplated, on the contrary, it might even decrease; an *eco-efficiency* form in which innovation decouples economic growth from the consumption of non-renewable resources through technological progress; finally a *systemic* form in which innovation promotes changes in institutions, culture and society in order to create positive feedback between the development of greener technologies and the conservation of non-renewable resources. These three forms of innovation are combined with an *increasing* or *decreasing* demand.

The result is a space composed by six areas, six interpretations of the relationship between innovation and demand that, following the notions introduced above, we could define as narratives (see Table 1). The area in grey in the graph represents the 'strong sustainability' zone where natural capital can be preserved in its absolute value by reducing its depletion and/or increasing the efficiency of its exploitation. On the contrary, the white area coincides with the 'weak sustainability' zone where human-made capital is considered a legitimate substitute of natural capital.

2.2.1. From non-eco innovation to green growth

The business-as-usual narrative refers to the pre-environmentalism paradigm in which economic growth

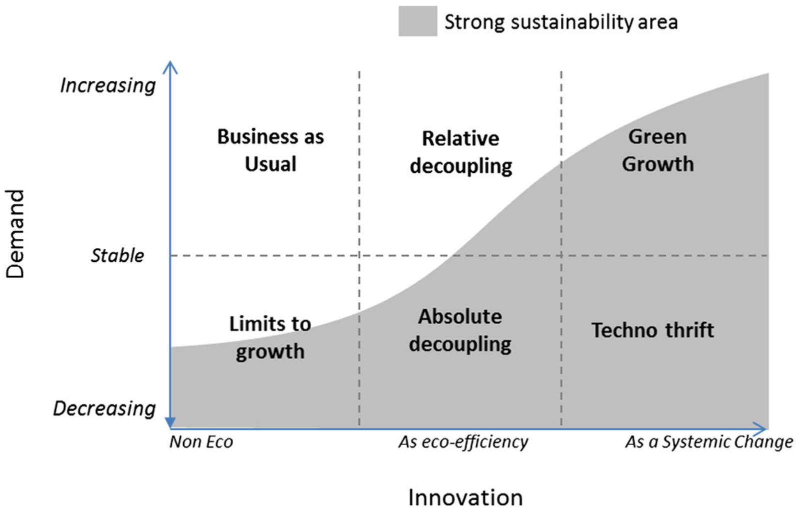

Fig. 1. Six narratives, and six pathways.

(and therefore consumption growth) is a priority, and environmental sustainability is not explicitly considered. In this case, innovation is not supposed 'to be green'. This narrative finds its legitimation in the frame of weak sustainability: as long as natural capital is converted efficiently into human-made capital, the system is considered to be sustainable. At the same time, the amount of human-made capital is supposed to increase at the expenses of natural capital (Arrow et al., 2004).

By introducing the concept of strong sustainability, this narrative can evolve through two sequential stages. In the first (i.e. from *Business as usual* to *Relative decoupling*), natural and human-made capitals are no longer considered interchangeable. As natural capital must be preserved, economic growth can continue only through an increment of eco-efficiency. Economic growth becomes compatible with environmental sustainability only when it is decoupled from resource consumption (Hammer et al., 2011).

In the second passage (i.e. from *Relative decoupling* to *Green growth*), economic growth and environmental sustainability are not only potentially compatible, but they have mutual positive feedback (Grossman and Krueger, 1991). In this view, as Kuznet's followers theorised, economic development is a prerequisite *to become green* (Martinez-Alier, 1995). On the one hand, economic growth is a prerequisite because higher demand encourages the development of greener technologies (Beckerman, 1992). On the other hand, environmental sustainability becomes an opportunity to create economic growth. We call this narrative as Green growth narrative. In the Green growth narrative, environmental innovation is seen as a win–win solution (Ambec and Lanoie, 2008), because any innovation that increases eco-efficiency has a positive impact on economic growth, and economic growth has a positive impact on the preservation of natural capital.

The strong sustainability of these narratives depends on the capacity of having a process of decoupling quicker than the pace of growth of economy (Shafik, 1994). This dynamic can be stretched to the limits of the extreme case of 'zero impact eco-innovation' (Deloitte, 2012; Schiederig et al., 2012), in which economic growth is no longer supported by material consumption, the so-called *dematerialised economy* (Daly, 1987; Roy, 2000). This is the consequence of the scenario depicted by the Nobel laureate R. Solow in his harsh critic to Meadows' work in the 70s (Solow, 2002). Such a scenario would imply major systemic changes not only in the technological sphere but also in the way production and consumption are organised (Raskin, 2008; Leach et al., 2012).

Nowadays, this narrative has a strong appealing because it addresses at the same time and with mutual benefits both economic crisis and environmental issues. Therefore it has been enthusiastically embraced by many scholars (Fussler and James, 1996; Klemmer Lehr and Lobbe, 1999; Keeble et al., 2005; Chen et al., 2006; Kemp and Pearson, 2007; Oltra and Saint Jean, 2009) and several influential actors, i.e. the OECD (OECD, 2010,2011; Hammer et al., 2011), the International Energy Agency (Pasquier and Saussay, 2012), the US Government (Doris et al., 2009), the European Union (European Commission, 2011b; European Commission, 2012), and the World Business Council for Sustainable Development (WBCSD, 2000), among many others.

2.2.2. From collapse to techno-thrift

The three narratives exposed above have been the targets of several criticisms (Hopwood et al., 2005). Even if eco-efficiency is acknowledged as a fundamental driver of innovation (Nordhaus, 1998), many scholars question the feasibility of an endless economic growth within the physical limits of our planet (Georgescu-Roegen, 1975; Leach et al., 2012). Others argue that the tendency to associate eco-efficiency with eco-innovation is not sufficient to tackle complex environmental problems like climate change and biodiversity disappearance (Jänicke, 2008). Although efficiency has steadily grown during the last centuries, few people would argue that the planet is not facing several simultaneous environmental crises (Rockström et al., 2009).

In an effort to overcome the shortcomings of eco-efficiency, the concept of eco-effectiveness has been introduced (Carrillo-Hermosilla et al., 2010). Eco-effectiveness includes those

Table 1
Frames underlying the six narratives.

	Define problems	Diagnose causes	Moral judgements	Suggest remedies
Business as usual	Low consumption hampers well-being	Low economic growth	More consumption is always better	Foster innovation to feed economic growth
Limits to growth	Demand collapses	Depletion of not renewable resources	The Planet is finite	Authoritarian governance/voluntary frugality
Relative decoupling	Increasing demand of non-renewable resource hampers future growth	Low eco-efficiency improvements	Priority of economy over the environment.	Foster eco-efficiency
Absolute decoupling	Increasing demand of non-renewable resource threat ecosystems balance	Consumption and efficiency are addressed separately	Priority of the environment over economy.	Foster eco-efficiency and at the same time control demand
Green growth	Consumption and economic growth do not decouple quickly enough	Markets do not prioritize green technology	The richer we are, the greener we are	Economic growth is a prerequisite for sustainability i.e. increase demand for green technologies to increase economic growth and vice versa
Techno-thrift	Demand decrease do not necessarily lead to well-being	Green technologies are not fully exploited through systemic changes	A thrifty society is more likely to produce sustainable technologies and vice versa	Foster systemic change in both culture and technology

eco-innovations that deliver cultural and/or technological systemic changes that are able to trigger an overall reduction of the consumption of natural resources. Those changes encompass producers and users, their behaviours, their technological horizons and the complex reality of the surrounding natural world.

The study of the rebound effects represents the first systemic attempt to unveil very accurately the contradictory relation between eco-efficiency and consumption (Herring and Roy, 2007). Jevons was the first to realise in 1865 that an increasing efficient consumption of coal was leading to an increasing consumption of it. The rebound effects (also known as Jevons or N-Curve effect) imply that the gains in efficiency produced by technological innovation can be minimized or even neutralised by an increasing demand (Saunders, 1992; Alcott, 2005; Polimeni et al., 2008). Commonly, rebound effects have been described as behavioural responses to technical improvements (Sorrell, 2007). For example, Tainter (2011) shows that, as vehicles with higher fuel economy entered the U.S. fleet from the late 1970s onwards, Americans responded by driving more. Similar conclusions are provided by other authors in several sectors (Newman and Kenworthy, 2006; Herring, 2006; Sorrell, 2007; Tsao and Waide, 2010; Saunders and Tsao, 2012). However, the real magnitude of rebound effects is quite hard to calculate due to the complexity of the systems in which they occur and the time dimension being considered. Furthermore the relations between innovation and consumption underlie over arching elements that cross the realm of technology. For example, relying on eco-efficiency solutions might lower the psychological commitment towards sustainable behaviours (Lorenzoni et al., 2007; Peters et al., 2012; Soland, 2013).

At the same time, the critique of the Green growth narrative comes also from those who question the very concept of economic development (Schumacher, 1973; Illich, 1973; Hirsch, 1977; Escobar, 2000) and those who criticise the concept of economic growth (Fournier, 2008; Martinez-Alier, 2009; Kallis, 2011). According to these authors, environmental sustainability can be achieved only through a shift of paradigm from a consumerist society to a steady-state economy (Daly and Farley, 2007) or to a de-growth society (Kallis, 2011).

Despite the differences between those approaches, these critics share an important conceptual point: in the long term, environmental sustainability implies an obligated limitation (or decrease) of demand/consumption. This limitation may or may *not* be accompanied by a technological push framed in terms of eco-efficiency. We call *Limit-to-growth* narrative the case in which a reduction in demand is not supported by an increase in eco-efficiency. In this case, the patterns of consumption encounter the natural limits of the planet and the demand/consumption levels inevitably shrink or eventually collapse (Meadows and Randers, 2006). This scenario can have either pleasant or unpleasant consequences. The pleasant case occurs if societies develop a keener attitude towards frugality and the awareness about the ecological limits in which humanity lives. The unpleasant one occurs when the encounter with the limits happens in societies that encourage consumption. This could be the case of economic recession where people suffer a rapid impoverishment or the case of *fortress-world,* an eco-fascist scenario in which an elite in its ivory tower decides *who can consume what* in order to deal with increasing resource scarcity (Raskin, 2008; Bonaiuti, 2012). Even if this scenario might potentially assure strong sustainability, it posits controversial moral issues.

The introduction of the eco-efficiency perspective moves the discourse towards the *Absolute decoupling* narrative. In this narrative, economic growth is not excluded as long as a pattern of reduction in the use of non-renewable resources is assured. This scenario creates a hierarchy in which environmental sustainability is prioritized over economic growth. This is what Raskin (2008) has called 'Conventional Worlds' pathways i.e. a number of cultural changes that would combine eco-efficiency with a voluntary reduction of personal consumption encouraged by a set of political reforms aimed at reducing absolute material consumption at macro-scale.

The last narrative, which we call *Technological thrift*, implies a scenario in which frugality and new green technologies go hand in hand. In the Green growth narrative, economic growth was the indispensable incentive to sustainability; here, frugality and parsimony are the indispensable incentives to it, because they forge the technological progress towards a clear sustainable commitment. This transition implies very deep changes in the way consumption and technology are perceived and performed, and it would include the deployment of a strong sustainability strategy accompanied by a paradigmatic shift in consumption behaviour.

This narrative may be fruitfully understood by combing the already mentioned keener attitude towards frugality at the consumption-innovation dynamics deepened by applying various systemic approaches that are nowadays very popular (Lundvall, 2007; Godin, 2007; Markard et al., 2012). Markard et al. (2012) have recently overviewed the 'sustainable transition' literature identifying, as in the case of the eco-innovation literature, a huge variety of terminology. They spot several research approaches that point to understand the complex mesh of relations between innovation, transition and sustainability. At the very core of all these perspectives, there is the idea that sustainability requires major societal transformations, not only in policies and technologies, but in practices and business models as well. As a consequence, the impact of innovation depends on the diffusion and consumption dynamics that occur among stakeholders (Geels, 2002, 2011; Penna and Geels, 2012).

The next section reports the main technological achievements and the market dynamics of the lighting industry. The case is thought to show how the eco-efficiency notion influenced the construction of sustainability narratives in the sectors and is the base for a discussion about future possible alternatives.

3. The evolution of the lighting industry

The lighting case is a remarkable example of a sector that has witnessed a tremendous increase in energy efficiency and, at the same time, a boom of energy consumption. It represents an extreme case that can provide useful insights to understand how the narratives exposed in the previous sections evolve. Extreme cases like this are potentially useful to formulate generalization that can be extended to other sectors (Flyvbjerg, 2006).

The history of the artificial lighting began with the use of the open fire as the first artificial light source about 1.4 Ma ago. However, only in the last century, which marks the dawn of era of electricity, three major lighting technological breakthroughs occurred: (i) the incandescent lamp (e.g. Edison and Tungsten light bulbs) at the beginning of the 20th century; (ii) the fluorescent lamp during the 20th century; and (iii) the light emitting diode (LED) technology today (and tomorrow). Looking retrospectively at the whole history, the efficiency of lighting technology has made several remarkable leaps forward (Krames et al., 2007) (see Table 2).

Table 2
Light efficiency is measured in lumens/W. Lumen is the standard unit of visible light emitted by a lighting source. The lumen/W measures the light emitted per unit of power. Source: own elaboration on Bright (1949), Nordhaus (1998), Coltrin et al, (2008), Pimputkar et al. (2009) and Navigant Consulting Inc. (2012a).

Device	Year	Lumens/W
Open fire	1.4 million B.C.	0.002
Neolithic lamp	10,000 B.C.	0.015
Candle	1800	0.075
Oil lamp	1815	0.134
Town gas lamp	1827	0.130
Kerosene lamp	1855	0.049
Edison lamp	1883	2.600
Tungsten lamp	1920	11
Fluorescent tubes	1947	30
CFL	1992	68
LED lamp	2010	97–135
LED lamp	2020	224–235
LED theoretical max	–	260–408
Maximum theoretical lighting efficiency	–	683

The last century shows the most amazing increase in energy efficiency. The tungsten lamp increased energy efficiency by 90-folds compared with the oil and gas lamps. The fluorescent tube and the CLF increased efficiency by 5–7 times in comparison with the tungsten lamp (Bright, 1949; Bright and Maclaurin, 1943), and the LED is expected to be 1500 times more efficient than the gas lamp.

Every new lighting technology quickly diffused in the market. The incandescent bulb was introduced at the beginning of the 20th century and, by the 1930s, it had conquered nearly 75% of the market share (Bright and Maclaurin, 1943; Fouquet and Pearson, 2006).

The fluorescent tube was introduced in the New York World Fair in 1939. Only 200,000 fluorescent lamps had been sold in 1938 but, after the fair, the number increased to 79,100,000 in 1947. The fluorescent tubes became the dominant technology in the non-residential market already in the 1950s (Smithsonian Institution, 2013). From the oil crisis in the 1970s, the lighting industry started working on the development of fluorescent tubes for residential applications, but the residential market only started to grow only at the beginning of the 21st century (Weiss et al., 2008). Table 3 reports the market share and average efficiency of the lighting technologies available in the 19th and 20th centuries.

Nordhaus (1998) calculated that such technological revolutions produced a drop in the price of artificial light of 99.75% over two centuries. To the date, the energy efficiency of lighting technology is still steadily increasing. For instance, in the last decade, the average efficiency of the U.S. lighting market rose by 30% from 45 lm/W in 2001 to 58 lm/W in 2010 (Navigant Consulting Inc., 2012c). Today, the incandescent technology represents half of the installed bulbs, but only one quarter of

Table 3
Evolution of lighting technologies in the UK. Efficiency is calculated in lumen-hours per kWh.Source: Fouquet and Pearson (2006).

Year	Candles		Whale oil		Gas		Kerosene		Electricity	
	Share	Eff.	Share	Eff.	Share	Eff.	Share	Eff.	Share	Eff.
1700	99%	28	1%	20						
1800	90%	37	10%	56						
1900	1%	80			82%	497	15%	246	2%	1310
1950					1%	887			99%	11,660
2000									100%	25,000

energy consumption and only 8% of the artificial light are produced every year (Navigant Consulting Inc., 2012c).

This historical trends show that energy efficiency undoubtedly has been one of the major drivers of innovation and one of the strongest incentives to the expansion of the market. Lighting worldwide accounts today for 2600 TWh, which is roughly 19% of world electricity consumption and it is directly responsible for the emission of 1900 million tons of CO_2 in 2006 (European Commission, 2011b). Those data are remarkable but also paradoxical: the energy efficiency of lighting technology has tremendously increased but so had the energy consumption for lighting. In order to understand this dynamic, it is important to look at the patterns of consumption in the lighting sector and compare them with the patterns of efficiency increase.

Since the very beginning of lighting industry, several analysts acknowledged that the introduction of incandescent bulbs was actually increasing the demand for lighting (Nye, 1992). For instance, Bright noticed that '*where once 5 or 10 fc were deemed adequate, from 50 to 75 fc are not now considered excessive*' (1949, p. 4). According to the same author, in 1939 31 billion kilowatt-hours was consumed for electric lighting and almost one-fourth of public utilities investments were allocated to the provision of electricity for lighting (Nye, 1992).

The increasing use of the incandescent bulb created the conditions to investigate new and more efficient lighting technologies. Inman (1939) indicated three main issues related to the diffusion of the incandescent lamp that fostered the research for new more efficient lighting technologies: (i) cost of electricity bill; (ii) wiring overload; and (iii) uncomfortable increasing indoor temperature because of excessive heating dissipation from the incandescent filament.

Again, as for the diffusion of the incandescent technology, the net effect of the new fluorescent technology was to increase the total consumption of lighting and the number of the installed bulbs (Bright and Maclaurin, 1943). Several studies have recently investigated the overall dynamics of energy consumption for lighting. For instance, Fouquet and Pearson (2006) report an increase of total lighting consumption, expressed in lumens-hours, by 1,2700,000 times and pre-capita by 6500 times in the last three centuries. Tsao et al. (2010) have analysed lighting consumption patterns over the last three hundred years in six continents founding that '*the result of increases in luminous efficacy has been an increase in demand for energy used for lighting that nearly exactly offsets the efficiency gains — essentially a 100% rebound in energy use*' because '*there is a massive potential for growth in the consumption of light if new lighting technologies are developed with higher luminous efficacies and lower cost of light*' (Tsao et al., 2010: 15). They report that expenditure for lighting has constantly represented the 0.72% of the GDP over the last three hundred years, irrespective of the efficiency of the technologies in use. Similar considerations about the persistence of rebound effects in the lighting sector have been reported by Birol and Keppler (2000) and Herring (2006).

4. Framing sustainability in the lighting sector

We show that the lighting sector is in the middle of a *narrative transition* from a *Business-as-usual* narrative to a *Green growth* narrative. This happens because society has increasing concerns about sustainability and, as a result of the rebound effects, the energy demand for lighting did not show sign of decreasing. At the same time, we show that the practices that a Green growth narrative inspires cannot assure an absolute reduction of energy consumption. As an alternative, we use the framework introduced above to propose a new pathway based on a number of systemic changes in which efficiency and demand measures are jointly considered. This alternative pathway should imply the development of new business models that are consistent with the absolute decoupling/ technological thrift narratives, reframing how technologies and practices are perceived in the lighting sector.

Before moving on, we would like to stress that our considerations focus only on energy efficiency in lighting industry and intentionally exclude other eco-efficiency dimensions (e.g. raw materials, energy consumed, and pollutants produced through the whole life-cycle) as well as other sustainable-related dimensions (e.g. losses of biodiversity due to lighting pollution, health effects on circadian human systems, impacts of heating for lighting on energy loads for cooling/ heating systems) that would add more complexity to the analysis. In addition, we do not take in account the opportunity, external to the lighting sector, of enlarging the area of strong sustainability by increasing the use of renewable sources in the production of electricity. Given such simplifications, we acknowledge that this exercise represents a theoretical/conceptual contribution, more than an operational one, to understand the potential impacts of narratives construction in shaping relations between innovations and sustainability in the lighting sector.

4.1. A dominant narrative: the tale of green growth

As we have seen above, the Green growth narrative preaches the stretching of the extant technological paradigms to revamp economic growth in a new environmentally sustainable fashion. In this quest, eco-innovation as framed in a market economy plays a central role. The frame of the green growth can be shortly presented in four steps:

- *Defining problem*: In all the advanced economies economic growth is slowing down. The sustainability of economic growth in the long term is at risk.
- *Diagnosing causes*: The slow pace of eco-technological improvements cannot tackle environmental degradation and limits further economic growth.
- *Making moral judgments*: The richer we are, the greener we are. Economic growth is crucial for human well-being because it opens new possibilities. More consumption is always better.
- *Propose remedies*: Since the development of green technologies requires economic growth and vice versa, a strong commitment in fostering the ecological modernization of all the present technological paradigms is needed.

The Green growth narrative is dominant within the discourse of the three most influential lighting players i.e. Philips, Osram and General Electric (Bryant, 2012). From their public discourses, it emerges that these companies expect the LED to become the future of green lighting technology, opening new opportunities for the market. General Electric, for instance, labelled its main lighting programme 'ecomagination'. The initiative aims at achieving innovative solutions to tackle the 'present environmental challenges and foster growth'. OSRAM indicates that it is possible to do more with less thanks to efficiency improvements (Sylvania, 2009). Similarly Philips expects that improving efficiency is a key driver of sustainability (FrostLighting Supply, 2010; Philips, 2013). According to Philips, LED opens tremendous opportunities for new applications and solutions (Provoost, 2009).

These companies see a positive relation between economic growth and sustainability thanks to the development of the LED technology: increasing demand of light will create new opportunities for developing more efficient lighting technologies and, vice versa, new efficient lighting technologies will create new demand for lighting. A similar approach is shared by scholars (Kemp and Pearson, 2007), policy makers (Machiba, 2010; OECD, 2011; European Commission, 2011a; European Commission, 2012; Navigant Consulting Inc., 2012a,b; UN, 2012), and research players (COWI, 2009; Wuppertal Institut, 2009).

The Green growth narrative in the sector finds its environmental legitimation in the tremendous increase of efficiency that occurred through the history and, above all, from the expectation of future fabulous efficiency performances created around the LED technology. Energy efficiency of lighting is today 1000 times higher than in the 18th century, 500 folds higher than in the 19th century and 5 folds higher than in the first half of the 20th century. The LED is expected to push further the efficiency performance of lighting devices. The 'Haitz's law' (Haitz et al., 1999) indicated that LED technology will show a cost reduction by a factor of 10 per decade and an increase of lighting output per LED by a factor of 20 per decade. It is today estimated that LED efficiency will grow up to 224–235 lumens per Watt (W) in 2020 (Navigant Consulting Inc., 2012b) with a maximum cap of 260–408 lm per W (Coltrin et al., 2008; Pimputkar et al., 2009). By 2020 energy efficiency of LED bulbs is expected to be 15 times higher than the incandescent ones and 4–6 times higher than the fluorescent ones, with a theoretical limit of 683 lm per W. By 2015 the standard price for LED solutions is expected to be competitive with the other pre-existing technologies. By 2030 the LED is expected to achieve 73% of the market share (Navigant Consulting Inc., 2012c). This trend is supported by several studies (for an exhaustive review see Tsao et al., 2010).

One of the reasons that moved the dominant actors in the industry to embrace a Green growth narrative can be found in the traditional business model adopted in the sector that rewards the sale of more efficient lighting bulbs in two ways. First, new efficient bulbs artificially reduce the life cycle of the old ones, because consumers may be tempted to change the old bulbs, even if working, to reduce the energy bill. Second, new efficient bulbs can be sold at higher price because of their potentiality of saving energy. Therefore, the development of ever increasing efficient bulbs is a priority for the economic sustainability of the lighting sector, as already observed in the case of the fluorescent tube (Bright, 1949) and of the compact fluorescent lamp (U.S. DOE, 2006). Consequently, the lighting players have started support actions that focus on increasing the efficiency performance of lighting bulbs (e.g. the EU ban on incandescent bulb) as a way to purse sustainability and create a new market for more efficient lighting bulbs. LED technology is claimed to be able to save 75% of the energy currently consumed in the sector (Navigant Consulting Inc., 2012). For this reason, in the lighting industry the LED is widely framed, by the green growth advocates, as the greenest technology ever (Haitz et al., 1999).

The players within the industry may discourage actions designed to reduce energy consumption because such measures have a negative impact on their traditional business models for two reasons: i) energy conservation measures reduce the value of more efficient electric bulb because it lowers the potential of energy savings by shifting towards more efficient solutions; and ii) energy conservation may prolong the lifecycle of the current installed bulbs.

Nevertheless, despite the enthusiasm of the lighting industry, the LED is expected to increase the energy efficiency of lighting by 4 times; a modest advance if compared with the increase of 1000 times achieved in the last century. These figures suggest that the efficiency of the lighting technology is approaching a sort of technological/physical limit. Reaching such limit may become a relevant problem, because there are no clear signs of saturation on the demand side that may assure that such advance in efficiency will decrease energy consumption for lighting. Tsao et al. (2010) foresee that the consumption of energy for lightning is likely to duplicate in the next decade, a scenario that would offset any improvement delivered by the LED. Similarly, an analysis carried out by McKinsey and Company (2011) suggests that 6 out of 7 projected megatrends of the lighting market will be characterized by an increase in lighting demand.[1]

Consequently, we argue that the widespread diffusion of the LED technology within the dominant Green growth narrative is likely to further improve the energy efficiency of

[1] According to McKinsey and Company (2011) the factors that increase light consumption are population increase, urbanization, ageing, rising income, sharing space, and electronic miniaturization. On the other hand, the development of electronic control systems is likely to decrease energy consumption for light.

lighting technology but those improvements might not be sufficient to reduce the energy consumption for lighting. We argue that, in order to reduce energy consumption for lightning in absolute value, the sector should integrate the development of highly efficient technology like the LED with measures that aim at reducing the demand. Inevitably, such a change implies a reframing of the Green growth narrative.

4.2. Exploring alternative narratives: from bulbs to lightness

The need to develop a countervailing narrative in the lighting sector opposed to the Green growth one emerges from the major consideration emerged in the previous section: the expected increases of energy efficiency delivered by new lighting technologies are likely to be inferior to the estimated increase in consumption of lighting.

In order to reframe sustainability in the lighting sector we propose to focus on the real meaning of light in daily life (Bowers, 1998). Lighting has the purpose to fulfil the human need of performing visual tasks. In this sense, electric light extends the function of natural light in situations in which more light is needed. If one focuses on the 'function or usefulness of light' – what we call 'the functional approach' to light – we can say that electric light is wasted when: (i) it is used whilst natural light is available (i.e. it is redundant); and (ii) it is not used to perform visual tasks (e.g. illuminate empty spaces).

The functional approach leads to at least two strategies to reduce the demand for artificial light by: (i) increasing the use of natural light when it is available through the rational design of natural light sources in buildings (i.e. reducing redundancy through fenestration) and; ii) adapting/switching off the lights, through Automatic Control Systems (ACS) (i.e. technologies that rationalized the use of lighting) when visual tasks are not performed. These two strategies, by focusing on reducing the demand for artificial light, can be combined with the effort to increase the energy efficiency of lighting bulbs to create three potential strategies (showed in Table 4).

The challenge, therefore, is to develop new business models in which all these three strategies are integrated and rewarded for their capacity to produce useful light. The next section focuses on the business model aspects, but before moving there, we briefly explain the meanings and potentialities of the two demand-oriented strategies (i.e. fenestration and ACS).

Fenestration usually refers to the design and construction of openings in a building. Before the 1940s, fenestration was the most important source of indoor illumination (Edwards and Torcellini, 2002). Fenestration does not include only windows, but also other old (e.g. skylight, roofless inner courtyard) and modern solutions (e.g. sun-tunnels that combine optic fibres, luminaries and glass structures in order to carry solar lighting beams even in areas in which windows are inadequate or absent). The fenestration concept includes also the Automatic Blind Systems (ABSs) that control the opening of blinds according to the intensity and direction of the direct light. The diffusion of the electric bulb had a dramatic impact on the way in which buildings were designed to use natural and artificial lighting. The birth of the electric light gave new opportunities for building solutions, because lighting could be provided even far from fenestration devices. The electric light became so predominant that today it is used even when natural light is available (Bierman and Conway, 2000), especially to control unwanted glare from sunlight. However, literature shows that users seldom restore the original natural daylight conditions when the glare is over (Leslie et al., 2005). The result is that daylight is now often disregarded as a lighting source in modern buildings (Shaw, 2010). The development of an alternative frame for building lighting should require the full (re)integration of fenestration, today limited to the field of architecture and building industry, in the lighting industry and the frame of daylight as a 'natural' lighting bulb that as a remarkable efficiency of 93 lm for watt (Shaw, 2010) for a full spectrum light. Compared to these figures, current fluorescent bulbs have a similar energy efficiency performance but a reduced spectrum of colours.

Another strategy suggested by the functional approach is to minimize the waste of *useless* light from artificial sources through the diffusion and promotion of the ACSs. ACSs are systems that adjust the light quality and quantity according to the inputs received from specific sensors. ACS can achieve a reduction of lighting consumption between 20% and 80% (Galasiu and Newsham, 2009; Navigant Consulting Inc., 2012c; Dolin, 2013). However the market is still poorly developed (Verify Markets, 2011). It is estimated that only 1% of residential buildings and 27% of commercial ones use ACS in the USA (Navigant Consulting Inc., 2012c).

It is worth to notice that the fenestration and ACS are here discussed as separate strategies because of their different impacts (increasing daylight vs. decreasing useless artificial lighting). However the effectiveness of these solutions for energy saving depends on how they are integrated because the quality of daylight (e.g. the degree of homogeneity) that penetrates in a building influences the efficiency of the automatic control systems. Therefore the integration of the two strategies is also a technical challenge that forces to increase the efficacy of the overall lighting system.

4.3. Alternative business models

Today the three strategies described above (i.e. more efficient bulbs, fenestration, ACSs) are not integrated. Their integration would require a shift in the current dominant *business models* in the sector in favour of hybrid models that

Table 4
Strategies to reduce energy consumption for lighting. The parenthesis indicates the impact on the efficiency and the demand of electric light.

		Source of light	
		Natural	Artificial
Use of light	Useful	Better integration of fenestration (− demand)	Increasing efficiency of electric bulb (+ efficiency)
	Useless	Not relevant	Widespread diffusion of ACS (− demand)

reward both efficiency efforts and demand-oriented measures. Lighting solutions could be evaluated for their capacity to allow users to perform visual tasks and for their capacity to reduce energy consumption. In this sense, providing natural light could be equalised to the provision of artificial light and be rewarded in the same way. Specific meters could be developed to calculate the sum of lumens produced by fenestration devices (i.e., the natural bulb) and the electric bulbs only when the light is actually used for human needs.

This new business model can be developed by new players, the 'Lighting Service Companies' LISCO which aim is to provide useful light by integrating the different sources. The acronym LISCO explicitly recalls the ESCO 'Energy Saving Company' concept, because both approaches have a functional-based business model, but with one relevant difference: ESCO bases the business models on the sale of energy saving, whilst the LISCO focuses on the sale of *useful illumination*. The company Eco-nation is an interesting example of using the LISCO model. By installing the 'Lightcatcher' sun tunnel and a smart meter for free, the company tracks the quantity of saved electricity and gets paid according to the effective savings (EcoNation, 2013). The birth of facility/building management market is a second interesting example of a different way of framing lighting. Recently, the International Building Owners and Managers Associations (BOMA) has indicated the reduction of lumens as one strategy to improve the energy performance of buildings (BOMA, 2013). Fig. 1 proposes a conceptual space to confront the traditional players and the different business models with the LISCO proposal (Fig. 2).

The development of the LISCO business model is expected to encounter several barriers, given the dominance of the Green growth narrative. The last part of this section aims at highlighting some of the elements that can influence the development of this alternative model:

4.3.1. Technology

A functional approach requires two types of technologies/ solutions: i) technologies that provide light (i.e., LED or other electric bulb, and fenestration); and ii) systems that integrate and manage all these technologies (i.e. ACS).

Regarding the first category, we do not perceive any specific barriers that may hamper the development of these technologies that are today progressing both in terms of efficiency and feasibility.

At systems level instead, the challenge is to develop *smart* lighting system, an acronym used to indicate specific more dynamic lighting controlling systems that focuses on interaction between users, buildings and lighting (Lightolier, 2007). For the purpose of our proposal, these systems may provide smart meters and smart sensors able to track: i) the need of light according to the visual tasks performed; ii) the availability of natural light through the different fenestration devices; iii) the need of supplementing artificial light to create the optimal lighting environment; and iv) the provision of lighting from each of the artificial and the natural sources.

The *smart lighting* market is still at an infant stage, and it is expected to exploit the potentiality for customization given by LED. The main trend is to integrate internet and Wi-Fi communications in lighting systems in order to create a dynamic interactive lighting environment. The *smart lighting* perspective gives relevant solutions able to develop the LISCO business model and its focus on the concept of useful light. For instance, a specific *smart* approach can identify the need of lighting according to the actual use of the space: when a person is sitting at a desk, the system may recognize the 'working/ reading' condition, and the lighting system may reduce general background light in favour of a directional one. A different approach can be obtained by tracking personal devices (e.g. smartphone, computers) which communicate personal positions, mood and type of activities. Consequently the lighting system can customize the lighting environment according to the information received by the devices. For example, a user may set a 'reading' mood in its smartphone that allows the lighting environment to adapt at that particular situation/ object. The last approach integrates the concept of building zones to predict the usage of specific indoor areas according to

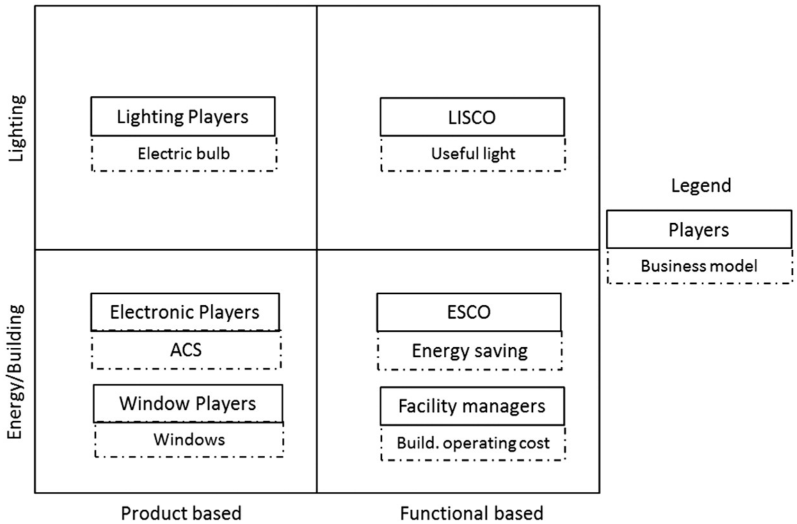

Fig. 2. The position of the proposed LISCO player and the new business model in comparison with the traditional players and business models.

the functional use of that space (e.g. a corridor, a bathroom, a living room) at any time of the day.

Those solutions are still far to reach a technological maturity. We guess that this happened not only because of a specific technical complexity, but partially because the lighting sector has underestimated the importance of controlling systems governing the demand of light, because of the dominant narrative focusing on the supply side.

4.3.2. Policy and society

The policy side has several opportunities to promote a transition towards the functional approach. First, policy makers must become aware of the dynamics of lighting industry. Today lighting demand is usually reported in terms of energy consumption (Bertoldi and Atanasiu, 2010). Even if this measurement correctly assesses the environmental impact of lighting, it does not provide information about the dynamics of demand. This is an inexcusable inadequacy, because the governance of any complex markets requires consistent knowledge about the dynamics of both the supply side and the demand one. Therefore policy makers need to be informed about the consumption of lighting (i.e., the quantity of lumens-hours produced) and the related energy consumption. We think that this complete information could increase awareness about the patterns of consumption increase and its effects of the demand of lighting in the last century. Light pollution is a paradigmatic example of the effect of lack of awareness in the political agenda and in measurement systems (Cinzano et al., 2000; Hollan, 2009). A remarkable example in that direction is the 'lights out' initiative of Chicago in which tall building night lights are switched off during bird migratory season (Elliott, 2013) or the efforts to report data about lumens/h production for the USA lighting market inventory (Navigant Consulting Inc., 2012c).

Second, policy makers shall enforce the integrations of ACSs by setting more stringent building standards about the use of dimming, occupancy and daylight sensors in order to reduce the waste of unneeded lumens. In the USA, the ASHRAE 189.1-2011 norm prescribes the use of automatic systems to reduce light intensity at least by 50% when no one is present (Jouaneh, 2013).

Third, policy makers should also promote the functional approach by setting a mandatory lighting label for building which indicates the performance of the building in providing natural illuminations, and managing the artificial ones. Such information could actually lead to policies that set more stringent standards for quantity of natural lighting in building (and quality for the artificial one).

Lastly, a paradigmatic shift should occur to change the idea that the electric bulb is the only source of light. Policy makers should promote new lighting organisations that include all the lighting actors, not only the ones associated to the electric bulb. Such actors may ease the transition by bringing different narratives and technologies in the lighting arena. For instance, the 'Liter Bottle Lamp' designed by the My Shelter Foundation is a case of reframing of fenestration as a lighting solution that relies on frugal engineering that reduces material use and meets social needs (Sharma and Iyer, 2012). By adapting a used plastic litre bottle, it is possible to have a lamp equivalent to a 60 W incandescent bulb, but with no need for electricity (My Shelter Foundation, 2013). From September 2011, around 15,000 'Liter Bottles' were already providing sun-light to thousands of simple dwellings in the slums of Manila. We do argue that My Shelter Foundation is a lighting player and the Liter Bottle is a lighting technology.

4.3.3. Taxation

Energy tax should target reduction of energy consumption (for lighting). Tsao et al. (2010) propose to stabilize energy price through the raise of taxation every time that efficiency increases. Since lighting demand depends on the energy price and not on the energy efficiency, this approach would sterilize the increasing demand for lighting due to increasing of efficiency. We share the importance of this proposal but we highlight that this is a partial answer, because there is also the need to reduce the consumption of useless light, even if efficiency is stable.

We indicate two ways in which the proposal of Tsao et al. can be updated to include the incentives to reduce the demand of (useless) light, not depending on gain of efficiency. First, energy taxation may increase every time that energy consumption does not follow an established pattern of reduction. Therefore the locus of taxation is not the gain of efficiency, but the missing reduction of consumption. Taxation, however, has a relevant redistributive effect that can create conditions of unfairness, given the different incomes and consumption baskets of consumers. A fairer, but more complex solution, would be to separate the taxation on consumption of useful light from the taxation on the consumption of useless light, in which the former shall follow the proposal of Tsao et al., and the latter shall be taxed as a luxury good. This system may be considered much fairer than the former one, but it has an evident shortcoming: the evaluation of useful and useless lights requires a complex assessment system with high associated transaction costs.

A last remark regards the critical difference between the implementation of the three strategies in new constructions or through building renovation. The latter may have relevant costs if it regards new fenestration devices. In this case, higher taxation on lighting may turn not to promote such transformations, because of the insurmountable costs of building renovation. As a result, we highlight the importance of the labelling systems and the proposed taxation mechanism for the new constructions, whereas further considerations are required for the case of existing building stock.

5. Concluding remarks and future research

In this work we show that the notion of environmental sustainability is far to be an objective and monolithic concept but is the contested ground of competing interpretations framed in turn in a number of what we have called *sustainability narratives*. The deconstruction of those narratives, we argue, is crucial to understand the dynamics that shape certain sustainability discourses and, above all, the interests and the actions of the actors involved in the process. The important function of discourse in this formulation is its constitutive nature: language does not simply represent the world but enables world's transformation through action. In the present work we show that it is possible to open up the debate about a sustainable future reframing the relations between technical change and demand/consumption in multiple ways.

Another important contribution of the present work is the application of the analysis of multiple narratives of sustainability to the lighting industry that is potentially useful to the formulation of alternative business models for the sector. By analysing the current trends of the lighting sector, we conclude that the dominant Green growth narrative is not enough to achieve an absolute decoupling. We propose a number of alternatives to reconcile the efficiency perspective with measures that are designed to decrease the demand. In this sense, we indicate a conceptual change of the lighting sector from being the realm of the electric bulb to a more integrated perspective in which natural and artificial sources of lighting are fully integrated. In this way, conservation and efficiency measures refer to electric lighting, whereas increasing of demand refers to the use of natural light. LED plays a pivotal role in leading such transition, because it is a semiconductor electronic device which can be fully controlled by centralized/decentralized systems. LED has therefore the potentiality of being the future green technology, not for its improved energy efficiency, but for its capability of promoting systemic lighting solutions. The possibility of this technology to fulfil such expectations will depend on the evolution of the dominant lighting narrative towards a more integrated one. This shift would imply major transformations of current policies, practices and actors, with the development of new capabilities and new markets coming from the integration of the traditional lighting and fenestration sectors.

We acknowledge that our results are limited both in methodology and in the theoretical dimension. From a methodological perspective, we already highlighted that we did not include other environmental dimensions besides the dimension of energy efficiency. An analysis of the whole lifecycle of the lighting technologies might achieve more accurate results. Similarly, we did not address the specific differences between the residential and the non-residential lighting markets. Our analysis focuses on the latter because the residential market posits two relevant challenges for our conclusions. First, the incandescent technology is still dominant in the residential market. Consequently the expected gain of efficiency resulting from widespread diffusion of LED is much higher than what we indicate in this paper. This different pattern may lead to different conclusions about the degree of sustainability of an eco-efficiency based narrative. Second, the consumption of energy of each dwelling/house is by far lower than the one in non-residential settings. This different magnitude implies that the functional business model may be unrealistic to be applied when the expected savings are too low. This is exactly what happens today about the ESCO business model, which is not getting popularity in residential settings. However, we highlight that the residential market is yet the most important market in terms of installed bulbs, but it represents only 8% of demand for lighting and 25% of demand of energy for lighting (Navigant Consulting Inc., 2012c). These figures indirectly suggest that the environmental impact of the non-residential markets (i.e., outdoor and non-residential indoor) is higher than the impact of residential markets.

From a theoretical perspective, we did not fully exploit the potentiality of the Discourse analysis, by explicitly analysing the notions of *power* and *democracy* in the discourse of lighting. Foucault, who forged the term *governamentality* to describe the capacity of language as social practice to govern and control the actions of third actors (Foucault, 1977,1984), indicated that the discourse can be used to legitimate, reinforce or exclude specific social practices. The introduction of the notion of governmentality in the analysis of environmental politics discloses the role of formal institutions i.e., governmental agencies and universities in the legitimation of science-based policy making. By reframing the environment as a highly complex system that can be understood only by experts, the sustainability debate ends up excluding vast sectors of civic society. The acknowledge that sustainability is a contested notion, as Hajer and Versteeg (2005) suggest, is the base to make a call for opening up the debate to the inclusion of alternative narratives constructed around a wider range of actors from the civil society i.e., NGOs, local communities and social minorities (Stirling, 2007). A more accurate analysis of the public discourse of the dominant player in the sector of lighting might shed light on the dynamics beyond the acceptance of the Green growth narrative within the industry but also among institutional actors like governments and consumers. Furthermore, another important limitation is that our analysis is designed to focus on developed countries. This is certainly a narrow goal since in the next future developing countries, hungry for new lighting applications, will become increasingly influential in the production, distribution and consumption of energy for lighting. How this will affect the present dynamics of the lighting industry is still an uncharted territory.

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