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Cuando la alta technología se encuentra con la baja technología : dinámicas de eco-innovación y estrategia corporativa en el sector de la construccíon

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When High-tech meets Low-tech: Eco-innovation Dynamics and Corporate Strategizing in the Construction Sector

In recent years green innovation or "eco-innovation" has grown increasingly to become one of the main drivers of economic development. This is a major change with regard to earlier times, when the environment in general was considered as a burden for businesses. This paper presents an empirical and theoretical analysis of the dynamics of the "greening" of industry in an effort to learn more about the competitive conditions for eco-innovation against a background of continuous change and in various economic contexts. We study the case of the corporate strategies of firms involved in the chain of production of paper in Denmark in regard to environment-related nanotechnology, using an "evolutionary capabilities" approach. Nanotechnology is of interest because it is at the early stages of development, because of its envisaged environmental potential and because of the environmental risks associated with it. It is also an example of the most high-tech side of eco-innovation and therefore of the absorption capacity of the construction sector.

Azken urteetan berrikuntza berdea edo «eko-berrikuntza» gero eta gehiago bihurtzen ari da garapen ekonomikoaren bultzatzaile nagusienetako bat. Aldaketa garrantzitsua da aurreko garaiekin alderatuz, oro har ingurumena zamatzat hartzen baitzen negozioetarako. Artikulu honek industriaren «ekologizazio» dinamiken azterketa enpiriko eta teorikoa biltzen du, hobeto uler daitezen eko-berrikuntzaren lehia-baldintzak, etengabe aldatuz doazela eta testuinguru ekonomiko ezberdinak dituztela. Danimarkako paper-katean nanoteknologia ekologikoaren alorrean esku-hartzen duten enpresen korporazio-estrategiaren kasua aztertu dugu, «gaitasun ebolutiboen» ikuspegia aplikatuz. Nanoteknologia interesgarria da lehenengo garapen-fasean dagoelako, ahalera ekologikoa aurreikusi zaiolako eta ingurumen-arriskuak dituelako lotuta. Era berean, eko-berrikuntzaren alderdi teknologikoenaren adibidea da eta, beraz, eraikuntza-sektorearen absortzio-gaitasunaren adibidea ere bada.

A lo largo de los últimos años, la innovación verde o «eco-innovación» se ha ido convirtiendo cada vez más en uno de los principales impulsores del desarrollo económico. Es un cambio importante respecto a épocas anteriores, cuando en general el medio ambiente era considerado una carga para los negocios. Este artículo recoge un análisis empírico y teórico de las dinámicas de «ecologización» de la industria para comprender mejor las condiciones competitivas de la eco-innovación, en continuo cambio y en distintos contextos económicos. Estudiamos el caso de la estrategia corporativa de las empresas que intervienen en la cadena de papel danesa respecto de la nanotecnología ecológica, aplicando el enfoque de las «capacidades evolutivas». La nanotecnología es interesante por encontrarse en la primera fase de desarrollo, por su potencial ecológico previsto y los riesgos medioambientales asociados a ella. También es un ejemplo de la vertiente más tecnológica de la eco-innovación, y por lo tanto de la capacidad de absorción del sector de la construcción.

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Keywords: Eco-innovation, windows, glass manufacture, nanotechnology, green nanotechnology.

JEL classification: L11, L22, L61, L74.

1. INTRODUCTION

Climate change mitigation has over the last few years come to present one of the most important global policy goals, increasingly shared across policy domains and regions. Associated with this strong climate agenda, there is a new global race to become leaders in what leading politicians term “the green industrial revolution” or the “New green deal” (Obama, 2009; Brown, 2009). There is a new focus on innovation as a means to solving environmental problems. This tendency is caught by the novel concept of ‘eco-innovation’ which is increasingly consolidated at the international (EU and OECD) policy level (EC, 2009; OECD, 2009). Eco-innovation concept is closely connected to green growth policies, symbolizing an rising synergy between environmental and innovation policies (Kemp and Andersen, 2004; Andersen, 2006; Andersen and Foxon, 2009, OECD, 2009). Eco-innovation is by now seen as a core driver of economic development and even as a means to ‘green recovery’ in the current serious global financial crisis (Milliband, 2007; Barroso, 2007; Andersen and Foxon, 2009; OECD, 2009).

This new attention to eco-innovation, particularly marked in the period 2007-2010, represents a dramatic shift from earlier. Only a few years ago the environmental agenda had a much lower standing and the expectations as to the effects on the economy were moderate if not negative. Generally speaking, environmental issues were considered a burden to most businesses and overall competitiveness by both business and policy makers (Kemp and Andersen, 2004). Accordingly, innovation policy and environmental policy used to be opposites (Andersen, 2006, 2009).

This paper seeks to contribute to our understanding of the industrial dynamics of the 'greening' of industry and how this has been changing over time. Applying an evolutionary economic perspective this paper posits to interpret the rise of eco-innovation and the 'green market' as a specific historic phase (Andersen, 2010a, 2010b). We know little about the changing dynamics of this green economic evolution over time and how it affects different parts of the economy, both theoretically and empirically. A core reason for this is that orthodox neoclassical economics has dominated environmental research and policy making and have, with their static notion of rationality and focus on short run allocation, failed to realize that markets are greening (Andersen, 2010a, 2010b).

The evolutionary economic perspective is quite different focusing on the role of innovation for long run economic and social development. As a starting point competitive conditions are presumed to be constantly changing (Nelson and Winther, 1982). A core interest within this field is to analyze the rate and direction of technological change (Dosi, 1982). Interpreting eco-innovation from this perspective means inquiring into what makes the economy move in a green direction (Andersen, 1999, 2002, 2010b).

This paper seeks to feed into this discussion by an empirical analysis of corporate eco-innovation strategizing along a value chain. This paper posits that applying an 'evolutionary capabilities' perspective to a value chain analysis may provide valuable insights into the dynamics of the 'greening' of industry. This perspective has only been very little applied to the environmental area (see Andersen, 1999, 2002). The evolutionary capabilities literature analyses changes in the economic organization resulting from the economic process; that is how firms organize and coordinate their production and learning in dynamic markets (Teece, 1986, 1996; Liebermann and Montgomery, 1988, 1998; Langlois and Robertson, 1995; Langlois, 1992, 2003, 2004). By looking into corporate strategizing of firms along a value chain, the analysis seeks to capture how interdependent but heterogenous firms at different places in the chain respond to the new profit opportunities.

In contrast much environmental analysis of firm or value chains tends to be managerial and of a prescriptive nature. Also the more evolutionary economic analysis have so far tended to focus strongly on the effects of environmental regulation on eco-innovation (Rennings, 2000, 2003; Hübner *et al.,* 2000; Markusson, 2001; Kemp, 2000; Foxon, 2005, 2007; van den Bergh *et al.,* 2006, 2007; Reid and Miedzinski, 2008; Carrillo-Hermosilla *et al.,* 2009). Overall, there has been limited analysis into the industrial dynamics of the greening of industry per sé. As data and statistics on eco-innovation is poor (Kemp and Pearson, 2007; Andersen, 2007; OECD, 2009) we overall know very little about trends in the greening of different industries and less about the greening dynamics in value chains.

The empirical case chosen is the uptake of green nanotechnology in the construction sector. More specifically, the paper is based on a qualitative study of corporate strategizing in the Danish window chain. The construction sector has been chosen because it is a very traditional, fairly low-tech and conservative sector (Gann, 2003). It is also a sector with a very high environmental impact both in the form of waste production and energy consumption.

As buildings account for 40 pct. of the global energy consumption the sector is increasingly influenced by the climate change mitigation agenda (Elvin, 2007; Andersen *et al.,* 2010). Energy efficiency has become one out of three main climate policy targets, the two other being CO_2 reductions and growth in renewable energy technologies. Also eco-innovation in construction is more generally seen as an important means to develop more resource efficient lifestyles, as buildings to a high degree influence on energy and resource use in the user phase.

Nanotechnology is interesting as a case because of the high expectations to the environmental opportunities. Nanotechnology is the ability to analyze and manipulate matter at the nanoscale, where the chemical properties are very different. The technology, though still at a very infant stage of development, is perceived as a general purpose technology expected to become an important driver of global economic and societal development possibly representing the next industrial revolution (Laredo *et al.,* 2010; Shapira *et al.,* 2010). Nanotechnology is a priority area in most countries attracting huge investments globally (Nanoforum, 2003, 2004; BMPF, 2004; Royal Society, 2004; Aitken *et al.,* 2006; National Research Council, 2006; Lux, 2007; NSET, 2009). The technology has from the start been associated with much hype, i.e. science fiction like speculations on reshaping the world atom by atom and grand expectations as to the problems it may solve, e.g. environmental problems, health, starvation, but also fear of risks to health and the environment (see EC, 2004; Royal Society, 2004; Andersen and Rasmussen, 2005; Friends of the Earth Germany, 2007; Elvin, 2007; Schmidt, 2007). The green nanopotentials in the construction sector have been emphasized, but still we know more about the potentialities than real trends in commercialization (Elvin, 2007; Schmidt, 2007, Andersen and Molin, 2007; Andersen *et al.,* 2010).

Nanotechnology is an interesting case of eco-innovation because of these very high expectations to the green profit opportunities mixed with the concerns for the environmental and health risks. The question is how will firms react to these mixed signals? Further, nanotechnology is a case of a high-tech emerging technology, whereas the construction sector is fairly low-tech. This raises general questions as to the absorptive capacity of the construction sector towards nanotechnology. Nanotech in the construction sector has only been little studied but there seems to be a slow uptake of nanotechnology in the sector (Gann, 2003; Crisp/SPRU, 2003; Bartos *et al.,* 2004; Zhu *et al.,* 2004; Fellenberg and Hoffschulz, 2006; Andersen and Molin, 2007; Geiker and Andersen, 2009).

Also, much eco-innovation in the construction sector used to be quite low-tech, i.e. unburned clay houses, straw houses ect. which formed part of 'eco-villlages' often initiated by green NGOs. Attention to high-tech eco-innovation in the construction sector is relatively novel.

The empirical analysis investigates a) the strategies and innovative activities of different types of firms in the Danish window chain towards nanotechnology and eco-innovation. And b) the level of market development, i.e. the emergence of respectively eco-innovation and nanotechnology as a selection criteria on the market, i.e. when and how producers and users use respectively the 'green' and the 'nano' term on the market. The question raised is if eco-innovation functions as a driver for nanotech uptake. Emphasis in the empirical analysis is mainly on the two middle steps of the value chain, the core glass and window producers, drawing in their relevant (nano-innovative) suppliers while further customers and trends in demand are covered more indirectly (as perceived by the mentioned actors).

The focus and ambition of the paper is to illustrate how the evolutionary capabilities perspective may be applied to the analysis of the greening of industry, in this case the window chain within the construction sector.[1] The paper does not attempt to discuss the specificities of eco-innovation as opposed to other innovations, as this entails are more in-depth conceptual discussion (see Andersen, 1999, 2006; for early thoughts on this).

The paper identifies a major shift in firm eco-innovation strategizing the latter years is apparent,. Not only is eco-innovation becoming a much more important issue for many firms in the window chain, it is influencing the innovative activities and strategies in several ways also towards nanotechnology.

The structure of the paper is as follows:

Section two discusses the theoretical considerations and hypotheses linking up selection processes, and organizational dynamics to eco-innovation and nanotechnology. Section three shortly introduces the window chain and brings an overview of the companies analyzed. Section 4 analyses the corporate strategizing in the Danish window chain. Section 5 concludes.

2. SELECTION, ORGANIZATION AND ECO-INNOVATION

The evolutionary economic perspective focuses on the role of innovation for long run economic and social development. As a starting point competitive conditions are presumed to be constantly changing (Nelson and Winther, 1982). Also, negative externalities, such as environmental degradation, are not given but subject to change, as innovation and framework conditions are shifting over time causing new externalities to occur and the formation of new institutional structures to deal with these (Nelson and Winther, 1982). Such a view on the economic process opens up for the possibility that externalities may be internalized into the economic process and that the market can go green (Andersen, 1999, 2009, 2010).

Eco-innovation has hitherto been defined in technical terms focusing on which kind of environmental impacts the technologies remedy, also by evolutionary economists (Kemp and Pearson, 2007). An evolutionary economic interpretation should define the concept in economic terms. *Eco-innovations are innovations which are able to attract green rents on the market* (see also Andersen, 1999, 2002, 2006, 2008a, 2008b, 2010a, 2010b). They are innovations which (appear to) reduce net environmental impacts while creating value on the market. Eco-innovation is a measure of *the degree to which environmental issues are becoming integrated into the*

[1] See Andersen, 1999, 2002 for an analysis of eco-innovation dynamics in the paper chain, and Andersen 2010 for a comparison of the window chain and the paper chain).

economic process. It is not decisive how green an innovation is but to what degree the environmental parameter has become a selection parameter on the market. The concept is hereby inherently linked to green competitiveness and green economic evolution. The eco-innovations may, as other innovations, be technical, organizational or marketing innovations as long as they improve the "green competitiveness" of a company (Kemp and Andersen, 2004; Andersen, 2006, 2008b). There are basically two ways a firm may attract green rents on the market: Either by acquiring a premium price for its green reputation or product, or to reduce production costs by achieving greater resource efficiency or reducing the costs of handling costly wastes. Different empirical studies have shown that incentives for engaging in eco-innovation vary widely for different types of firms and sectors but we still need to know more about this (Malaman, 1996; Ulhøi, 2000; Horbach (ed.), 2005; Kemp and Pearson, 2007).

The research question arising from the evolutionary capabilities perspective related to eco-innovation is how firm's organize their innovation in the greening market. According to the theories of economic organization the firm's capabilities are the most significant factors in determining what will be done by the firm or the market (Penrose, 1959; Richardson, 1972). Starting from this assumption the current paper suggests to apply a three pillar framework developed by Langlois and Robertson (1995) and Langlois (1992, 2003, 2004). The framework links up micro-foundations (capabilities and technological parameters) with aggregate market and institutional developments for analyzing long run economic change. The framework hence has some similarities with the (national) innovation systems framework (Lundvall, 1992, 2007; Nelson, 1993) but with a stronger micro-theoretical foundation. While the Langlois framework primarily has been developed to study major structural shifts in economic organization, i.e. the changing role of the large (Chandlerian) versus small firm for innovation under different (historic) conditions more generally, it could well be applied for the study of green economic evolution and nanotech evolution. The current paper seeks to apply this framework to the analysis of green nanotech development in the window chain.

The three pillars are (text only slightly modified)[2] :

1. *The distribution of existing capabilities in firm and market*. Are the existing capabilities distributed widely or contained importantly within the boundaries of large firms?
2. *The systemic/autonomous nature of the economic change*. Does the seizing of new profit opportunities require systemic reorganization of capabilities, including the learning of new capabilities, or can change proceed in an autonomous way?
3. *The level of development of the market.* To what extent can the needed capabilities be tapped readily from the market and to what extent must they be created from scratch? To what extent are relevant market-supporting institutions in place?

These three factors are highly time and space dependent. Noticeably as firms learn unevenly the relative strength of firm and

[2] The framework in modified from Langlois 2003 p. 360.

market capabilities continuously change giving rise to new coordination needs between interdependent firms. These lead to strategic considerations on vertical integration or disintegration depending on the 'dynamic transact costs' (Langlois, 1992). 'Dynamic transaction costs' are the interfirm coordination costs which arise when a firm does not have the capabilities it needs when it needs them (Langlois, 1992, 2004). They are the costs of persuading or teaching actors with relational assets (suppliers or customers) issues necessary for a given innovation. They are, in other words, the costs of bringing interdependent firms on the same 'wavelength' to secure coordinated, efficient innovation (Langlois, 1992). The strategic consideration for the firm is how to deal with these costs. They may lead to vertical integration or, more neglected, they may force firms to engage in coordination activities (persuasion, teaching) or creating varies market-supporting institutions, including formal and informal communicative or technical standards.

3. INNOVATION IN THE DANISH WINDOW CHAIN

With the Danish window chain is meant the firms active on the Danish market for windows as well as their suppliers and customers ; most of these are based in Denmark but there are naturally also international players involved. Emphasis is mainly placed on the middle of the value chain, the core glass and window producers, drawing in their relevant (nano-active) suppliers and customers (whole and retailers) while end customers and overall trends in demand are covered more indirectly (as perceived by the mentioned actors). The data are quite new, based mainly on interviews during 2009 and early 2010 but also web based information, secondary data and a national survey[3], mapping the nano innovation activities and their relevance for construction in Denmark, as well as related earlier studies by the author in the nanotech, green nanotech and nano-construction area (see Andersen and Rasmussen, 2006; Andersen and Molin, 2007; Andersen, 2006; Geiker and Andersen, 2009; Andersen and Geiker, 2009).

The vertical specialization in the window chain is characterized by a few very large technically advanced multinational glass manufacturers, many small mostly traditional glass processing and window manufacturers and a range of diverse project oriented construction companies (Andersen *et al.,* 2010). This creates a difficult environment for innovation, none the least high tech ventures. The Danish innovation system is further an example of a small innovation system, with only few big multinational players, relatively small universities, a relatively low level of R&D but still a high overall innovative performance. What kind and extent of eco-innovation and nanotech innovation strategies may we then expect in the Danish window chain? And how are they related?

Below table 1 brings an overview of the main companies in the Danish window chain of relevance for nanotechnology development. I.e. these are the companies that we shall return to in the rest of the

[3] The analysis draws on findings from the project "Green Nanotechnology in Nordic Construction - Eco-innovation Strategies and Dynamics in Nordic Window Chains", see (Andersen, Sanden and Palmberg, 2010) for a further account of the methodology and sources used. The nano-innovative companies referred to are partly identified via the mentioned survey, partly from the core window companies interviewed.

Table 1

Core case companies in the Danish window chain

Companies	Affiliation and country	Product area	Age
Fiberline Composites	DK	Composite materials for buildings and windmills	Year 1979
Dyrop	DK	Paint	Year 1928
Accoat	DK	Coatings	Year 1969
Superwood	VKR Group (DK)	Wood (nano) preservation	Year 2002 *(VKR 2006)*
Photocat	DK	Nano photocatalytic materials for glass and floors	Year 2009
ScanGlass	DK under Saint-Gobain Glass (Fr)	Glass processing, wholesale,	Year 1935, *(Saint-Gobain 1976)*
Pilkington Denmark	DK under Pilkington NSG Group (UK)	glass wholesale and minor processing,	Year 1978
Sunarc Technology	DK	(nano-) sheet glass for solar collectors, PV-modules, greenhouses	Year 2000
VELUX	VKR Group (DK)	Roof windows and skylights	Year 1941
Dovista, made up of Velfac and Rationel	VKR Group (DK)	Vertical windows and doors	Dovista 2004 Velfac 1961 Rationel 1954
PRO TEC Vinduer	DK	Vertical windows	Year 1993

Source: Based on company webpages and interviews. Data in italics refer to the mother organization. Company names in bold are those mostly analyzed in this case.

paper; the companies dealt with in more detail are in bold. The companies are listed according to their position in the value chain.

The analysis in the following sections covers most but not all the identified nano-innovative companies in the Danish window chain but includes the main different types of companies involved in the window chain. In all seven companies form the main basis of the current analysis, which represent both the big multinational incumbents (1), the medium sized incumbents and (3) medium to early start ups (3).

The overall findings are that despite the generally low uptake of nanotechnology in the construction sector we do find quite a high number of nanotech applications in the Danish window chain, and these are predominantly green. But all the major eco-innovations are not nano. Both start-ups, the really big multinational companies and perhaps more surpricingly, the medium to small sized incumbents, have shown to play important but different roles in the development and uptake of (green) nanotechnology in the window chain. But while eco-innovation is on the uphill, becoming an increasingly important driver for innovation in the construction sector, nano-innovation seems to be on the downhill. [The search for green profit opportunities is intense by all actors in the window chain, also influencing on the nanoinnovation activities. The pursuit of nano profit opportunities, on the other hand, seems to be lessening or at least becoming more discreet. Firms in the window chain market themselves strongly as eco-innovative while there is currently hardly any nano marketing even among the nano innovative firms. Hence eco-innovation is very much becoming a selection property while nano is not at the current stage of development. It also means that there is a lot of nanotechnology in the window chain that is little known.] Below we will expand on the details of these strategies and innovative activities.

4. GREEN NANO-INNOVATION IN THE DANISH WINDOW CHAIN

4.1. Developments in the eco-innovation strategizing

Unquestionable, energy efficiency is the most important environmental parameter in the Danish construction sector; as mentioned the sector accounts for approximately 40 pct of overall energy consumption. With the rising attention to energy efficiency as a policy goal following the topical climate agenda, energy efficiency has the later years become the most important driver of innovation in the Danish window chain. There are by now widespread expectations among all the companies in the window chain that stricter policies for energy efficiency will be introduced and that energy efficiency is a key and lasting profit opportunity.

In the Danish window industry the role of windows for energy efficiency have changed dramatically from being part of the problem in the 1980s and 1990s to becoming part of the solution in the zeroes. Much product innovation into low E and energy control glass[4] has taking place meaning that the best of the windows now contribute to ‘zero emission buildings’ or even ‘plus energy buildings’. And lately, also the window frame and the positioning and use of the window is beginning to be taken into consideration. The most energy efficient windows are now more energy efficient than well insulated walls, and hence glass facades may compete with other buildings materials, at least on energy issues.[Much of this eco-innovation has been undertaking by the large multinational glass companies, to some degree as a spillover from the more innovative car industry, the second biggest customer of flat glass.]

The opposite condition was the case up till the 1980s. The extensive policy measures to improve the energy efficiency

[4] Low E = low emissivity glass, energy control glass reduces overheating and the need for ventilation which is a big energy consumer.

of buildings had started in the 1950s, and over the years the energy emissivity of the window glass was restricted still more. Environmental regulation at the national and increasingly EU level, was and still is a core and very direct driver of innovation in the glass and window industries. The window frame was not taken into consideration. But in the 1980s the Danish authorities introduced limitations in the amount (area) of windows that were allowed in new buildings since these were considered energy losers. Accordingly, windows were a none-green product and the glass and window producers had a negative environmental profile at that time. The big glass multinational companies were already heavily engaged in R&D to improve the energy performance of the glass. The window industry, on the other hand, were less active at this time. Design and maintenance were and still is an important product criteria and elegant and low maintenance wood-alu windows became popular among Danish window producers in the 1990s and zeroes despite the fact that they are little energy efficient.

While the glass had become quite green the window frame had not, and policymakers and users have been late in realizing that the window frames function as a thermal bridge.

In the late zeroes we see a marked shift in the eco-innovation strategizing. There is by now an intense search for new green profit opportunities by seemingly all actors in the window chain, at least those participating in the current analysis. This is none the least the case for the window industry. But many of these represent the larger players in the chain, particularly in the window industry. For the smaller players the situation may be different.

Lately we see an interesting strategic change among the largest Danish window companies, who are shifting from focusing on developing windows to acting as developers of green buildings. They are increasingly engaged in advanced quite high-tech systemic eco-innovations. These companies have developed pro-active eco-innovation strategies aiming to prove that it is possible to develop energy efficient buildings with a large amount of windows. Seemingly with success.

Below we will look more closely into the eco-innovative activities among the core actors in the Danish window chain, with a focus on those involving nanotechnology. First focusing on the glass industry and succeddingly on the window industry.

4.2. **Green nano-innovation**

The glass industry

The main entry of nanotechnology to the Danish window chain has taken place through the big multinational glass companies. The multinationals Pilkington and Saint Gobain have dominated the Danish and Nordic glass markets through their national offices or subsidiaries within glass processing and distribution since the 1970s, but there are also some 29 mainly small companies dealing with glass processing or whole sale In Denmark. There is no float glass production left in Denmark.

Nanoscience has dominated glass coatings the last 30 years, long before the rise of the nanotechnology buzz word. All modern flat glass coatings are based on nanotechnology. The multinational glass companies have taken the lead in developing these advanced glass coatings. According to Pilkington Denmark, the competition on glass is hard and very technology oriented. Modern glass production is continuous, large scale mass production and highly capital intensive. Concentration in the sector is very high. In 2004 it is estimated that the four largest global players, the companies NSG (since 2006 including the large Pilkington Group), Saint Gobain Glass, Asahi and Guardian Industries alone held a combined share of at least 80% of the flat glass market in Europe.[5]

Product innovation the last 30 years has focused on developing glass meeting a growing range of functionalities, none the least to achieve energy efficiency. Apart from light and panorama, functionalities such as low emissivity (thermal insulation), solar control (to control heating and reduce ventilation), safety (breakage resistance), security (resistance to burglary), fire resistance, noise reduction, anti-reflective, self-cleaning, anti-scratching and decoration. These high-value products are made from processing the basic float glass by laminating, toughening and none the least coating, as well as assembling the glass into insulating glass units (double or triple glazing). Today's coatings are multi-layer, up to 7 or more layers, to achieve multifunctional glass. Research and development into these continuous to be intense.

According to Pilkington Denmark energy efficiency has been a core and still rising driver within glass innovation, driven very much by policy initiatives, which have been substantial over the last 20 years. Low emissivity and solar control glass are standard in today's markets, achieved via 'soft coatings'. Danish and Nordic markets are considered advanced markets for glass products. But there are still many areas, e.g. in Eastern Europe but also the US, which are way behind in insulating glass and still primarily have one-layer standard glass in the current building stock. The 'hard coating' technology is particularly interesting in the area of glass for solar technologies where the market is booming due to the strong climate agenda, despite the severe economic crisis in construction. Green demo houses in Denmark and elsewhere are seen as playing an important role for advancing radical product innovations in glass and windows. Radical innovations may be tested and more money is available in these projects.

All the big glass players have extensive R&D activities and a varied product portfolio in flat glass production directed at their two main quite different customers: The traditional, low R&D construction sector is the main customer with 80% to 85% of the total output, whereas the highly innovative and R&D intensive automotive and transport sector is the other, accounting for the main of the remaining applications. Several of the parent companies have extensive activities in other parts of the construction sector, and relevant for nanotech development, also in materials and chemicals. Pilkington spends around £33 million a year on research & development, which is undertaken by two globally, managed organizations within the two business lines, Building Products and Automotive Products.

Pilkington launched in 2001 the first self-cleaning window, which became world famous as one of the first well-known nano-consumer products. This product has though been a big flop despite a good functionality. Despite the nano-fame from

[5] Source: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1781, 2007.

the self- cleaning glass product, Pilkington officially does not use the terminology "nanotechnology" but rather refers to "coatings". Pilkington generally obtains a low profile related to nanotechnology and there is no information on nanotechnology in their information materials or web page. The other big glass producers follow a similar low- profile strategy towards nanotechnology, with the exception of PPG, no. six in size. According to Pilkington Denmark, the low profile is partly due to the unsettled debate on nano-risk issues, partly due to the considerable uncertainty as to what is nanotechnology and what is not. Examples of products which turned out to be nano-fake have created a negative reaction from customers. The company sees currently no profit opportunities in nano-marketing but markets itself strongly as a green company.

The other two examples of of nano entry into the Danish glass market are both Danish up-start companies. *Sunarc* started its commercial operation in year 2000 specializing in the production of nano-structured antireflective surfaces on large size glass sheets. The glass is aimed for the niche market within solar collectors and PV-modules and to a minor degree greenhouses. The idea is to minimize the light reflected by the glass to improve light transmission, especially important for solar technologies. The technology used is, according to the company webpage, unique in the world. Passing several bathes the glass is submitted to a special etching process in a fully automated process. The resulting AR-surface is a nano porous structure of approx. 100 nm thicknesses on both sides of the glass. The glass surface releases six to eight percent more sunlight in depending on the glass slope. Hence Sunarc's products are an example of a fairly simple nanotech production process where the nanostructure becomes part of the glass itself rather than by adding a coating. After a slow start there has been a steady increase in the sale which the last years have exploded with the boom in solar technologies. 99 pct. of deliveries from the Danish factory are exported to Europe. In 2006 the company moved to new production facilities and the same year the company received Børsen's Gazelle award for being the second fastest growing company in Denmark. A new production line is planned and Sunarc is also in the process of setting up new plants in other regions of the world.

The capabilities underlying the production are mainly tacit and rests among core employees. The critical elements lie in the fine adjustment of the production process which is essential to achieve a uniform high product quality. The company has chosen not to patent its technology. Many, also the big glass companies, have tried to copy what they are doing, but although lab scale production is easy, commercial up scaling is very difficult. Sunarc is still the leading full scale producer with this technology globally.

Sunarc is considering moving into low-E glass for general architectural use but hitherto they have had no interaction with construction actors. They see new profit opportunities in the rapidly growing market for very energy efficient windows. They particularly see potentialities in improving the currently not very good light transmittance in 3-layer insulating windows.

A third example of green nano innovation in the window chain is the Danish upstart company, Photocat A/S. Photocat is a newly established Danish company (from

July, 2009) which develops and markets advanced nano-structured materials and coatings with photocatalytic properties, e.g. self- cleaning functions. The company markets itself as a clean-tech nano-based company.

Photocat has one product directed at the glass market, ShineOn® Pro which is an aftermarket treatment to make window glass self-cleaning. Increasingly though the company is focusing more on developing floors with self-cleaning properties to improve the indoor climate. The companies sees new profit opportunities in the rising indoor climate problems from the increasingly tight energy efficient houses. Their self-cleaning nano-floors are targeted to remedy this.

The company is a spin out from the likewise young nanodedicated Danish company SCF Technologies A/S from 2003 specializing on the so called "supercritical technology". SCF experimented with a range of applications but focused relatively quickly on bio-oil from organic waste and on self-cleaning glass. Their first product launched in 2006 was based on imported nano-material from China but the product quickly encountered a number of technical challenges. As the problems became clearer the advanced material group of SCF began work to develop their own product the new ShineOn®. This work was not based on supercritical technology but rather on basic nanoscientific insights in photo catalysis. The basic technology developed consists of making and configuring sets of nanoparticles. Photocat has five patent applications in process. The new product consists of two fluids as well as a set of recommended spray containers and education to ensure safe and correct handling. The product is only being marketed to professional customers among glaziers and renovation companies.

As SCF Technologies increased their interest in the bio-energy field, considerations of spinning off the photocatalytic work began. The people working with the self-cleaning glass had made contact with a Swedish floor company, Välinge Innovation in 2007, and new ideas emerged within the group to produce depolluting floors to improve the indoor climate. Together with Välinge they developed a new patented composite floor, ActiFloor, where photocatalytic nanoparticles are integrated in the matrix of the upper layer, the first of its kind in the world. In the summer of 2009 the product was presented to the first three customers which formed the basis for founding the company Photocat in July 2009.

ShineOn is by now being marketed by license to whole sale companies in the UK and the US so far with moderate success. In Denmark marketing activities have been limited and no license partner has been found. During the development stage contact was taken to Dovista which tested the first version of the product, but they did not find it satisfactory. Because of this less successful event no further contact to Danish glass and window industries has been tried. A meeting was sought established with the Danish Glazier Guild but it was never carried out due to lacking interest from the SCF company at that time.

Documentation is an important element in Photocat's strategy; the product's self-cleaning properties have been independently verified and the cleaning capacity equals the one of the well-known Pilkington and Saint-Gobain brands. Also health and risk issues related to nanoparticles are documentet; all their products have full material data safety sheets made in cooperation with experts in the area and in compliance with regulation in the area.

Since Photocat's core business focus increasingly is in the upcoming floor product area, the glass product area is currently receiving somewhat less attention. Together with the Swedish floor company the two companies have formed a new IP company which will be starting up-scaling the floors to industrial production in its new production facilities in Sweden in 2010.

The window industry

There are around 300 small window companies in Denmark. The Danish window industry is dominated by one large Group, the VKR Group which has quite a high level of R&D. The VKR Holding Group, more specifically their two main companies Dovista and Velux who have a close R&D collaboration, is the locus of most of the nano activities in the Danish window industry.

Dovista is the mother group of the main Danish producers of vertical windows, Velfac and Rationel, and undertakes the R&D for these. The firm is so far little involved in nanotechnology but the interest is rising. They are continuously scanning their suppliers for new advanced solutions to their problems which include nano solutions, but there is no targeted search into nanotech innovations. Dovista began in 2009 their first nano R&D project aimed at reducing condensation problems of windows together with a Danish university. Condensation problems have been a major problem for many Danish window producers, but is rising because of the more tight energy efficient buildings.

VELUX, the dominating company within VKR, specializes in roof windows where they hold a well-known international brand. Nanotechnology has long been an aspect of interest to VELUX because it plays an important role among a number of their suppliers and in the components of their products. VELUX relies on internal R&D as well as dialogues with their suppliers in building their nano capabilities. They are interested in keeping track of developments in the area. They want to have the necessary capabilities to be able to select the right products at the right time.

Most of Velux's nanoactivities are supplier oriented. They have participated in only one nano R&D project with knowledge institutes, , the Danish "NanoPaint" project from 2005 to 2009, which involved some Danish paint, coating and chemical suppliers as well as knowledge institutions. Velux were interested in the development of more durable paint for wood as well as more environmentally friendly metal coatings, seeking to find alternatives to the toxic 'Chrom 6. The outcome was limited. According to VELUX their main sources of know-how on coatings remain their big international suppliers who VELUX sees as being in front of the technological development, also on nano coatings.

The Velux R&D does not only focus on frame production but also contains a glass section as the selection of the best glass is a key competitive factor. Nano scientific insights are important in the glass R&D section where they have a close dialogue with the big glass producers on nano-coatings which they know of in detail. Nano-coated multifunctional glass is standard in the product portfolio of Velux. Self-cleaning glass, for example, is interesting since roof windows are difficult to clean; it is the standard in some countries, while in other countries it is an optional choice on special types of VELUX windows. They see demands for high energy performance as the core driver for glass product innovation the last 20 years but intensifying the last five to ten years. Today Low-E and solar control glass are standard on the markets VELUX sells to.

But the VKR Group is also recently engaged in quite a radical nano-enabled eco-innovation in wood conservation. In 2006 they bought up the young small Danish upstart company Superwood which had developed a new environmentally friendly method for wood preservation based on nanotechnology (the 'supercritical technology'). With a patent from 2001 Superwood made the world's first complete preserved spruce protected all the way into the kernel. Also, the lifespan is longer ,the method enables the impregnation of wood species such as spruce that cannot be impregnated using traditional methods; and the wood may be used immediately after the impregnation.The 'superwood' is unique in the world and is commercially available for consumer use since 2006; the market for this green product is expanding rapidly. Superwood markets their products as green products rather than nanoproducts.

Since 2008 Dovista and Velux are engaged in a joint R&D project with Superwood; partly testing the superwood in the windows in their green demo house projects; partly engaging in a further development of the product to serve the specific needs of wind production. The idea is to use the supercritical technology not only to obtain durability due to anti-fungus treatment of the wood but also to obtain a water repellent effect. The results are so far very promising and they hope to be able to start large scale production of the modified superwood frames in a foreseeable future. Such a production will be unique in window production in the world.

As mentioned energy efficiency in window frames has traditionally not been a core innovation driver among Danish window producers. However, the growing green demand following the hot climate agenda and more strict but flexible and systemic policy measures directed at the energy balance of the entire window, has lately created incentives for more radical green product innovations, in fact two examples of window frames based on composites. While many composite materials are nano-enhanced, these are however not.

One of the smaller Danish incumbent window producers, Protec, recently engaged in a radical product innovation shifting from alu-wood production into window frames made from composite materials, a much more energy efficient material seeking to develop a green product. The innovation has been quite difficult demanding a range of complementary innovations, in e.g. handles, closing systems ect. Protec cooperated closely with their composite supplier, the Danish well-established high-tech company Fiberline, which is a leading producer of glass fibre reinforced composites for use in buildings and building components (including windows) as well as windmills. They supply to several other foreign window producers, also before the uptake on the Danish market, and are active advocates for radical innovations in the construction sector, none the least green ones, arguing and demonstrating that their material is light, strong and energy efficient and can be used in novel ways within construction, e.g. via advanced self-developed demo-products in their large show room. It was, in other words, relatively easy for Protec to tap into Fiberlines' capabilities which were already directed at the window market. Fiberline, though quite high-tech, is not active in nanotechnology development and the company only possesses minor nano insights and interests, despite the fact that nano composites is a fairly big theme. The company has considered three minor nanotech issues (coatings), but no innovation has taken place so far. So far, Protec competes successfully attracting a minor premium price for their energy efficient products, arguing that the buyer will save energy costs in the long run.

The other producer which has begun to look into the development of composite window frames is Dovista, also with the purpose of producing more energy efficient windows. They are seeking to develop new composites specifically targeted for window production engaging in a demanding R&D project in a collaboration with foreign suppliers. So far their composite frames are still under development, and are only being applied in their green demo houses so far. The expectations to the new material are high and they hope to be able to scale up within a foreseeable future. In the meantime, the production of wood and alu-wood frames continues to be the main standard in the VKR Group which needs to be able to supply large quantities in a verified quality.

The most radical eco-innovation in the window chain is of a more strategic character than technical. We see an interesting strategic change among the VKR Group in the end zeroes as they increasingly are shifting from focusing on developing building components to develop green buildings. Velux and Dovista now function as the main actors in several advanced green demo house projects. The green demo houses, build by many municipalities, are seen as important sources of experimental product innovation where prices matter less. Via these projects they are engaged in developing systemic smart eco-innovation at the building level. E.g. they are integrating windows with advanced electronic systems and engaged in optimizing the design of green houses to achieve a better utilization of daylight (the position of windows in a building matters greatly for the energy performance), artificial light (nano-based LEDs) and natural ventilation, thereby saving energy in the user phase. Via these measures the VKR Group is seeking to prove that it is possible and attractive to make advanced green buildings with a large share of windows. Hereby they may threaten existing construction companies, taking on a new role as system integrators on the rising market for green buildings.

Both Velux and Dovista has long had an advanced environmental management systems and green search rules seem to be integrated at the R&D level, considering not only energy efficiency but the toxicity, waste handling and waste minimization of associated with their production and products routinely. For the most nano-active company VELUX their engagement in nanotechnology is weighed carefully with the possible negative implications of nanotechnology for the environment and health, an issue they keep a very close eye on.

The rest of the mainly small window producers continue to rely on wood and wood-alu window frames for the time being[6] and may phase a difficult competitive environment in the future given the advanced eco-innovations emerging lately in the window frame area, as far as the green demand continues to be high.

5. CONCLUSIONS

An overall empirical conclusion is that eco-innovation seems to be a very important driver of nanotechnology, since all the identified nanotech applications in the window chain were green. However, not all the main eco-innovations were nano but many were. There is a surprisingly high degree of nanotech applied in the window chain; surprising because of an expected low absorptive capacity of the relatively low R&D construction sector towards the high-tech nanotechnology, but also because much of the nanotech applied in the window chain is little known. Also surprising because only a few years ago green buildings were not considered to be very high tech but more reinventing traditional building techniques, some indeed very eco-efficient.

In seeking to look more closely into the industrial dynamics behind this trends, the findings will be discussed below under the three themes in the framework of Langlois and Robertson (1996), but reshuffling the order a bit. We start with discussing the distribution of capabilities in firm and market, move on to address the level of market development and end with the nature of the economic change. The discussion is complicated because it mixes necessarily the dynamics of eco-innovation with the dynamics of nanotech evolution. But a core point of this paper has exactly been to illustrate the multifaceted nature of the economic process. While eco-innovation often is treated in isolation in environmental research, it is important to emphasize how it forms part of and competes with many other trends and technological trajectories on the market at a given time; these influence each other and change in their relative importance in the overall economy over time. The multifacetness is a core challenge to corporate strategizing.

5.1. The distribution of capabilities in firm and market

Unquestionable, the very large integrated organization in the form of the large glass companies act as core technology developers in the window chain; this seems none the least to be the case when it comes to the highly science based nanotechnology, where their big labs and large scale opportunities for experimentation make a decisive factors in the technology development. Also the big chemical and metal material suppliers are important as nanotech developers, where as it seems smaller local (Danish) suppliers and knowledge institutions have been less important. The large integrated organization seems overall to contain nano capabilities in important ways, and have done so for a surprisingy long time, which function as the main source for firms further downstream to tap into. These organizations seem early to have pursued effective proactive eco-innovation strategies and built green capabilities, contributing significantly to the fact that the glass (the pane) became

[6] There are a couple of the other smaller window producers who are trying to develop other types of energy efficient windows (the so-called “Russian window” with an advanced air circulation system) not entailing nanotechnology.

green (at least measured by the central energy efficiency parameter) before the frame in Danish window production. None the least the advanced nano-coatings for thermal insulation and solar control are by now commercial successes and already a market standard in many economies. A more global distribution of these, which is expected with the global chimate change attention, will have a major impact on carbon reductions.

The very large and semi-large integrated organization seems also to be an important means of knowledge migration and coordination; not only within the value chain, e.g. between the flat glass manufacturers and the glass processing and -distribution actors, but also between different sectors and markets. I.e. the spillover from nano glass innovation for cars into the construction sector within the same large glass Group, or the transfer of knowledge from one company in the VKR Group to the others, e.g. operating on respectively the market for roof windows and vertical windows. Still, we also see discrepancies in the level of nano strategies and -capabilities within even medium sized organizations, like the differences between Velux and Dovista within the VKR Group despite quite a close R&D collaboration.

The big players are, however, complemented in important ways by the dedicated upstart companies who, as expected, develop important niches within both radical and less radical high- tech eco-innovations. This picture suggests that both the large and the small firms play significant roles for green nanotech development at the current stage. Additionally, however, the main medium big players in the Danish window industry show a considerable absorptive capacity towards nanotechnology with widespread nanocapabilities, but also play a surprisingly active role in actual nanotech development in the frame area. The vertical specialization in the window chain with a few very large advanced international glass manufacturers, many small mostly traditional glass processing and window manufacturers and a range of project oriented construction companies seem possibly not to be such a difficult environment for high-tech nanotech ventures as expected. The combination of the large and small firms as nanotech developers and the relatively technology advanced system integrating medium players as key users and further developers seem to provide quite a high absorptive capacity for nanotechnology. The window industry seems to be able to pull in a variety of nanotechnologies and seem to be key for the commerzialisation of nanotechnology in the window chain more broadly.

It is therefore interesting that the bigger window players are increasing their roles as system integrators with the recent strategic shift from windows to building providers, a shift which is clearly driven by the eco-innovation trend. It seems that the more systemic eco-innovations emerging also are becoming increasingly high-tech (smart/intelligent systems). This may influence significantly on the industrial dynamics of the greening of industry, giving an advantage towards the companies and sectors with a certain level of R&D.

We see all the actors in the window chain (at least those studied) on an intensive search for new green profit opportunities, but it is the window industry who is changing their economic organization redistributing their capabilities the most, with their rising roles as system integrators of smart green buildings. There is not the same intense search for nano profit opportunities but still the nano interests and activities are there and nano capabilities are growing at least in the upstream and middle part of the chain .

Interestingly, also the medium incumbents such as Protec and Fiberline are showing to be quite innovative and in fact responsible for some of the most radical eco-innovations, in fact possibly more radical than those of the start ups, who are often seen as the initiators of radical green niches.

This may be seen as a sign of generally widespread green strategies and capabilities in the chain.

Firms, it seems, are increasingly on a similar 'green wavelength'(see also Andersen, 1999, 2002, 2010b). At the fundamental R&D level we see the emergence of green search rules and green capabilities which become increasingly widespread, feeding into a growing green underlying knowledge base.

This overall intensifying greening of the economic process does not mean that all firms, or even the quite greens firms, are pursuing a very advanced green competitive strategizing. Other competitive concerns may well over rule the green ones. E.g. we see examples in the window industry where wood-alu frames continue to dominate the market despite the fact that they function as thermal bridges, while the market for the more energy efficient composite frames still is a small niche.

The core point is that we see a marked rise in the level of proactive corporate strategizing for eco-innovation particularly in the late zeroes and the formation of strong green expectations among the firms in the chain. We need to know more about the distribution of eco-innovation strategies and capabilities among the actors further downstream, including the end users. We need particular to know more about how the small and medium to small incumbent companies are reacting to the rising green profit opportunities, such as the many smaller window and glass process and distributions companies in Denmark.

5.2. **The level of market development**

Overall, we see growing green selection properties on the Danish construction market as part of an overall green economic evolution. It is clear that environmental regulation has played a major and very direct impact on the eco-innovation activities, and has led to quite reactive strategies among the companies in the chain, where innovation only took place in anticipation of new regulations until the mid zeroes. The original conditions for pro-active eco-innovation strategies were difficult in the early years when windows were energy losers and the industry had a negative environmental reputation on the market and generally the green market was not that developed. Window companies competed on other parameters than the green ones, design having always been a key competitive factor in the construction sector. This has changed dramatically, particularly in the last few years, as windows via innovation are beginning to contribute positively to the energy performance of buildings. This shift illustrates a central element in corporate strategizing for eco-innovation. The degree of green reputation on the market is decisive for the firm's incentive to develop strategies for green competitiveness. Firms must have some expectation that it is possible and attractive to attract green rents. These expectations may change due to both internal and external factors, but the extent of the green market matters.

The rapid recent greening of the window chain extending into the wider construction sector, illustrates the more consolidated stage of the green market in the zeroes. The green market is by now quite well-functioning; market supporting institutions are largely in place or can quickly be established, and there are rising shared green expectations and visions among the companies in the window chain. Interdependent firms are generally moving in the same green direction though not necessarily at the same pace. Accordingly, the interfirm coordination needs and dynamic transaction costs are drastically reduced compared to the situation in the 1980s and 1990s when the green market was in an early, slow and uneven stage of development. Green capabilities are now fairly easy to tap into and environmental practices are well-established.

The case show quite dramatic changes in the green economic evolution the last 20 years, which is the period of the main emergence of the green market in the richer economies such as the Danish one. The case illustrates clearly green economic evolution entailing qualitative changes in the economic system. We see how environmental issues come to act as a new selection property and companies move in to utilize the new green profit opportunities. Increasingly the market acts as a still more effective green selection device. Green competitiveness becomes increasingly important and influences on the selection of products, but very much, and for many companies and sectors more important for their green competitiveness, on the selection of suppliers and customers, (who are often important as green learning partners), employees, financial and insurance institutes etc. With the growing green market there are sunk costs to eco-innovation and it has become still easier to engage in eco-innovations for late comers, but the economic returns may also be lesser as many more actors are seeking to attract green rents.

The green wave is strongly felt on the construction market and is currently quite loud (active marketing), while the much newer and more immature nano wave seems to be somewhat on the downhill at least compared to the high attention to nano issues in the beginning of the millemium. Currently the nano marketing is quite silent (passive if not evasive marketing). The uncertainties related to the risk issues related to nanotechnology play a significant role for the market formation.

The green wave in the economy influences heavily and quite directly on the uptake of nanotechnology in the window chain. This may simply be due to the fact that climate change issues currently is a rising driver of economic development, none the least in the energy consuming construction sector. But a hypothesis could be that nanotech is moving into socially beneficial areas such as environmental problems, health, food and energy supply to a high degree, because of an extraordinary need to outweigh possible nano-risk issues with societal benefits. Particularly in the early stage of technology evolution characterizing current nanotechnology development when the uncertainty as to the scope and effects of the technology is large, there is a strong need to legitimize the new technology and create a positive reputation. Hence it seems nanotechnology is born not only with a strong attention to risk issues but also with strong moral concerns. The initial grand expectations to varies societal benefits seem to translate into economic trends. This may cause a high degree of nanotechnology to be green. This hypothesis needs to be tested further though.

Overall, the case illustrates how the competitive conditions for eco-innovation have undergone considerable change within a short time span in the end zeroes.

5.3. **The nature of the economic change**

The nature of the green economic change seem lately to have obtained quite a transformative effect on the construction market. We see companies moving into new roles and reconfiguring their capabilities in the search for novel green profit opportunities. The green wave seems pervasive influencing widely on firms strategies, search rules and capabilities.

The process of green economic evolution seems to be strongly affected by history. The previous lock in into none-green strategies, practices, and capabilities which has lasted for 30-40 years seem to have been broken to quite a high degree, which should mean that eco-innovations are likely to accelerate further in the coming years. The case hence indicate that a revolutionary change has occurred in the end zeroes where green growth experienced a market breakthrough which seems to be of a considerable scope. The durability of this market breakthough remains to be seen though, but it seems that lasting structural changes are occurring, with the creative accumulation of new greener strategies, search rules and capabilities and the creative destruction of none-green strategies, search rules and capabilities.

It is important to remember though that the case takes place in a chain which is currently strongly affected by the hot climate agenda due to the high level of energy consumption in the construction sector. It is also a chain where core actors, (technology developers, integrators and distributors), have the potentiality to contribute positively to green solutions. Other sectors and chains are affected differently, experiencing either less pressure on their eco-innovative behavior or having a worse environmental reputation top deal with (e.g. the highly pollution industries or industries with a high degree of environmental scandals.

Nanotechnology does currently not have nearly the same transformative power on the economy despite the huge global investments in the area; it is still at a too early stage of economic evolution. It seems though as if the commercialization process is entering a more serious phase currently.

At the technological level we see a rising trend towards more high tech radical and systemic eco-innovations; both in the form of the radical materials innovation, the rise of composite materials, which is not nano but still quite high tech, but especially in the more innovative window companies' stronger focus on systemic green innovations for houses. It seems that future green houses will be increasingly smart/intelligent, allowing for flexible uses of energy and resources. High tech innovations are likely to become increasingly important which also creates new opportunities for nanotechnology in green construction. At the moment there are as yet few signs of nano-enabled systemic eco-innovations which require complementary innovations. On the contrary, the nano-coating technologies, which possibly are the most widely known elements of nanotechnology, are often interesting to business because they can solve problems without interfering on existing products and production processes. A possibly exception is the nano-enabled LED lighting systems which are rapidly in the process of replacing incandescent lighting systems mainly because of their higher energy efficiency, an innovation with highly systemic and disruptive effects. The new opportunities for integrating energy efficient LEDs in building materials may well come to influence on the use of windows in the future just as nano-enabled transparent building materials may[7]. These issues present a strategic challenge to the glass and window industry which some of the more innovative players seem to be attentive to.

The current analysis has illustrated the need for applying an evolutionary capabilities perspective to the analysis of the greening of industry, in order to create a better understanding of the competitive conditions for eco-innovation in different economic contexts. These have been changing considerably over time, lately quite dramatically.

While there are some specificities related to the evolution of both the green market and the nano market, which go beyond this paper to discuss in detail, there are also interesting similarities, such as the mission oriented nature of the innovation, the pervasiveness, flexibility in the use of respectively the green term and the nano term in the marketing ect., issues to be further analyzed.

We need more studies into green nanotechnology development to know more of its scope and dynamics. The current analysis of the window chain should be supplemented by further analyses into the green industrial dynamics of different value chains and by analyses in different regional settings.

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[7] A fake LED based look-alike ‘window’ is already invented by a Danish company.

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