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The Muddle over Green Race

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THE GREEN RACE, A RACE FOR JOBS

"Green race" in the media has been closely associated with the climate change agenda. However, economic underpinnings are not straightforward, as the scientific value of the very idea of a race, when applied to countries and not to firms, has been largely contested in the 1990's. Yet the empirics have dramatically changed over the last decade, the scope of "tradable" activities opened to world competition enlarging. Consequently, the race for technology and for technology-induced productivity gains is now primarily a race for jobs – more specifically for non-routine and non-tradable jobs.

THE EU LEADERSHIP IN THE WIND AND PHOTOVOLTAIC SECTORS

Green technologies are expected to provide the EU with a means to make up for exhausted growth potential, while enabling the fast transition toward a low-carbon society. No breakthrough technologies are expected in the renewable energies (REN) sectors studied – namely wind and photovoltaic (PV) – in short term though. Labour and sectoral (value added) perspectives are much more certain and supportive of REN innovation and deployment. The majority of value added and jobs are located in the EU, with so far limited entry from foreign firms into significant segments of the chains. The EU has a clear leadership of the wind energy sector, and the majority of business opportunities created worldwide benefit EU PV firms.

HYPERCOMPETITION AS THE DOMINANT GLOBALISATION NARRATIVE?

Even though the current competition structure in wind and PV energy value chains is beneficial to EU firms, this situation might not be stable over time. Hypercompetition could become the dominant narrative in the wind value chain (offshore), and could turn out to be oligopolistic and conventional in the PV sector, to the detriment of EU firms prevented from accessing markets such as China. In both sectors, public policies are at stake: in the EU, through sustained incentives; and globally through the negotiation of "sustainable energy trade agreements".

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The Muddle over Green Race

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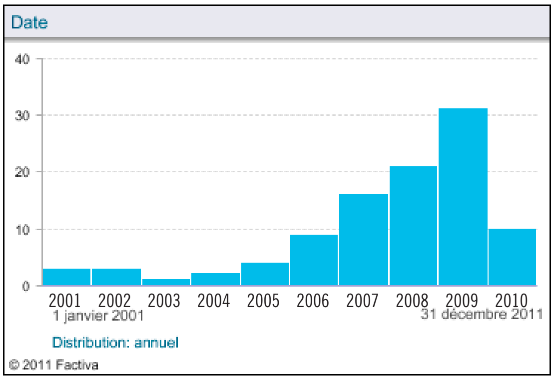
1. WHY A “MUDDLE” OVER THE GREEN RACE?

1.1. The green race at country level: a political obsession

While it is not known exactly who first coined the term “green race”, occurrence in the media has been closely associated with the climate change global agenda. Two weeks before the Rio Earth Summit took place (in June 1992), the “green race” was already on, opposing at that time the US and Japan, which was deemed “ten years ahead” in “green technology”[1]. A few months before the Kyoto conference on climate change (COP 3 – December 1997), Japan “raised the stakes in the race to develop cleaner and more frugal vehicles”, taking “pole position in green race”[2]. Still, the peak in the use of the term “green race” in the media occurred in 2009, at a time when green stimulus packages were being enacted to cope with the recession, and when the widely publicised Copenhagen climate change conference (COP15) was just a few weeks away (figure 1).

Figure 1. Incidence of “green race” in newspaper titles or content (2001-2010)



For those slower countries and industries that would have missed the early 1992 start between the US and Japan, catch-up opportunities have come along successively, with new “starts” trumpeted here and there. Hence *The Australian* announced in July 1999 that the “race is now on”[3], and it was on again when Obama “fired the starting gun” in his January 2009 speech on renewable energy, according to *The Times*[4]. The “green race is on” has been a sort of mantra in UK and US newspapers ever since[5].

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[1] Ramon Isberto, “Earth Summit: Green Race Between US and Japan?”, Inter Press Service Global Information Network, 1 June 1992. This is the first occurrence of “green race” in the media according to the Dow Jones Factiva database we have used.

[2] Haig Simonian, “Honda takes pole position in green race”, Financial Times, 21 October 1997.

[3] “The green race is now on”, The Australian, 29 July 1999.

[4] Camilla Cavendish, “Obama surges ahead in the race to be green; The President’s bold speech on renewable energy has thrown down the gauntlet to the rest of the world’s leaders”, The Times, 6 February 2009.

[5] “Green race is on; China is sprinting toward its goal of cleaner energy while the U.S. is taking baby steps”, *Las Vegas Sun,* 8 July 2009. “U.S., China can bridge emissions gap absent U.N. deal – CEOs”, *Greenwire*, 14 October 2009. “India Inc discussion focuses on Vision 2050: the new agenda for business”, India Infoline News Service, 5 February 2010. “NRTEE Creates New G8 Low-Carbon Performance Index”, *Marketwire*, 20 May 2010. “WBCSD Annual Council Meeting in China Focuses Global Sustainable Development on ‘Green Race’”, *PR Newswire*, 2 November 2010. “CO_2-Problem ist technisch lösbar; Siemens-Vorstandsmitglied Barbara Kux über die Bekämpfung des Klimawandels”, interview: Bendikt Vogel, Berlin, *Basler Zeitung*, 3 December 2010.

The emergence of green race rhetoric in the 1990s was accompanied by heated debates among economists on the scientific value of the very idea of a race, when applied, as was the case at the time, to countries and not to firms. Against the view of then-president Bill Clinton that each nation is "like a big corporation competing in the global marketplace"[6], supported by his Council of Economic Advisors[7], some outstanding economists such as Paul Krugman recalled some basic economics to explain countries' growth and employment records, dismissing the idea of any race between countries. *"[C]ountries do not compete with each other the way corporations do"*, he wrote in his essay "Competitiveness: A Dangerous Obsession"[8]. *"If the European economy does well, it need not be at US expense (…) While competitive problems could arise in principle, as a practical, empirical matter the major nations of the world are not to any significant degree in economic competition with each other. Of course, there is always a rivalry for status and power – countries that grow faster will see their political rank rise*". The race between the US and Japan was therefore a political race for power and status. China overcoming Japan slightly changes the picture yet.

1.2. The disputed gains from international trade

Over the last 10 years, the empirics have dramatically changed. *"[R]ecently we crossed an important watershed"*, Krugman wrote in December 2007 in a New York Times Op-Ed[9], *"we now import more manufactured goods from the third world than from other advanced economies. That is, a majority of our industrial trade is now with countries that are much poorer than we are and that pay their workers much lower wages. (…) The highly educated workers who clearly benefit from growing trade with third-world economies are a minority, greatly outnumbered by those who probably lose"*. Krugman concluded: *"[T]hose who are worried about trade have a point, and deserve some respect"*.

Two intertwined reasons can be pointed out, both of which relate to the countries currently "racing" – the BASICs (Brazil, South Africa, India and China), and no longer the Quad countries (the United States, the European Union, Canada and Japan). First, international trade, which today represents an even greater share of national GDP than in the 1990s, no longer covers products but rather tasks, enlarging the scope of "tradable" activities opened to world competition[10]. Secondly, it increasingly occurs between high-wage and low-wage countries in both service sectors (India) and manufacturing sectors (China), two features that were far less salient 20 years ago. As a consequence, the "race" propelled by globalisation may become detrimental to the leading country as long as the catching-up process entails a transfer of wealth from the leading to the catching-up country through outsourcing, imitation and innovation.

This was formalised in a highly controversial paper by another Nobel Prize winner. In 2004, Paul Samuelson sketched out the possible consequences of China catching up with the US in the very sector where the US enjoyed a comparative advantage – in other words, where it was leading the race. In his paper, this was supposed to happen thanks to technical innovation ("imitation or home ingenuity") and outsourcing. *"What does [the] arithmetic tell us about realistic U.S. long-run effects from such outsourcings? The new […] productivities [levels] imply that, this invention abroad that gives to China some of the comparative advantage that had belonged to the United States can induce for the United States permanent lost per capita real income"*[11].

Forecasts on future investments in clean energy technology (figure 2) and anticipated trends in installed renewable energy capacity between the EU27, China and the US (figure 3) provide possible illustrations of the "Samuelson syndrome": real wages in the sector concerned and potential overall real GDP could decline should China continue to catch up in green technologies and to grasp an ever wider share of the value added in the supply chain. The problem there is not that renewable technologies present salient features that firms and countries must consider while racing, but basically that China and India tend to specialise in these very sectors or tasks where, historically, Quad countries enjoyed undisputed comparative advantages when trading with one another. In short, the EU could be in trouble if what happened between China and Japan on PV cells over the last

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[6] Quoted by Krugman, P. (1994), "Competitiveness: A Dangerous Obsession", *Foreign Affairs,* March/April: 28-44.

[7] See the popular book by its Chair: Laura D'Andrea Tyson (1992), *Who's Bashing Whom: Trade Conflict in High-Technology Industries*, Institute for International Economics, Washington, DC.

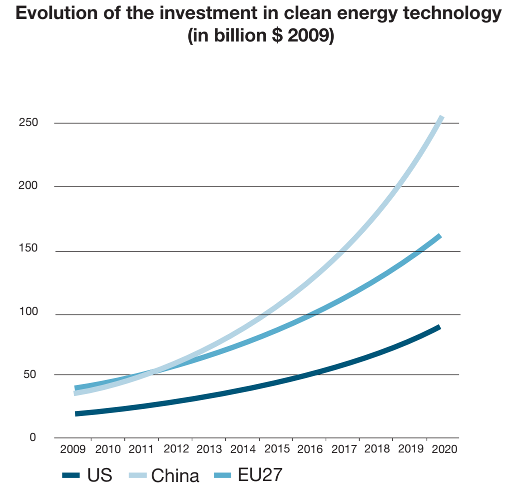
[8] See note 6.

[9] Krugman, P. (2007) "Trouble With Trade", *New York Times*, December 28, 2007.

[10] See Grossman, Gene and Esteban Rossi-Hansberg (2006): "Trade in Tasks: A Simple Theory of Offshoring", NBER Working Paper No. 12721.

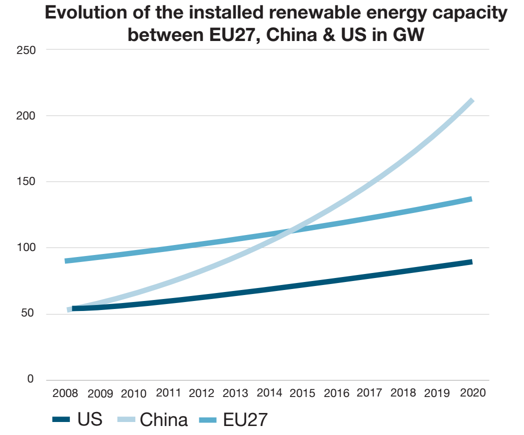
[11] Samuelson, P. (2004) "Where Ricardo and Mill Rebut and Confirm Arguments of Mainstream Economists Supporting Globalization", *The Journal of Economic Perspectives*, vol. 18, n° 3 (Summer, 2004): 135-146.

Figure 2. Investment in clean energy technology



Source: IDDRI based on PewResearch Center.

Figure 3. Installed renewable capacity



Source: IDDRI based on Pew Research Center.

These two Charts are more interesting for what they reveal than for what they show. Computed on the basis of Pew Research Center forecasts, they reveal the fear of the US lagging behind China. Forecasts by European-based renewables associations such as European Wind Energy Association and European Photovoltaic Industry Association give a far less dramatic upsurge in China's installed renewable capacities until 2020.

five years is generalised to larger segments of key renewable supply chains.

Relative productivity gains across countries induced by different innovation and technical change patterns may therefore occur *without* mutual benefits for all trading countries. Growing trade with major emerging countries such as China (the Krugman 2007 argument above) could hurt not only OECD manufacturing sector workers, but also the tradable services labour force, with technological progress spurring offshoring[12] in the form of (international) "trade in tasks". Consequently, the race for technology and for technology-induced productivity gains is now primarily a race for jobs – and more specifically, for non-routine and non-tradable jobs associated to the so-called green new tech.

In its macro dimension, the "green race" unfolds in the EU in a quite specific context. Let's recall first that capital accumulation and innovation are the two main engines of growth. Following Aghion and Durlauf (2006)[13], let's further recall that the EU – contrary to the US – resorted mostly to capital accumulation, imitation or adaption of technological innovations made elsewhere between 1945 and the 1970s. *"In 1945, Europe's stock of physical capital had been largely destroyed and its technological knowledge as reflected by its average level of per capita GDP was far behind per capita GDP in the US. So, what it would take to grow at that time, was for Europe to accumulate capital and to imitate or adapt technological innovations made elsewhere. And this is what Europe did quite successfully during the "trente glorieuses", with the support of economic institutions and policies that were adapted to those goals"* Aghion and Durlauf emphasize. *"However, by the late 1980s Europe had largely caught up with the world technology frontier in terms of its capital labor ratio and also in terms of its per capita GDP level. This in turn implied that Europe had largely exhausted capital accumulation and technological imitation as its main sources of growth, and had to turn to an alternative source, namely innovation"*[14]. Green technologies provide the EU with a means to make up for exhausted growth potential generated by factor accumulation and stagnating capital-labor ratio, while enabling the fast transition toward a low-carbon society.

1.3. Two narratives of globalisation

Against this backdrop, the main counter-arguments in defence of globalisation emphasise the classical gains from trade, and the rather unchanged distribution of value added along

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[12] Offshoring is the relocation of production sites (jobs) to foreign countries to take advantage of lower (labour) input costs. This phenomenon is often mislabelled as "outsourcing", a term that refers to the organisational structure of the firm instead (i.e. the choice of what selection of tasks are to be performed outside the firm); outsourcing may or may not involve the relocation of jobs to a foreign country.

[13] Aghion, Ph., and Durlauf, S. (2007) "From Growth Theory to Policy Design", mimeo.

[14] Ibid.

global value chains between rich and poor countries. The most widespread example, flagged by WTO director Pascal Lamy to argue for freer trade, is the iPod, the majority of whose added-value accrues to US firms even though the product is labelled "made in China". Mr. Lamy stressed that if trade statistics were adjusted to reflect the actual value contributed to a product by different countries, the size of the US trade deficit with China – $226.88 billion, according to US figures – would be halved. He argued that political tension over trade deficits is therefore probably higher than it should be. On job aspects, some authors also stress that increased competition through offshoring with low-wage countries does not change the specialisation pattern of OECD countries towards "non-routine" tasks, which began in the mid-1970s, well before such countries emerged in the global economy[15].

Arguments and counter-arguments over the originality of the current high-tech race unleashed by globalisation and the rising economic power of emerging countries delineate two distinct narratives of globalisation.

The first narrative contends that the current wave of globalisation is no different from the previous one, enabling any country to be better off thanks to comparative advantage efficiency gains. Innovation lies at the heart of growth in firms and countries. It is spread across countries thanks to international trade and foreign direct investments (FDI) and, if properly secured through intellectual property rights (IPR), rewards the innovative firm or country with higher productivity levels than the followers. At first sight, the rationale for the green race at country level remains more political (relative power mirroring relative growth rate) than economic. In economic terms, basically only relative growth gains are at stake. From a US or OECD perspective, the offshoring of part of the supply chain for high-tech products occurs to the benefit of such countries, whose firms continue to reap profits in their national territories in the most valuable segments of the chain (see the iPod story). Deindustrialisation is one aspect of this narrative: a temporary stage of the development of rich countries, following on from the temporary stage of industrialisation. Ultimately, deindustrialisation is good news as long as it allows firms to (re)locate most of the value added in the home country and generate some surpluses for export to balance trade[16]. Let us call this narrative "conventional competition".

The second narrative emphasises the asymmetric gains and losses induced by globalisation for leaders and followers. It stresses that global competition spurs incremental innovation and imitation, allowing an ever wider range of countries and firms to access the best available technology through declining patent costs. In a way, globalisation rewards the follower more than the leader. This second narrative suggests that it encourages imitation, not innovation,. Distributive impacts will appear all the more costly to the leader as the productivity gains induced by technological innovation decline over time and promptly vanish because of imitation and/or financial acquisition of national companies by foreign firms and state-owned enterprises (SOEs). Additionally, this narrative suggests, OECD countries may be unable to cope with displaced workers and the victims of trade – through "social safety nets" for instance, this narrative recalls that historically, the more open economies have had the biggest governments to cope with trade-induced shocks[17] – because of their fiscal basis being siphoned by tax avoidance, fiscal competition and bail-out plans, which are all the result of unleashed globalisation forces[18]. Ultimately, deindustrialisation and offshoring are not only a dent in the social contract, but the very reason real GDP will eventually decline because of the incapacity of such countries and firms to drive the supply-chain and benefit from the additional value-added gains associated with the driving/leading position. Let us call this narrative "hypercompetition".

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[15] In their paper, Grossman and Rossi-Hansberg (see footnote 10) divided labour input into "routine tasks" requiring the methodical repetition of procedures that can be well-described by a set of rules, and "non-routine" tasks requiring visual and motor processing that cannot easily be described by rules. The two categories cut across skill levels. It was expected that it would be easier for a firm to offshore routine tasks than non-routine tasks, independent of the skill level of the job. What they found is that the number of routine tasks has been falling since 1970, while that of non-routine tasks has been rising, with acceleration in each case in recent years. What this means is that relatively more US workers are doing jobs that cannot be well-described by mechanical rules, specialising in those tasks that cannot be performed remotely.

[16] See for instance Julia Cagé, "Vive la désindustrialisation", *La Tribune*, 01/03/2011, http://www.latribune.fr/opinions/20110301trib000604972/vive-la-desindustrialisation-.html

[17] Rodrik, D. (1998), "Why Do More Economies Have Bigger Governments?", *Journal of Political Economy*, 106(5), October.

[18] Rodrik, D. (2011), *The Globalization Paradox: Democracy and the Future of the World Economy*, W.W Norton, New York and London.

2. THE FIRST-MOVER ADVANTAGES AND DISADVANTAGES

The main academic contributions on the rationale for moving first and racing ahead stem from management reviews such as the *Strategic Management Journal* and *The Journal of Product Innovation Management* or *The Journal of Marketing*. We have found almost nothing in globalisation and trade economic reviews, probably because these tend to focus more on countries than on firms, with a bias for comparative static analysis leaving very little room for innovation processes, considered as exogenous or proxied with R&D and education expenses. Below we present a conceptual framework of first (or "early") mover advantages and disadvantages, established on the basis of the most salient contributions to the aforementioned marketing and management reviews.

2.1. A conceptual framework

In their seminal work and reference paper, Lieberman and Montgomery identify three primary sources from which first-mover advantages (FMAs)[19] arise.

1) *Technological leadership*, enabling firms to reap advantages derived i) from the "learning" or "experience" curve, where costs fall with cumulative output (the classical economies of scale argument), and ii) success in patent or R&D races, where advances in product or process technology are a function of R&D expenditure (the classical endogenous growth theory argument).

2) *Pre-emption of scarce assets*. Here, the first-mover gains advantage by controlling assets that already exist, rather than those created by the firm through the development of new technologies. Such assets may be physical resources or other process inputs (e.g. rare earths). Alternatively, the assets may relate to positioning in "space", including geographical space, product space, shelf space and so on.

3) *Switching costs and buyer choice under uncertainty*. In this case, late entrants must invest extra resources to attract customers away from the first-mover firm. Switching costs may stem from initial transaction costs or investment that the buyer makes in adapting to the seller's product. They may also arise due to supplier-specific learning by the buyer; or they may be intentionally created by the seller. A related strand of literature deals with the imperfect information of buyers regarding product quality. In such a context, buyers may rationally stick with the first brand and/or technology they encounter that perform the task satisfactorily. Psychology literature suggests that the first product introduced receives disproportionate attention in the consumer's mind.

Frynas, Mellahi and Pigman (2006) add a fourth source of first-mover advantages, namely firm-specific political resources[20]. Acquiring, exploiting and sustaining firm-specific political resources in international business can lead to significant FMAs in the international marketplace, they argue, drawing examples from Shell-BP in Nigeria, Volkswagen in China, and Lockheed Martin in Russia. Nevertheless, they stress that the causal relationship between political resources and FMAs is a complex one. Political resources may indeed lead to early market entry, but firms can also obtain considerable political resources by being the first to market. Neither can FMAs be taken for granted.

All these authors acknowledge that the mechanisms that benefit the first-mover may be counterbalanced by various disadvantages that are in effect advantages enjoyed by late-mover firms.

1) Late-movers may benefit from the ability to free-ride on a pioneering firm's investments in a number of areas including R&D, buyer education, and infrastructure development.

2) Late-movers can gain an edge through the resolution of market or technological uncertainty (and/or take advantage of the first-mover's mistakes). Entry into an uncertain market entails a high degree of risk. Early entry may be more attractive when the firm can influence the way this uncertainty is resolved – for example, the firm may be able to set industry standards in its favour. Interestingly, in many new product markets, uncertainty is resolved through the emergence of a "dominant design" (e.g. Ford T and DC-3 in the automotive and aircraft industries). After the emergence of such a design, competition often shifts to price; thereby giving greater advantages to firms possessing skills in low-cost manufacturing. The case of the PV sector, in which China overcame Japan on the world export market within five years, suggests that this kind of late-mover advantage is driven by standardisation and price competition (figure 4). 3) A third late-mover advantage – or first-mover disadvantage – consists in technological discontinuities that provide "gateways" for new entry (steam locomotive manufacturers failing to respond to the invention of diesel, for instance).

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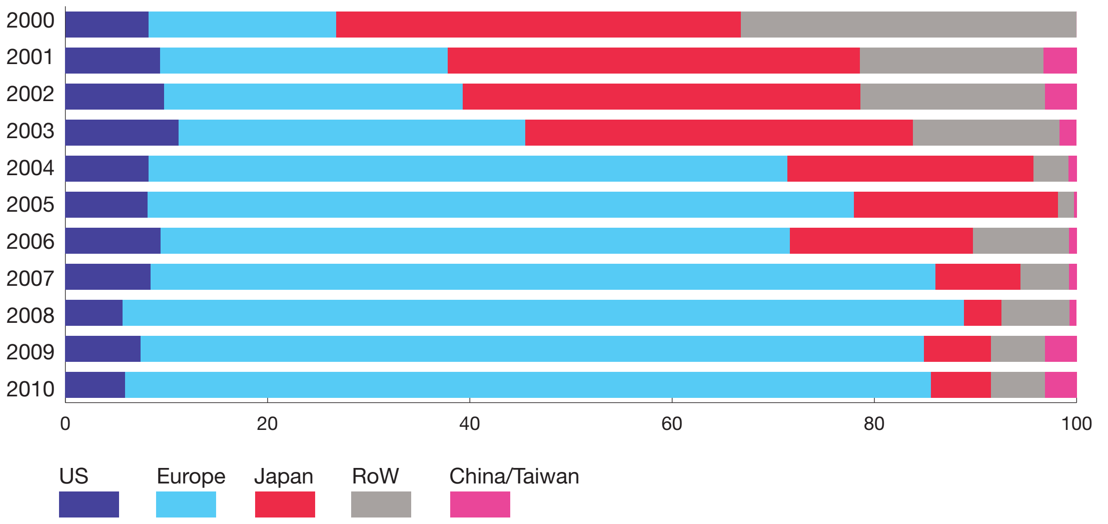
[19] Lieberman, M.B., and Montgomery, D.B. (1988), "First-Mover Advantages", *Strategic Management Journal*, 9: 41-58.

[20] Frynas, J.G., Mellahi, K., and Pigman, G.A. (2006), "First-Mover Advantages in International Business and Firm-Specific Political Resources", *Strategic Management Journal*, 27: 321-345.

Figure 4. PV module shipments (“market”) and installations (“production”), 2000-2010 (%)



With only small quantities (less than 1 GW annually) of modules shipped and installed during the years 2000-2003, local markets worldwide were supplied by local production. From 2004 onwards, an increasing number of Japanese modules were imported to the EU in order to supply its rapidly growing market. The same phenomenon happened with Chinese modules, reaching more than 50% of the global PV module production in 2010, against less than 15% in 2006.

Customer needs are dynamic, creating opportunities for later entrants unless the first-mover is alert and able to respond.

4) In the same vein, first-mover vulnerability is often enhanced by incumbent inertia, the firm being locked into a specific set of fixed assets, or reluctant to cannibalise existing product lines; for fear that the firm may become organisationally inflexible.

First-mover advantages and disadvantages are summarised in Table 1.

The debate concerning the green race points primarily to the first line of Table 1 (technological leadership) and to a lesser extent to the second (scarce assets) and the fourth (captive local markets; public procurement targeted at national firms, etc.). The green race so far often seems to be a race for (public) spending such as the one echoed by discussions on the “best” or “more ambitious” green recovery package[21]. What the Table also shows is that it is not necessary to lead the technology race in order to reap the profits. For instance, one might assume that competitive advantages are not sustainable if an obvious resource is easy to imitate, but this assumption may be wrong if other, less obvious, resources (access to customers, for instance) are difficult to imitate. The difficulty of imitating some key resources makes early-mover competitive advantages sustainable despite the fact that the product itself is easily imitated[22]. What the Table eventually recalls is that it may sometimes be counterproductive to lead, in comparison with a late-mover position.

Table 1. First-mover advantages and disadvantages

First-mover advantages	First-mover disadvantages
Technological leadership i) learning or experience curve (costs fall with cumulative output) ii) patent and R&D	Free riding on pioneering firms’ investments Technological discontinuities that provide “gateways” for new entry
Pre-emption of scarce assets i) physical resources, process inputs ii) positioning in “space”	Incumbent inertia
Switching costs and buyer choices under uncertainty	Resolution of market or technological uncertainty by late-movers
Firm-specific political resources	Firm-specific political resources exist for late-movers as well

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[21] See, for instance, UNEP (2009) “Rethinking the Economic Recovery: A Global Green New Deal”, Report by Edward Barbier for UNEP Economics and Trade, Division of Technology, Industry and Economics, and HSBC (2009), “Building a green recovery”, Caring for Climate Series, UN Global Compact.

[22] This is the case of the money market mutual fund industry in particular, see Makadok, R. (1998), “Can First-Mover and Early-Mover Advantages Be Sustained in an Industry with Low Barriers to Entry/Imitation?”, *Strategic Management Journal*, 19(7): 683-696.

2.2. Empirical results on first-mover advantages: a literature review

Empirical results confirm the balanced view given by Table 1, while conveying interesting insights concerning the various meanings of innovation. Measuring innovation and innovativeness requires carefully defining these constructs. Definitions actually abound, differing across the marketing, engineering, and new product development disciplines. What the literature in all these strands shows is that innovation processes have been identified for not only “radical”, “incremental”, “really new”, “discontinuous” and “imitative” innovations, but also “architectural”, “modular”, “improving”, and “evolutionary” innovations. Garcia and Calantone propose a typology basically distinguishing “radical”, “really new”, “discontinuous”, “incremental” and “imitative” innovations[23]. In most empirical literature, a further simplification is made in this typology, with a basic distinction between “really new” and “incrementally” new product-markets to start with.

Two empirical works deserve mention in this respect. The first one answers the following question: does the first entrant in a new market struggle to survive, or do first-mover advantages provide protection from outright failure? Min, Kalwani and Robinson identified 264 new industrial product-markets, emerging in the US economy from 1960 to 1995, for which they compared survival risks in markets that were launched with a really new product with those that were launched with an incremental innovation. What they found is that when a pioneer starts up a new market with a really new product, it can be a major challenge to survive. In contrast, in markets launched by an incremental innovation, market pioneer survival risks are much lower, meaning that the likelihood of survival is higher. In particular, the authors stress that early followers have the same survival risk across both types of markets. Overall, in markets launched by a really new product, the first to market is often the first to fail. In contrast, in markets launched by an incremental innovation, first-mover advantages protect the pioneer from outright failure[24].

From a century-long perspective, Agarwal and Gort examine historical changes in the US market for the duration of the interval between the commercial introduction of a new product and the time when entry by later competitors begins. Interestingly, they recall that investment in innovation is driven by expectations of transitory monopoly returns, protected either by patents or by developing innovations and getting to the market first. At the turn of the 20th century, competing firms in the infant phonograph record industry, for instance, relied heavily on secrets to protect their property rights. *“Even patenting a device was considered tantamount to advertising it”*[25], they remind us. Whether or not such a strategy would be equally effective in the same industry today is the question they ask. They collected data for 46 major product innovations and discovered that the average time span between the commercial introduction of a new product and late competitor entry was almost 33 years at the turn of the 20th century and declined to 3.4 years for innovations in the period1967-1986.

Why has the rate of initial competitive entry into new markets been rising steadily and rapidly over the last century, pointing to a weakening of entry barriers on net balance? They attribute this outcome largely to (a) the increased mobility of skilled labour; (b) improvements in communications and, as a consequence, a more rapid diffusion of technical information; (c) an increase in the number of potential entrants; and (d) growth in the absolute size of markets. They conclude that these results do not necessarily imply a reduction in the incentive to innovate, but are consistent with one possible effect of the observed trends: that firms may increase their reliance on patenting rather than trade secrets.

This conclusion was already suggested by other scholars who observed that the increase in patenting in the US as from the 1980s had been driven by changes in the management of innovation, involving a shift to more applied activities, favouring “incremental” innovation rather than technological revolution protected by trade secrets[26]. The shift towards environmental patenting seems to be a common feature of both early-mover and late-mover emerging countries in the environmental sector industry. Globally, some 215 000 green technology patent applications were filed worldwide over the period 1998-2008, including some 22 000 in developing countries, out of which about 7 400

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[23] Which pertain both to the product (technology) and its marketing, see Garcia, R., and Calantone, R. (2002), “A critical look at technological innovation typology and innovativeness terminology: a literature review”, *The Journal of Product Innovation Management* 19: 110-132.

[24] Min, S., Kalwani, M.U., and Robinson, W.T. (2006), “Market Pioneer and Early Follower Survival Risks: A Contingency Analysis of Really New Versus Incrementally New Product-Markets”, *Journal of Marketing* 70: 15-33.

[25] See footnote above.

[26] Kortum, S., and Lerner, J. (1997), “Stronger protection or technological revolution: What is behind the recent surge in patenting?”, NBER working paper 6204.

Table 2. Intellectual property implications: PV, biofuel, and wind

TECHNOLOGY	PV	BIOFUEL	WIND
IP access limitations on current market for energy (For reducing emissions or participating in CDM)	Few concerns over IP	Essentially no concerns over IP	Possible concerns over IP, but likely to involve at most a small royalty
Major developing country concerns in future market for energy	Possible difficulties in obtaining advanced IP-protected technologies	Possible barriers or delays in obtaining cellulosic technologies	Possible risk of anti-competitive behaviour given concentration of industry
IP access limitations on entering the industry as a producer of key components or products	Possible barriers or delays in obtaining or creating the highest quality production systems	Possible concerns over access to new enzymes and conversion organisms – but at most a royalty issue	Possible difficulty in obtaining most advanced technologies
Most important overall concerns in area	Access to government-funded technologies, Standards	Global trade barriers in the sugar / ethanol / fuel context. Access to government-funded technologies, Standards	Access to government-funded technologies, Plausible anti-competitive behaviour, Standards

Source: Barton, J.H. (2007), "Intellectual Property and Access to Clean Energy Technologies in Developing Countries. An Analysis of Solar Photovoltaic, Biofuel and Wind Technologies", Trade and Sustainable Energies Series, Issue Paper 2, ICSTD, Geneva, p. 18.

were actually owned by developing country residents, according to a study commissioned by EU DG Trade[27]. When the last four years of the period are compared to the first four years, the global patent count increased by 120%, but by nearly 550% in developing countries. Solar energy and fuel cell patents account for 80% of the count and for most of the growth as well, followed by wind energy as a distant third. In 1998, 1 in 20 patents for the relevant technologies was protected in a developing country; in 2008 it was 1 in 5. Competition and marginal (or incremental) innovation patenting together explain why intellectual property right (IPR) protection does not seem to be a decisive leading factor (or late-mover obstacle) for key renewables when compared with learning and experience curves (scale returns) and firm-specific political resources (Table 2).

It is sometimes claimed that the exclusive ownership rights that patents bestow on their holders create a monopolistic market structure and drive up the price of the goods that embody these innovative technologies, thereby making them less affordable for low-income developing countries. The DG Trade-commissioned study on IPR provides a picture of the distribution of patent rights by country of residence of the patent holder, which can be considered as a good means of gauging the strength of monopolistic powers in the market. The study shows that no single nationality actually dominates the market for a particular IPR-protected technology.

Even if they face patent issues in entering the field as producers, late-movers are likely to be able to obtain licences on reasonable terms because of the large number of firms in the industry, Barton (2007) points out. The possibility of entry is demonstrated by Tata-BP Solar (India), based on a joint venture, and Suntech (China), based on a combination of its own technologies and of purchases of developed world firms (Barton, 2007).

2.3. The sustainability of first-mover advantages

Understanding the dynamics of first-mover advantages and disadvantages (encapsulated in Table 1) is crucial to determining the likelihood that EU countries and firms will sustain an edge in the near future over their rivals or be caught up in specific market segments. Heated debates abound in the FMA literature as to whether the current phase of globalisation inexorably makes FMAs more and more temporary, while according to the opposite view, sustainability still prevails and is attainable by first-mover countries or firms, at least under specific conditions.

Authors like D'Aveni stress that we have entered an age of "hypercompetition"[28] and "temporary advantages"[29], where hypercompetition is defined as *"an environment of fierce competition leading to unsustainable advantage or the decline in the sustainability of advantage"*. How organisations can successfully compete, evolve, and survive when firm-specific advantages are not sustainable or

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[27] Copenhagen Economics A/S and the IPR Company APS (2009), "IPR as a Barrier to Transfer of Climate Change Technology", report commissioned by the European Commission (DG Trade), 19 January 2009.

[28] D'Aveni, R.A., 1994, *Hypercompetition: Managing the Dynamics of Strategic Maneuvering*, Free Press: New York.

[29] D'Aveni, R.A., Dagnino, G.B., and Smith, K.G (2010), "The Age of Temporary Advantage", *Strategic Management Journal*, 31: 1371-1385.

enduring, but more temporary in nature, is the question they raise. Such conditions, they argue, may exist due to fast-paced competitive actions and counter-responses among rivals, or where frequent endogenous and exogenous competence-destroying disruptions and discontinuities make sustaining one's advantage impossible.

Empirically, Thomas (1996)[30] and Thomas and D'Aveni (2009)[31] contend that 20th-century industries based on sustainable oligopolies were being replaced by industries that had become hypercompetitive. Recalling Schumpeter's theory of competitive behaviour, according to which competitive advantage will become increasingly more difficult to sustain in a wide range of industries, Wiggins and Ruefli (2005) find support for the argument that over time, competitive advantage has become significantly harder to sustain and, further, that the phenomenon is limited neither to high-technology industries nor to manufacturing industries, but is seen across a broad range of industries. They also find evidence that sustained competitive advantage is increasingly a matter not of a single advantage maintained over time, but more a matter of concatenating over time a sequence of advantages[32]. For these authors, the two key sustainable advantage models (Porter's five forces model and the resource-based view of the firm) are obsolete (Box 1). Distinguishing temporary advantages from sustainable advantages is an empirical matter, however, just as much as the distinction between the two globalisation narratives upon which they depend (Table 3).

While Table 1 lists the circumstances under which an industry or firm may emerge in a given country and capture a share of the home market, Table 3 circumscribes the factors determining whether the profits of such a firm are sustainable or disappear over time. We provide some empirics in the following sections through the analysis of FMAs and competition structure in the wind and PV supply chains.

Table 3. The two globalisation narratives revisited in the light of first-mover advantages

Sustainable FMAs	Globalisation potential changes	Temporary FMAs
High entry barriers Weak suppliers and buyers Few threats from substitutes Limited rivalry Firm-specific resources are: non-tradable non-substituTable or non-imiTable	More supply chain segments in competition Low labour cost competitors Incremental innovation (lower margins in wider markets)	Low entry barriers (contestable markets) Strong suppliers or buyers Substitutes Rivalry Firm specific resources are: tradable substituTable or imiTable
Globalisation narrative: conventional competition		Globalisation narrative: hypercompetition

Box 1. Are sustainable first-mover advantages still sustainable?

Porter's (1980)[1] five forces model suggests that firms can sustain advantages by the selection of industries and the way they position themselves within industries. This model is supported by substantial but somewhat dated research on the structure-conduct performance paradigm from industrial organisation economics. Specifically, Porter suggests that firms seek to position themselves in industries with high entry barriers, weak suppliers and buyers, few threats from substitutes, and limited rivalry.

The resource-based view conceives of firms as collections of resources (Penrose, 1959)[2]. Barney (1991)[3] formalised the framework for explaining how a firm's resources can be used as a source of sustainable competitive advantage. His framework is based on two fundamental assumptions: (1) firms within an industry are heterogeneous in the resources they control, and (2) these resources may not be perfectly mobile across firms (Barney, 1991). With these assumptions, Barney argues that markets for resources are imperfect and, therefore, a firm can achieve sustainable competitive advantage by acquiring or developing resources that are valuable, unique, non-tradable, rare, non-substituTable, or non-imiTable. But what does this model say about sustainability when factor markets continue to move towards perfection or towards constant disruption through innovation or rivalry? Or what if there are dramatic or even constant changes in resource value, uniqueness, tradability, and imitability?

Source: D'Aveni, R.A., Dagnino, G.B., and Smith, K.G (2010), "The Age of Temporary Advantage", *Strategic Management Journal*, 31: 1371-1385.

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1. Porter, M., (1980), *Competitive Strategy,* Free Press: New York.
2. Penrose, E.T., (1959), *The Theory of the Growth of the Firm*. John Wiley & Sons: New York.
3. Barney, J.B., (1991), "Firm resources and sustained competitive advantage", *Journal of Management* 17(1): 99–120.

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[30] Thomas, L.G., (1996), "The two faces of competition: dynamic resourcefulness and the hypercompetitive shift", *Organization Science* 7: 221–242.

[31] Thomas, L.G., D'Aveni, R.A., (2009), "The changing nature of competition in the U.S. manufacturing sector, 1950 to 2002", *Strategic Organization* 7(4): 387–431.

[32] Robert R. Wiggins and Timothy W. Ruefli (2005) "Schumpeter's Ghost: Is Hypercompetition Making the Best of Times Shorter?", *Strategic Management Journal*, Vol. 26, No. 10, pp. 887-911.

3. CONVENTIONAL COMPETITION: THE EU WIND ENERGY SECTOR

3.1. Facts and figures: the EU, an early mover and still leader

According to the European Wind Energy Association (EWEA), cumulative wind energy installations in the EU in 2010 reached 84.1 GW (including 1.6 GW offshore by the end of 2009). This is twice as much as China's global wind power capacity (42.2 GW) and that of the US (40.2 GW), even though China's new installations (off-grid included, which amounts to as much as 30% of installed capacities according to some sources) are increasing sharply. The breakdown of annual market share among top wind turbine manufacturers reflects both the EU leadership in this field and the massive entry of emerging country firms, whose market share is mostly secured by the development of their home wind energy market (Annex 1). Firm-specific political resources (Table 1) such as public subsidies and public procurement policies are key factors in the emergence of these firms. The world wind turbine market seems fragmented at the regional level, with EU firms operating in the EU, the US, Latin America and Africa, but not in India or China, where national companies hold the market (Annex 2).

Europe has the lead in wind power technology, with a complete supply chain, a professional function division, and comprehensive measurement and testing facilities, including public testing of wind farms, professional services, and equipment testing centres. Five companies, of which four are European, hold 90% of the world market. European original equipment manufacturers (OEMs) are well represented among the world leaders: Vestas (Denmark – world leader), Enercon (Germany), Siemens (Germany), Gamesa (Spain), Repower (Germany), Nordex (Germany) and Acciona (Spain). European turbine manufacturers are present in other continents, with production facilities in Asia, North America and South America.

The quality of European components with high-technology content and precision engineering (transmission, bearings, and blades) is now well established. European companies are among the top world leaders in this field (Siemens, ABB, etc.). Some 'sensitive' European components are exported to China (ABB, Siemens, Hansen) and integrated into Chinese turbines when needed, especially in projects with due diligence conditions (projects financed by international financial institutions – World Bank, Asian Development Bank).

The European wind energy market is a well-structured, mature, competitive market, with European actors operating at every stage of the project. Europe is the largest wind energy market; in particular, Europe is the first market for offshore wind energy with a market share of 97% of MW installed (2010). The only non-European installations in 2011 are Chinese and Japanese. So far, Europe has a 20-year lead over the US (which should enter the market in 4-5 years) and China, which is just entering the market. This lead is observed across the whole value chain: R&D, foundations, equipments, interconnections and services (operation and maintenance).

The wind capacity installed in the EU by the end of 2010 would in a normal year produce 181 TWh of electricity, representing 5.3% of electricity consumption. Annual installations of wind power have increased steadily over the last 15 years from 814 MW in 1995 to 9.295 MW in 2010, an annual average market growth of 17.6%. Interestingly enough, wind power installations accounted for 16.8% of new capacity installations in 2010, the first year since 2007 that wind power installations did not exceed any other generating technology[33]. In spite of this, perspectives for 2020 (low/high scenarios) provide figures such as 230/265 GW installed capacity, including 40-55 GW offshore (580.1/681.4 TWh), which represents 14-17% of total EU electricity demand (depending on total demand in 2020). EWEA supports and calls for 50% wind energy electricity in the EU by 2050.

Germany remains the EU country with the largest installed capacity, followed by Spain, Italy, France and the UK. Increasing installations in emerging EU markets – offshore in Northern Europe, and onshore in South East Europe (Romania, Poland and Bulgaria) – offset the fall in installations in the mature onshore markets of Germany, the UK, and Spain. Due to ongoing improvements in turbine efficiency and higher fuel prices, wind power is increasing in economic competitiveness against conventional power production. Furthermore, at sites with high wind speeds on land, wind power is considered to be fully commercial today according to EWEA.

Technology plays a key role in the rising trend of turbine efficiency. Turbine size, power and complexity have developed extremely rapidly, best evidenced by the increase in commercial turbine size by a factor of around 100 in 20 years (Figure 4). A common misunderstanding, as underlined by EWEA, is to consider wind energy as a mature

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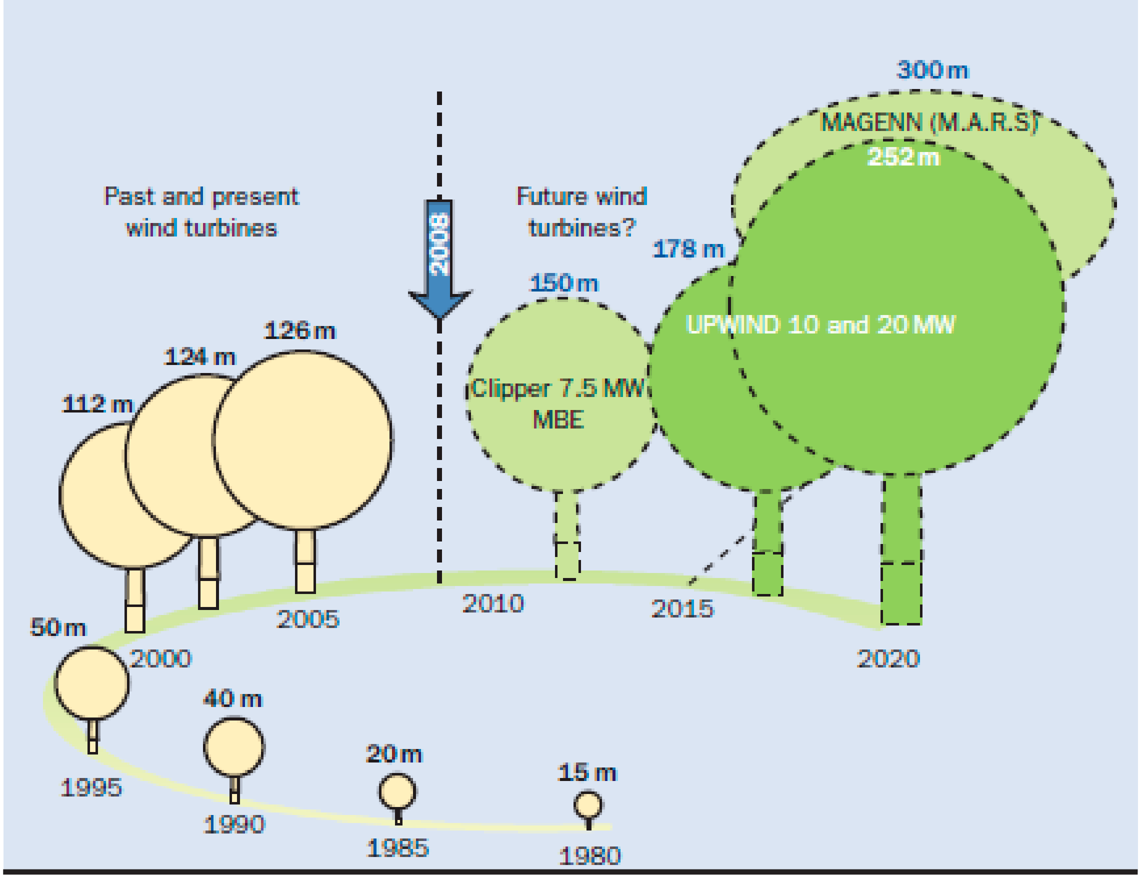
[33] EWEA further stresses that for only the second time since 1998, the EU power sector installed in 2010 more coal than it decommissioned, "highlighting the urgency of moving to a 30% greenhouse gas reduction target for 2020" – we follow them on this.

Figure 5. Growth in size of commercial wind turbine designs



Source: Garrad Hassan and European Wind Energy Association.

technology, which could lead to a reduced R&D effort.

MW-class turbines (above 1 MW) represent a market share of over 95%, leaving less than 5% for the smaller machines. Within the MW segment, turbines with capacities of 2.5 MW or above are becoming increasingly important, even for onshore siting. According to EWEA estimates, at present, production costs of energy for a 2 MW wind turbine range from 5.3 to 6.1 euro cents (c€) per kWh, depending on the wind resources at the chosen site. According to experience curve analyses, the cost range is expected to decline to between 4.3 and 5.5 c€/kWh by 2015.

Looking at jobs, 182 000 people were directly or indirectly employed in 2010 in the wind energy sector (Table 4). A significant share of direct wind energy employment (approximately 77%) is located in three countries, Denmark, Germany and Spain, whose combined installed capacity represents 70% of the EU total. EWEA's analysis concludes that 15.1 jobs are created in the EU for each new MW installed. In addition, 0.4 jobs are created per MW of total installed capacity in operations and maintenance and other activities related to existing installations

Overall, wind turbine and component manufacturers are responsible for 59% of direct wind energy employment in the EU (Table 4). The EU wind sector could represent 446 000 jobs by 2020, and 479 000 by 2030, with offshore progressively overtaking onshore (Table 5).

Table 4. Employment breakdown across sectors

Manufacturers	37%
Component manufacturers	22%
Developers	16%
Installation/repair/operations & maintenance	11%
IPP / utility	9%
Consultancy/engineering	3%
R&D/University	1%
Financial & insurance	0.3%
Others	1%

Source: European Wind Energy Association.

Table 5. Perspectives on EU wind sector jobs by 2030

	2008	2010	2015	2020	2025	2030
Onshore	143 782	148 057	200 870	290 276	228 104	185 478
Offshore	11 415	34 232	81 489	156 143	238 879	293 746

Source: European Wind Energy Association.

The typical wind energy job profiles required by the different industries display a wide range of skills and qualifications in all of the types of company operating in the sector (annex 3).

3.2. The wind power value chain

The main factors driving wind power economics are investment costs, such as auxiliary costs for foundations and grid connection; operation and maintenance (O&M) costs; electricity production (depending on the average wind speed); and the discount rate. We focus on the two main costs associated with wind turbines during their lifetime: investment costs and O&M costs. Investment or "capital costs" are incurred in the initial installation phase, whereas O&M costs are recurring costs that are necessary for the continued proper operation of a wind turbine.

3.2.1. Capital costs

Looking at capital costs, and focusing on onshore wind energy projects, EWEA estimates show that investment costs are dominated by the cost of the wind turbine[34]. The total investment cost of an average turbine installed in Europe is around € 1.23 million per MW, including all additional costs for foundations, electrical installation and consultancy (in 2006 prices)[35]. The main costs are distributed as shown in Table 6. The single most important additional component (to the cost of the turbine itself) is the cost of grid connection, which, in some cases, can account for almost half of the auxiliary costs, followed by typically lower shares for foundation costs and the cost of the electrical installation. Other cost components, such as control systems and land, account for a minor share of the total costs.

Table 6. Cost structure of a typical 2 MW turbine installed in Europe (in 2006€)

	Investment (1000/ MW)	Share (%)
Turbine	928	75.6
Foundations	80	6.5
Electric installation	18	1.5
Grid connection	109	8.9
Control systems	4	0.3
Consultancy	15	1.2
Land	48	3.9
Financial costs	15	1.2
Road	11	0.9
TOTAL	1227	100

Note: Calculation based on selected data for European wind turbine installations.
Source: Risø DTU National Laboratory, Technical University of Denmark and European Wind Energy Association.

A typical wind turbine contains up to 8 000 different components. Table 7 breaks down the turbine costs into its major components[36], the two most important ones (tower and rotor blades) being untradable over long distances due to overwhelming weight-related transportation costs.

Table 7. Cost/5 MW wind turbine component (%)

Wind turbine component	Cost (%)
Tower	26.3
Rotor blades	22.2
GearBox	12.91
Power converter	5.01
Transformer	3.59
Generator	3.44
Main frame	2.80
Pitch system	2.66
Main shaft	1.91
Rotor hub	1.37
Nacelle housing	1.35
Brake system	1.32
Yaw system	1.25
Rotor bearings	1.22
Screws	1.04
Cables	0.96

Source: European Wind Energy Association

For this reason, most of the component and turbine manufacturing stages are located in the country or region where the wind power capacity is to be installed – the EU in the hypothetical case described in Chart 1. Chart 1 provides first-hand expert estimates of local/foreign supply of different materials as well as the strategic/non-strategic aspects of these for the EU.

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[34] Whereas the costs are much more evenly distributed in offshore technology. This results in the fact that costs for the foundations, installation and grid connection of offshore wind turbines are much higher than those of onshore turbines.

[35] The costs for an average offshore wind turbine, in contrast, range anywhere between € 2 000 and 3 000 per kW.

[36] These figures are estimates based on a REpower 5 MW MM92 turbine with 45.3 meter blade length and a 100 meter tower.

The location partly depends on upfront costs. Some parts represent a high technological risk (gearBox, bearing, generator and blades). Supplies in this case are usually secured by OEM own manufacturing (blades) or by vertical upstream integration in Europe to cope with possible disruption costs (e.g. Vestas, Gamesa and Siemens integrated gearBox suppliers in order to secure at least 20-30% of their supplies). Some parts are also manufactured close to the development site because of logistic costs, which may sometimes be higher than the manufacturing cost (towers and blades). Some other parts can be easily supplied by subcontractors (towers), with the possible externalisation of the manufacturing process – yet these cannot be shipped across thousand of miles for obvious logistic reasons. For offshore projects, tower manufacturing plants are usually located in ports in order to avoid land transport. The same occurs for onshore projects, where land transport is avoided as much as possible. **All this makes the wind power supply chain a local and non-tradable chain for most of its costly components. Chart 1 thus shows that foreign penetration into the value chain is limited to raw materials (steel, aluminium, copper, etc.) and low-tech/non-strategic components (nacelle frames, for instance).**

But the location also partly depends on local policies. The quality of European (and US) wind energy projects is usually ensured through a heavy certification process (design evaluation conformity statement and type test conformity statement – with the *IEC Wind Turbine Standards as a benchmark for various countries*). Internationally, the certification of wind power has more than 30 years history and actually began in Europe. Newcomers to the market need to meet the same conditions as European OEMs, which are already certified for their turbines. This head start represents a competitive advantage for 'historical' actors in the market (European and American companies), placing them in front of Indian or Chinese companies.

Moving upstream in the value chain, which is more connected to world market, two issues are worth noting. The first relates to fluctuations in world raw material prices, and the second to rare earths. China dominates the market for rare earths and accounts for 95-97% of world production. But China is in the process of decreasing exportation through export quotas, which have a considerable impact on export prices. New mining projects are already in the pipeline in order to counter this dependency. Nevertheless, studies are not clear as to whether or not there will be a shortage of supplies, leading to price inflation. Some sources predict a shortage of Neodymium used in the wind turbine industry (Box 2).

Overall, the need to manufacture the heavy and large components (towers, blades, nacelle assembling) close to the exploitation site means EU FMAs are sustainable ones. Foreign penetration into the European wind market depends on strategic FDI (acquisition of turbine manufacturers) or strategic agreements with utilities and developers. From time to time and on a small scale, foreign companies may export turbines to Europe, but this remains uncommon. For large-scale projects, foreign presence in Europe must go through local production by opening new facilities, which means employment, investment or the acquisition of European companies. US, Chinese and Indian companies present in Europe operate this way. Occasionally, Chinese turbines may be found on the European market, but in this case they will probably have a significant level of European content.

3.2.2. Operation and maintenance costs

Operation and maintenance costs constitute the second major share of the total annual costs of a wind turbine. For a new turbine, O&M costs may easily make up 20-25% of the total levelised cost per kWh produced over the lifetime of the turbine. If the turbine is fairly new, the share may be only 10-15%, but this may increase to at least 20-35% by

Box 2. Rare earths in direct drive and gear-driven wind turbines

Globally, the demand for rare earths from the wind turbine industry will follow the evolution of new installations and should increase sharply. Turbine synchronous generators use either electromagnets (with copper coils) or permanent magnets to generate electricity. The latter consist mainly of Neodymium but also Praseodymium and Dysprosium and are mainly used in the manufacturing of direct drive turbines (without gearBoxes). The choice between a direct drive configuration and a gearBox is made on the basis of many technical and economic parameters. Direct drive turbines present several advantages, including higher power density and no gearBoxes (which represent a high technological risk). When it comes to maintenance, especially for offshore projects, direct drive turbines may be cost-saving. One German manufacturer has always produced direct drive turbines (Enercon). Several companies have started testing or have already produced models using permanent magnets (direct drive or gear-driven), including leaders like Vestas, Siemens and Gamesa.

At this stage the vast majority of turbines are made with asynchronous generators. Depending on sources, average use of Neodymium is 200 to 300 kg/MW for direct drive turbines, against 20 kg/MW for a gear-driven turbine with permanent magnet.

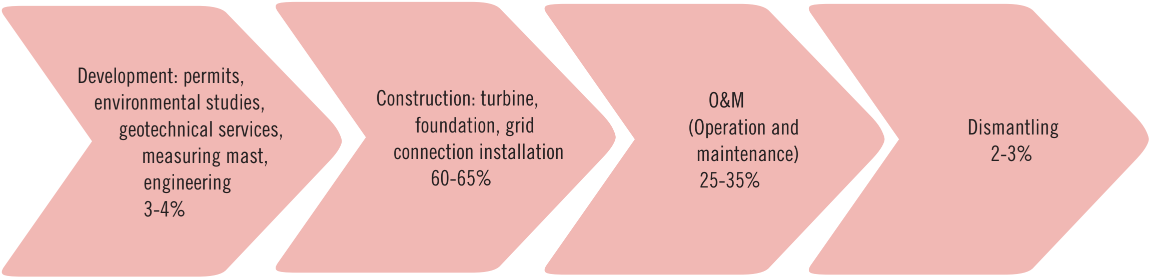
Some experts estimate that European Neodymium demand from the wind turbine industry will be multiplied by 5 by 2020 and by 8 by 2030, according to the curve for new capacities installed, if no new R&D developments are made to improve gearBoxes or to use more sophisticated solutions for the direct drive.

Chart 1. Wind energy vertical value chain (linked to wind turbine components)

raw material suppliers	steelplate: world market steeliron: world market cast iron: world market copper for cabling: world market. Refinery led by Chinese companies. Germany was leading exporter of semi-refined copper in 2009 (Aurubis). aluminium: world market, led by 5 main groups (Alcoa/US, Rio Tinto Alcoa/Canada, Chinalco/China, Russal/Russia, Hydro/Norway). concrete: world market nickel for casted components GFRP (glass fiber reinforced polymer): supplied mainly by China CFRP (carbon fiber reinforced polymer): see above balsawood: main suppliers are Papua New Guinea and Brazil. polyester, epoxy, polyurethane, rubber, ceramics permanent magnets / gearless turbines (which include rare earth – neodymium mainly): China world leader in rare earths (97% of world production) teflon (PTFE)
components manufacturing	– foundation (more important for offshore). For onshore: concrete (90%), stainless steel, steelplate. Made in Europe (project site) – tower: steelplate, copper, concrete. Low tech' content, ideally made near the project (to lower logistic costs) – cables: made mainly in Europe for offshore – nacelle and controls – controllers a& electronics: customized by OEMs in general – transformer: stainless steel. Can be of different origins, generally in the projects' country due to national standard requirements – generator & power electronics: stainless steel or cast iron (shaft), permanent magnets, copper coil. High tech' content, made in Europe – cooling system (for the generator) – gear Box: cast iron, stainless steel. Strategic component, made in Europe – main shaft: steel or cast iron. Different origins, not strategic – shaft brake/yaw brake: cast iron and steel. Not strategic, different origin – high speed shaft: steel – yaw motor / yaw bearing: steel. Strategic component, usually made in Europe – main bearing: steel-main bearing housing: cast iron; High tech' content, made in Europe (SKF, etc.) – nacelle frame: cast iron, nacelle cover: GRFP Low tech' content, can be made everywhere (China mainly) wind measure instruments (anemometer, wind vane) – rotor – hub: cast iron – pitch bearing/pitch motor: cast iron, stainless steel. High tech' content, usually made in Europe – root cover: GRFP; Low tech' content, can be mede everywhere (China mainly) blades: glass-fiber reinforced polymer composite (with epoxy, polyester, etc.), carbon fiber foam, balsawood. Strategic part, usually made by OEMs or LM Wind Power (EU), world leader in blade manufacturing
Turbine manufacturers	All steps described hereunder are done in the EU by EU companies, unless design and engineering made by foreign companies which must be certified for the EU market. – design, engineering, certification, software, assembly, tests, transportation, construction, lift, commissioning, operation

Source : EWEA + direct interviews

Chart 2. Wind energy project life cycle (cost ratio)



Source : EWEA + direct interviews

the end of the turbine's lifetime. As a result, O&M costs are attracting greater attention, as manufacturers attempt to significantly reduce these costs by developing new turbine designs that require fewer regular service visits and less turbine downtime.

O&M costs are variable costs related to a limited number of cost components, and include insurance, regular maintenance, repairs, spare parts and administration. These components vary according to the type, size, and age of the turbine, given that O&M costs increase with the age of the turbine.

Operation costs are control-oriented costs that are necessary to run wind turbines, such as site management, staff, tools and equipment, and supervisory control and data acquisition[37] costs. These costs are not directly involved in repairing or overhauling turbine components, but play an important role in overall O&M costs.

Maintenance costs are directly associated with wind turbines. Each component has an estimated lifetime within the overall 20-year turbine lifetime. Maintenance costs are related to turbine size and configuration, and generally escalate over time as the machines age and parts wear out.

From a life-cycle perspective, operation and maintenance make up for a significant part (about 1/3, see Chart 2) of the overall cost/value added of a wind farm project. O&M costs for onshore wind energy are generally estimated to be around c€ 1.2 to 1.5 per kWh of wind power produced over the total lifetime of a turbine. Spanish data indicates that less than 60% of this amount goes strictly to the O&M of the turbine and installations, with the rest equally distributed between labour costs and spare parts. The remaining 40% is split equally between insurance, land rental and overheads.

The O&M market was estimated at € 3.3 billion in 2010 and is expected to grow at 19% compound annual growth rate (CAGR) to reach € 9.2 billion in 2016. **Europe was the largest wind O&M market in 2010**. China is expected to become the largest market in 2016.

GearBoxes, generators and turbine blades are the three main components that need regular servicing and make up approximately 80% of total turbine maintenance costs. Independent service providers (ISPs) are gaining traction in many mature wind markets[38]. Offshore, which accounts for only 5% of the present O&M market, has a higher O&M cost than onshore O&M. Limited accessibility, lower availability of trained personnel and logistic issues make it difficult to provide offshore O&M services, resulting in higher costs.

Overall, **Europe has a competitive advantage in O&M services thanks to several decades of experience**. O&M is a key issue for onshore wind energy, and even more so for offshore. O&M should be carried out as far as possible using local teams to reduce costs. **Little or no foreign penetration is currently observed in O&M supply chain segments (local staff, teams, subsidiaries, thus employment, and investment).** Development of ISPs and strategic alliances between ISPs in order to offer a comprehensive service for all components (e.g. Global Wind Alliance) could be fostered, as well as strategic agreements between ISPs and OEMs and contracts between ISPs and developers. European companies could use this advantage to foster their presence on foreign markets with a structured offer in terms of services.

3.3. Sustaining EU leadership

Applying Table 1 (first-mover advantages and disadvantages) to the wind energy market, it

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[37] Computer systems that monitor and control the wind farm.

[38] Offshore wind turbine installations account for 1.7% of global cumulative wind energy capacity, but represent 5% of the global wind O&M market. Offshore wind O&M costs are 2 to 2.5 times higher than onshore O&M costs.

follows that the outstanding position of the EU in the wind energy global value chain is primarily due to its technological leadership (early mover), itself due to historically high R&D levels, the preemption of the EU internal market with an early positioning in countries such as Germany, the UK and Italy, and public incentives and standards propelling EU supply chain (and particularly technology) deployment.

The fact that the supply chain is local or "captive" in many of its segments, particularly downstream, does not necessarily give the EU a sustainable FMA over the coming decade(s): sustaining R&D expenses, enhancing the incentive and regulatory EU framework and circumventing the potential threats roused by foreign dependence on potentially key raw materials (rare earths) are some of the main drivers of EU sustainable FMAs, which are pinpointed below.

3.3.1. Addressing R&D and technology challenges

- **Technology is moving fast**, through incremental innovations; breakthrough technologies are much less likely in the near future (at least for onshore projects, see Box 3).
- **New turbines and components are to be designed to meet increasing EU demand for renewable energy**: the development and testing of a large-scale turbine prototype (15-20 MW) is a necessary step, along with the implementation of testing facilities and the standardisation of harbours to service the next generation of wind turbines (see Chart 2).
- **Development of offshore structures**: the development and testing of new structures, the demonstration of mass manufacturing processes and a procedure for structures integrating larger turbines than onshore ones are still ahead.
- Gear-driven versus direct drive turbines: the challenge is to replace traditional gearBoxes and high-speed generators with bigger, low-speed generators that do not require a geared transmission. The objectives are to gain weight and reliability and to cut costs. GE and Siemens are set to achieve this. Enercon (Germany) has been producing direct drive turbines since 1993. This is of considerable interest for offshore projects, where maintenance is a key issue in terms of costs.
- Grid integration: the next step should consist in demonstrating a long-distance high-voltage direct current (HVDC), offshore flexible connection to at least two countries, as well as multi-terminal offshore solutions.
- Wind resource assessment and spatial planning: the publication of an EU27 Wind Atlas is expected by 2015, prior to the statistical forecast distribution on wind speed and energy production.

Box 3: Incremental versus breakthrough innovation in the wind energy industry

Onshore: mature market where innovation is mainly incremental. Breakthrough innovation could come through vertical axis turbines. But the 'blade-rotor-nacelle' model is a proven technology. After 30 years of growing production capacity through increasing wind turbine size, the challenge now is how to produce more electricity without increasing the turbine size. This optimisation is one of the main drivers of R&D.

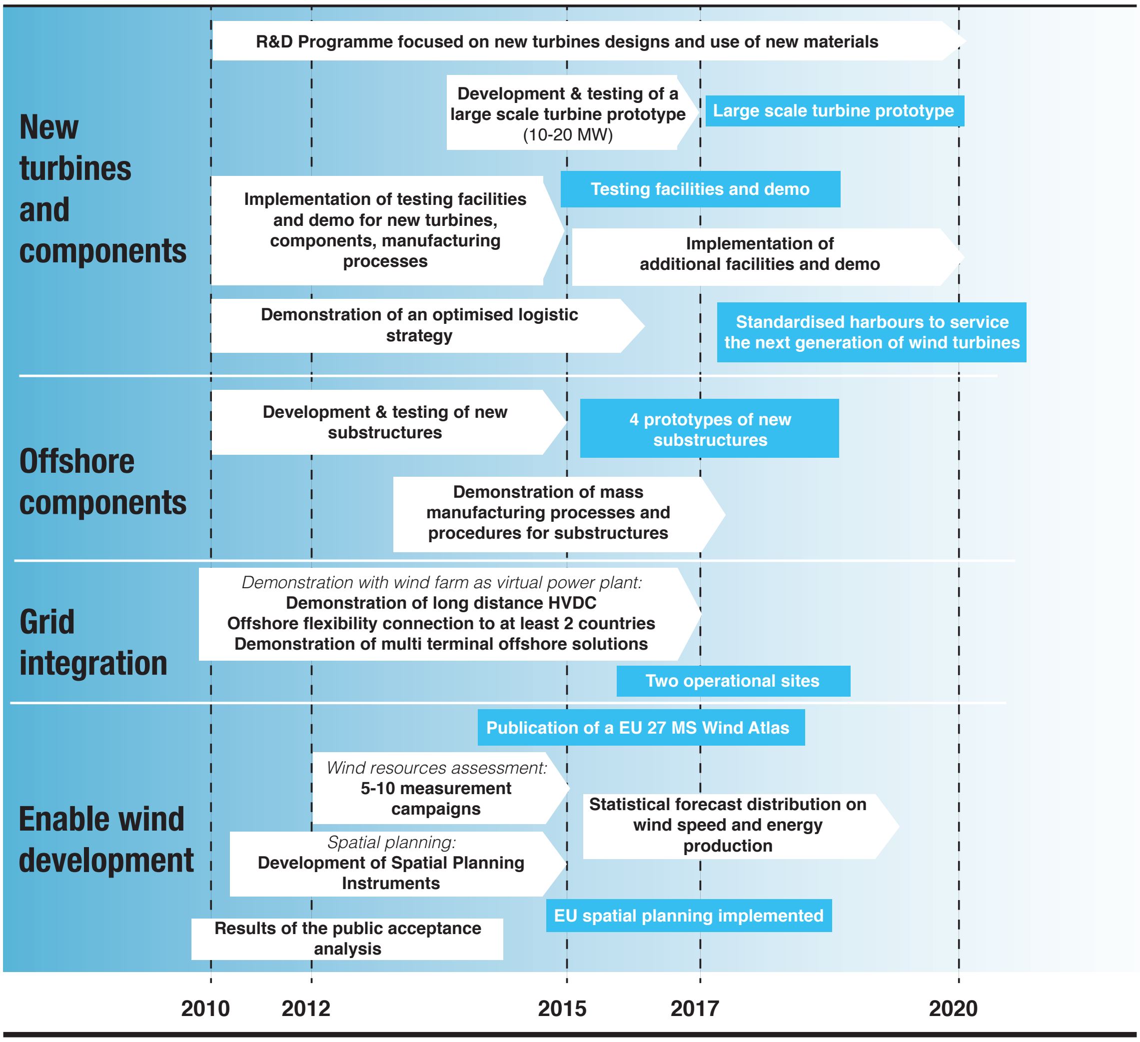
Offshore: immature market. More possibilities in terms of breakthrough innovation, especially for foundations, cables, rotors and interconnectors.

The funding for the EU roadmap requirements (Chart 3) are not yet secured. As EWEA stresses, and as we have already mentioned, "*a common misunderstanding is to consider wind energy as a mature technology, which could lead to a reduced R&D effort*". For the first time, in 2010, the EU wind energy market witnessed investment flows for offshore projects by pension funds, which represents a positive – albeit currently unpredicTable – trend for the sector.

3.3.2. Increasing access to non-EU markets for EU firms

- **Export:** the European lead in several parts of the value chain, namely manufacturing and services (components, O&M), could be fostered to gain new market share on the world wind energy market through a further reduction of tariff and non-tariff barriers in major potential importing countries.
- **Components:** strategic European parts are used in the turbines of China's leaders in wind turbine manufacturing (Sinovel, Goldwind, Dong-Fang and United Power). Components such as gearBoxes, blades, bearings, converters and control systems used in Chinese turbines are partly 'made in Europe', with the risk of these being transferred through loose intellectual property (IP) protection.
- **Offshore:** new European projects are in the pipeline. The EU market is likely to experience a sharp increase in terms of total MW to be installed and project size (MW). Larger, deeper and more distant (from the shore) projects are driving innovation on substructures and vessels. The US, South Korea, China, Taiwan, Canada

Chart 3. WIND – Technology Roadmap 2010-2020



Source: European Commission, DG Energy.

and Japan should be the next markets for future development. China is the most advanced (behind the EU) on this subject (manufacturing turbines, project development, etc.). Foreign companies are announcing the development of new turbines.

3.3.3. Coping with threats

- Rare earths: China has a monopoly on the production of rare earths, with about 95-97% of the total. At present, there is no other country that can supply Neodymium (the rare earth used in permanent magnet manufacturing for generators). There are growing concerns among EU firms about China's export quota policy, which impacts world prices. Yet substitution technologies could be developed and new mines are currently being explored.
- Raw material price instability: dependency on world market price fluctuations for steel, iron, copper, nickel, aluminium, glass fibre and carbon fibre. China is usually the leading country for these raw materials.
- Finance & economics: securing renewable project development at EU level is a priority, given the current Member States debt crisis and unpredicTable year-to-year budget changes.

4. HYPERCOMPETITION: THE EU PHOTOVOLTAIC SECTOR

4.1. Facts and figures: EU leader in installed capacities

Over the last 10 years, progress has been impressive in the PV industry worldwide. The total installed PV capacity in the world has multiplied by a factor of 27, from 1.5 GW in 2000 to 39.5 GW in 2010 – a yearly growth rate of about 40%. Such growth has proved to be sustainable, allowing the industry to develop at a stable rate. In 2010, the photovoltaic (PV) industry production more than doubled and reached a worldwide production volume of 23.5 GWp of photovoltaic modules. Business analysts predict that investments in PV technology could double, from € 35-40 billion in 2010 to over € 70 billion in 2015, while prices for consumers should continuously decrease over the same period.

The EU, having overtaken Japan, is now the clear leader in terms of market and total installed capacity (75% of total cumulative world PV capacities), thanks largely to German past initiatives (now about 18 GW installed capacities) that have helped create global momentum. Japan (3.6 MW) and the US (2.5 GW) are far behind and are the only countries with more than 1 GW installed outside Europe. The situation should evolve in the coming years with the rapid growth recorded in other regions such as North America and Asia. China in particular has entered the top 10 on the market and should reach its first GW in 2011. China is expected to become a major market in the coming years.

Current solar cell technologies are well established and provide a reliable product, with sufficient efficiency and energy output for at least a 25-year lifetime (Box 4). Crystalline silicon (c-Si) technologies have dominated the market for the last 30 years and now represent 85% of the market. C-Si technologies have been used mainly in both stand-alone and on-grid systems. Within the c-Si technologies, mono- and multi-crystalline cells are produced in fairly equal proportion. However, multi-crystalline cells are gaining market share. Ribbon c-Si represents less than 5% of the market. Crystalline silicon technology is a field-proven mature technology where innovation is incremental. R&D is focused on production, especially on process optimisation in order to reduce costs and wastes.

Box 4. Most common available commercial PV technologies

Crystalline silicon technology

- Crystalline silicon cells are made from thin slices cut from a single crystal of silicon (monocrystalline) or from a block of silicon (polycrystalline).
- Their efficiency ranges between 12% and 17%.
- Three main types of crystalline cells can be distinguished: Monocrystalline (mono c-Si), polycrystalline (or Multicrystalline – multi c-Si), Ribbon sheets (ribbon-sheet c-Si)
- Most common technology representing around 85% of the market today

Thin film technology

- Thin film modules are constructed by depositing extremely thin layers of photosensitive materials onto a low-cost baking such as glass, stainless steel or plastic.
- Lower production costs compared to the more material-intensive crystalline technology, a price advantage…
- …which is currently counter-balanced by substantially lower efficiency rates (from 5% to 13%).
- Four types of thin film modules (depending on the active material used) are commercially available at the moment: Amorphous silicon (a-Si), Cadmium telluride (CdTe), Copper Indium/gallium Diselenide/disulphide (CIS, CIGS), Multi junction cells (a-Si/m-Si)
- Around 5% of the market

The second generation of thin film technology represents a market share of around 15%. While amorphous silicon (a-Si) has been the preferred clear thin film technology used over the past 30 years, its market share has decreased significantly compared to more advanced and competitive technologies, such as Cadmium telluride (CdTe), which grew from a 2% market share in 2005 to 13% in 2010. The thin film technology is less mature than crystalline silicon and its yield is still lower. Fundamental R&D is focused on technology innovation (Box 5).

When compared to conventional renewables such as wind and biomass, PV is the most expensive in terms of cost per installed kilowatt or kilowatt-hour and is, in general, currently more expensive than traditional means of producing electricity (Barton, 2007). Yet over the last 20 years, PV has shown impressive price reductions, with the price of PV modules decreasing by over 20% every time the cumulative volume of PV modules sold doubles. System prices have declined accordingly; over the last five years, a price decrease of 50% has been achieved in Europe. According to EPIA, system prices are expected to decrease in the next 10 years by 36-51%. The cost of PV electricity generation in Europe could decrease from € 0.16-0.35 per kWh in 2010 to € 0.08-0.18 per kWh in 2020, depending on the system size and irradiance level.

Figure 5 displays the main PV cell R&D results in terms of efficiency since 1975 and the impressive development of innovations over time in a limited number of countries (the EU, Japan, Germany and, recently, Israel and China). The best results obtained are not developed on a large scale in open B2C or even B2B markets: they remain limited to laboratories or very specific uses such as the aerospace industry.

The production of PV panels is expensive and requires large-scale precision manufacturing capabilities. Nevertheless, the industry is quite decentralised, as shown in annex 10, which lists all firms shipping over 50 MWp around the world, as well as firms shipping smaller amounts in developing nations. This is a moderately concentrated industry; the four leading firms produce about 45% of the market (Barton, 2007, using 2005 data). Another study lists five firms, Sharp, Kyocera, Shell Solar, BP Solar and Schott Solar, as holding 60% of the market. The industry consolidated heavily in the 1990s. Today's firms are concentrated in the developed world, but there are five firms in the developing world, each producing at least 10 MWp, making it closer to the "hypercompetition" narrative than to the conventional competition one, where a few historical firms reap the profits of patents and increasing returns.

Finally, the PV industry has created nearly 100 000 jobs in Europe in the last few years, under the impetus (in descending order) of Germany, Spain, Italy and France, through an extensive list of direct and indirect occupations (annex 11). Labour-intensive segments of the supply chain are mostly downstream, as we will see below.

4.2. The PV value chain

The PV market and industry can be broken down into one complete process, from the first production stages for metallurgical silicon to the turn-key system for the end customer, including all services linked to such systems. Different technologies within the European PV industry, such as crystalline and thin film technology, lead to different production processes and value chains (Chart 4).

Box 5. Main PV technologies under development or starting to be commercialised

Concentrated PV

- Some solar cells are designed to operate with concentrated sunlight. These cells are built into concentrating collectors that use a lens to focus the sunlight onto the cells
- Main idea: to use very little of the expensive semi-conducting PV material while collecting as much sunlight as possible
- Efficiencies are in the range of 20% to 45%.

Flexible cells

- Based on a similar production process to thin film cells, when active material is deposited in a thin plastic, the cell can be flexible
- Used for new applications: building integration (roof-tiles) and end-consumer applications

Dye-sensitized solar cells

- Inspired by photosynthesis
- Several laboratories and companies are working on the subjects: Tel-Aviv University, State Key Laboratory of Metal Matix composite (Shangha Jiao-Tong University), Konarka Power Plastic solar cell technology (USA – thin film dye sensitized solar cells), synthetic solar energy storage (Sun Catalytix / USA – Photosynthetically inspired energy storage & artificial photosynthesis)
- PV gel
- Quantum dot cells
- Organic cells
- Inorganic cells

4.2.1. Market structure

Upstream activities include all stages, from the manufacturing of equipment and materials to the production of modules, inverters and other balance of system (BOS) elements. Supply of certain materials and equipment is concentrated in the hands of a few very large players. For example, about 70 companies are active in polysilicon production. However, in 2009, more than 90% of the total supply was manufactured by seven major players from Europe, the US and Japan: Hemlock, Wacker Chemie, REC, Tokuyama, MEMC, Mitsubishi and Sumitomo. Many Chinese companies are currently ramping up capacity and are expected to account for a larger share of the polysilicon market over the next few years.

The market is more segmented and competitive in the area of wafer and cell manufacturing (Table 8). More than 200 companies were active in this sector in 2009, and the number of companies was estimated at 350 in 2010. Around 1 000 companies produced c-Si modules in 2010.

Also with respect to inverter production, the top ten companies produce more than 80% of the inverters sold on the market, even though there are more than 300 companies active in this segment.

In the case of thin film module manufacturing, about 160 companies were active in 2009 (Table 9). Some 130 of these companies produce silicon-based thin films, around 30 produce CIGS/CIS thin films, and a handful of companies are active in CdTe. There are currently more than 50 companies that offer turnkey c-Si production lines. Fewer than 30 manufacturers provide the PV industry with thin film production lines.

Table 8. Number of companies worldwide in the crystalline silicon value chain (2009)

	Silicon	Ingots Wafers	Cells	Modules
Number of companies	75	208	239	30
Production capacity	130 000 tonnes	15 000 MW	18 000 MW	19 000 MW
Effective production	90 000 tonnes	10 000 MW	9 000 MW	7 000 MW

Source: Energy Focus, Photon, Joint Research Centre and European Photovoltaic Industry Association.

Table 9. Number of companies worldwide in the thin film value chain (2009)

	CdTe	a-Si	a-Si/u-SI	CI(G)S
Number of companies	4	131		30
Production	1 100 MW	<300 MW	<400 MW	<200 MW

Source: Energy Focus, Photon, Joint Research Centre and European Photovoltaic Industry Association.

The latest figures regarding industry structure are given in the PV Status Report 2011 (Joint Research Centre Scientific and Technical Reports, European Commission). The number of companies involved in PV increased sharply in 2010 compared to the 2009 figures given above. It is now estimated that more than 100 companies are producing or starting up polysilicon production and more than 350 companies are producing solar cells. More than 200 companies are involved in thin film solar cell activities, ranging from basic R&D activities to major manufacturing activities, and over 120 of them have announced the start of or an increase in production. In 2005, for the first time, production of thin film solar modules reached more than 100 MW per annum. The first 100 MW thin film factories became operational in 2007, followed by the first 1 GW factory in 2010. If all expansion plans are carried out in time, thin film production capacity could be 17 GW, or 21% of the total 80 GW in 2012, and 27 GW, or 26% of a total of 102 GW in 2015, according to the report.

The downstream part of the value chain includes:

- Wholesalers operating as intermediaries between the manufacturers and the installer or end customer;
- System developers who offer their services in building turnkey PV installations;
- Owners of PV installations selling their power to the grid.

Many small to medium enterprises (SMEs) are involved in these activities and most are locally organised. As such, this part of the value chain is very fragmented and difficult to track. The engineering, procurement and construction (EPC) companies involved in the development of PV systems are experienced in obtaining finance, selecting the correct components and advising on a suiTable location and system design. Most are familiar with local legal, administrative and grid connection requirements. They can guide the PV system owner through the different types of support mechanisms. EPC companies also physically install the PV system using either internal personnel or qualified subcontractors. As a result of the latest technological developments in building integrated PV (BIPV) and concentrating PV (CPV), some developers have gained specific expertise and are now specialising in these areas.

PV systems have a typical lifespan of at least 25 years. At the end of its life, the system is decommissioned and the modules are recycled. In Europe, the PV Cycle association set up a voluntary take back scheme with a large number of collection points already established in different EU countries, where PV modules are collected and sent to specialised PV recycling facilities. The recycled materials (such as glass, aluminium and semiconductor materials) can then be re-used for the production of PV or other products.

4.2.2. Cost structure and labour-intensive segments

The price of a PV system is divided between the following elements:

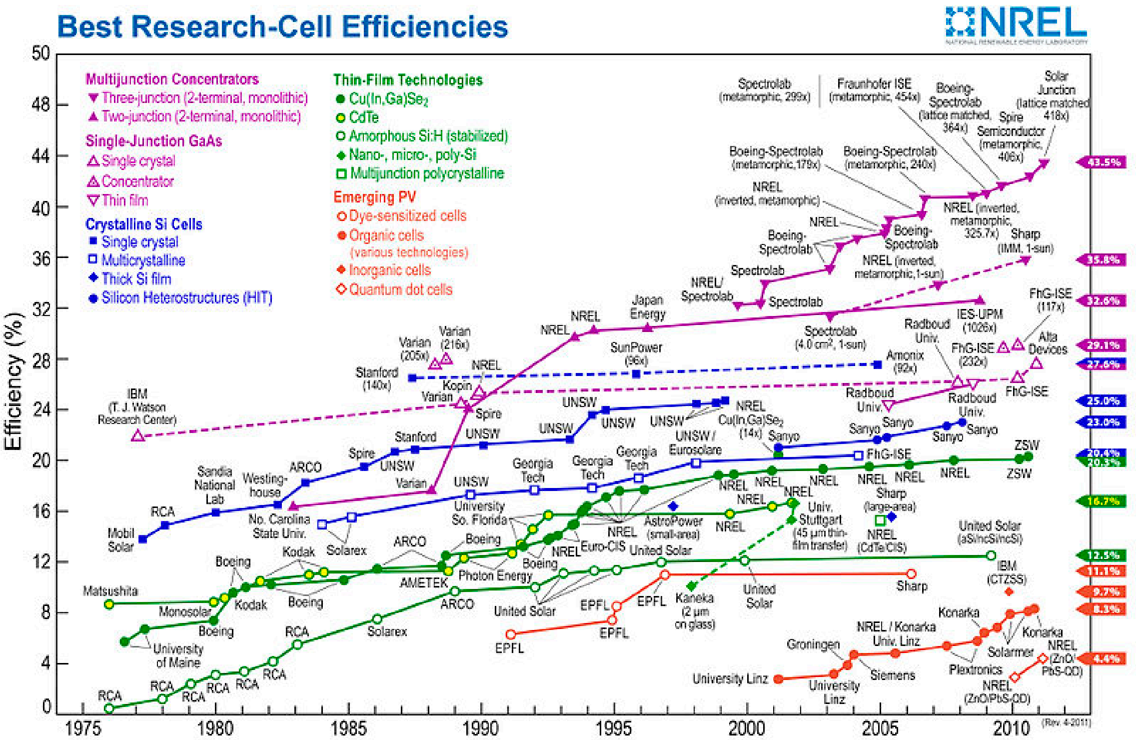
- PV modules;
- Inverter (enables connection of the system to the electricity grid);
- BOS or structural components (for mounting and connecting the modules);
- The cost of installation (including project development, administrative requirements, grid connection, planning, engineering and project management, construction and margins of the installers).

The module price reflected around 45-60% of the total installed system price in 2010, depending on the segment and the technology (figure 6). It is therefore still the most important cost driver. Additional costs must be considered for the total system lifecycle of the PV system, which nevertheless leave the breakdown of costs given in figure 6 unchanged:

- Cost of operation and maintenance services (includes margin);
- Cost of one inverter replacement for each inverter (because the lifetime of inverters is shorter than that of PV modules);
- Land cost (for large-scale ground-mounted systems only);
- Cost of take back and recycling the PV system at the end of its lifetime.

While in 2005, PV modules represented almost 75% of a PV system price for a large ground-mounted installation, nowadays they account for less than 60% of this price. For small residential systems, this may even be below 50%. The remainder includes the cost of the inverter and other balance of system elements (such as cables, mounting structures, etc.) as well as the cost and margins of wholesalers and installers, which are close to the end market. It is worth noting that the price

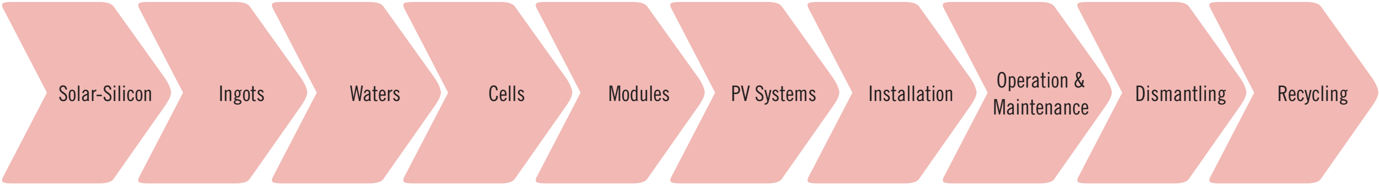
Figure 6. Best research cell efficiencies



Source: National Renewable Energy Laboratory, US Department of Energy.

Chart 4. Supply chain components for crystalline silicon and thin film technologies

VALUE CHAIN FOR CRYSTALLINE SILICON

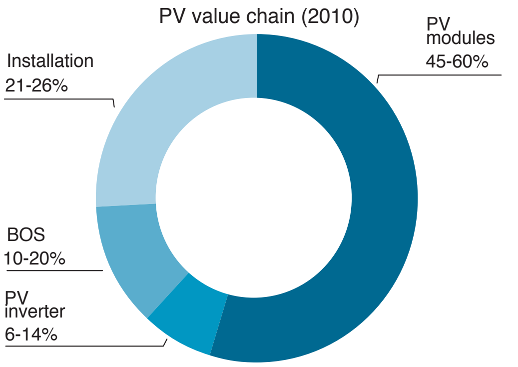


Source: PV Employment study, May 2009

VALUE CHAIN FOR THIN FILM

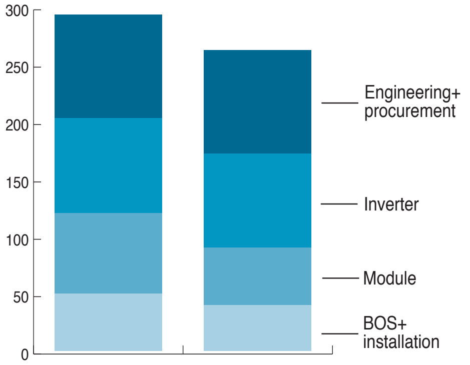
Source: PV Employment study, May 2009

Figure 7. PV value chain – average cost breakdown



Source: European Photovoltaic Industry Association unpublished data.

Figure 8. Costs of PV system elements



Source: European Photovoltaic Industry Association, EuPD, Navigant Consulting, Photon, Consulting, SolarBuzz.

of inverters has followed a similar price learning curve to that of PV modules. Prices for some BOS elements have not decreased at the same pace. The prices of the raw materials used in these elements (typically copper, steel and stainless steel) have been more volatile. Installation costs have fallen at different rates depending on the maturity of the market and the type of application. For example, some mounting structures designed for specific types of installations (such as BIPV) can be set up in half the time it takes to install a more complex version. This obviously reduces the total installation costs. Reductions in the prices of materials (such as mounting structures), cables, land use and installation account for much of the decrease in BOS costs. Another contributor to the decrease in BOS and installation-related costs is the increase in efficiency at module level. More efficient modules imply lower costs for balance of system equipment, installation-related costs and land use.

If we look at typical small rooftop (3 kWp) installations in mature markets, in only 5 years the share of the PV modules in the total system price has fallen from about 60-75% to as low as 40-60%, depending on the technology. The inverter accounts for roughly 10% of the total system price and the cost of engineering and procurement makes up about 7% of this price. The remaining costs represent the other balance of system components and the cost of installation (figure 7). **Thus, at least 50-55% of the total value of a PV system is created close to the end market, of which 80% was located in EU countries in 2010.**

Table 10 summarises the main benefits of the current EU PV market and cost structures for the EU. Among the four key segments of the supply chains, two (BOS and installation) are close to the end market, while the third (PV inverter) is a major exporter. The fourth segment (PV module) may appear to be detrimental to the EU, but although only about 15% of PV modules are assembled in the EU, more than 30% of the value is added in the EU.

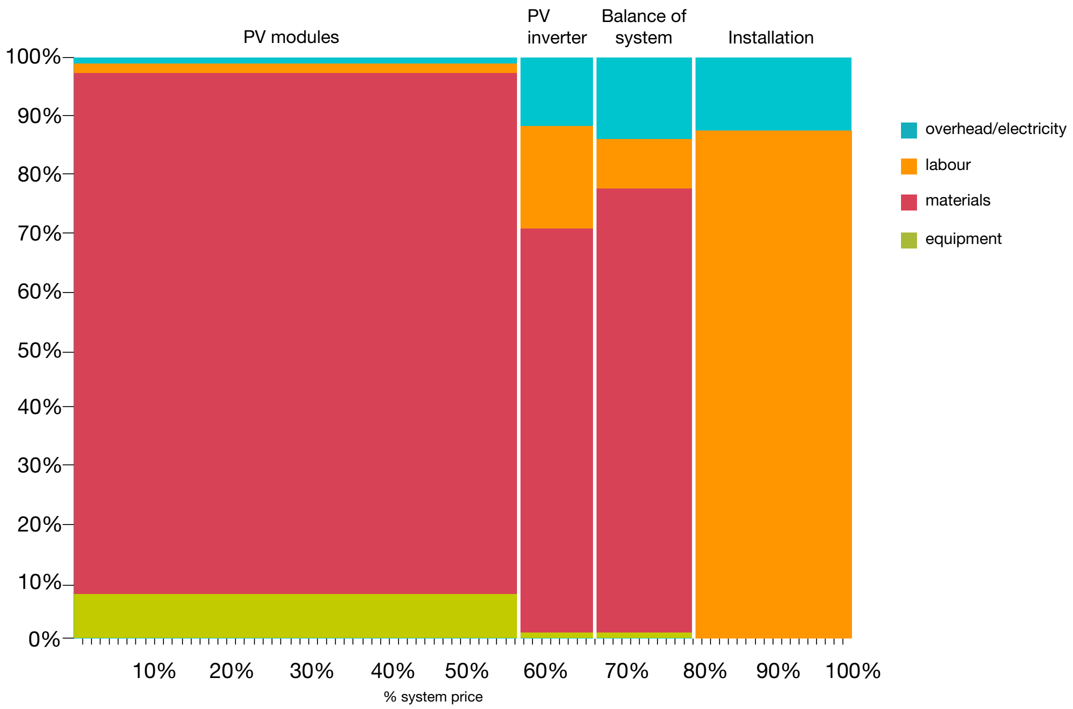
Table 10. A summary of PV cost structure and benefits for the EU

PV modules The module price reflects only 45-60% of the total system price Only 15% is assembled in Europe But >30% of the value (material, equipment, etc.) is created in Europe 8.5 billion business in Europe	**BOS** Represents 10-20% of the total system price Close to the end market 5 billion business in Europe
PV inverters The inverter price reflects 6-14% of the total system price 90% of the European production -> export to market outside Europe 4 billion business in Europe	**Installation** Represents 21-26% of the total system price Close to the end market 8.5 billion business in Europe

Source: European Photovoltaic Industry Association

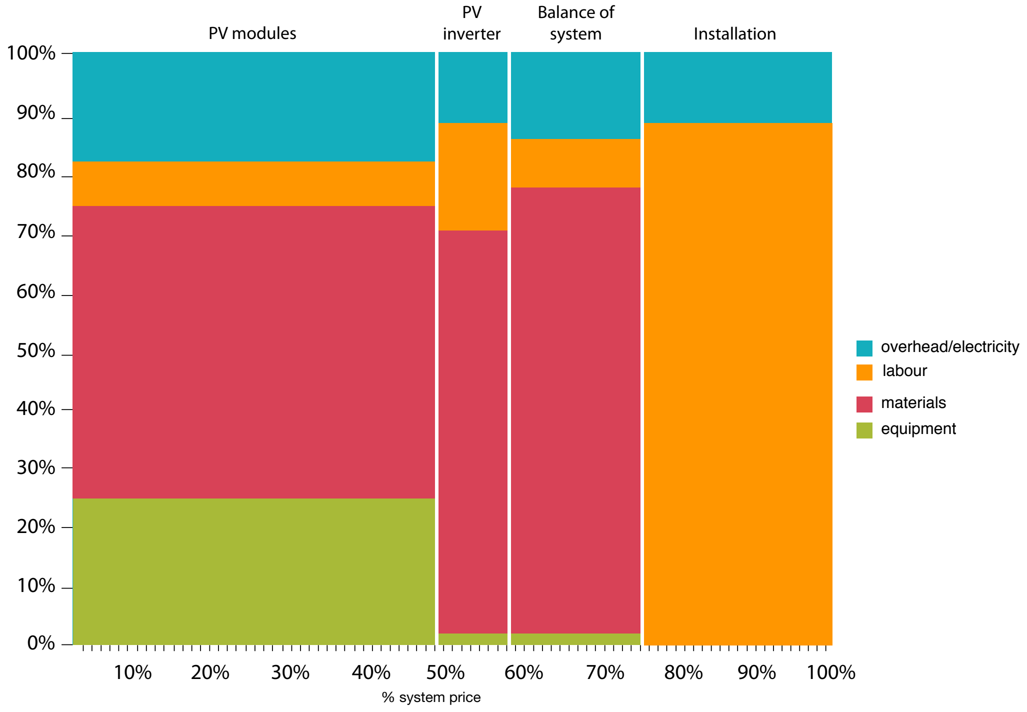
Figures 9 and 10 provide average estimates of the cost ratio of the various components (electricity, labour, material and equipment) for each of the main segments of the PV chain (cell, modules, inverter, BOS and installation). It is clear that cell and module production is very energy – and material/equipment-intensive, while BOS and inverter supply entails higher labour costs; the most labour-intensive segment is installation. Bearing in mind that EU close-to-market segments are BOS and installation, and that inverters are exported due to the high performance of EU firms (in 2010, about 80% of all PV inverters worldwide were produced in the EU), the overall prospects for job creation in the EU PV supply chain are bright. STable and sustainable PV market development can generate a large number of local jobs.

Figure 9. Marimekko graph for c-Si PV systems



Source: European Photovoltaic Industry Association unpublished data.

Figure 10. Marimekko graph for thin film PV system



Source: European Photovoltaic Industry Association unpublished data.

4.3. Foreign competition in the value chain

Only some components such as modules, cells and other electrical items can be produced outside Europe:

- **Wafers, cells and modules**: Chinese companies dominate the world production of cells and modules. In terms of wafers, the global production capacity was between 30 and 35 GW in 2010, of which more than **55% in China**. Germany accounts for more than 10% of global capacities, followed by Japan, Taiwan, Norway and the US.
  - **Crystalline-silicon cell and module capacities are now located mainly in Asia**. EPIA estimates that global c-SI cell production was around 27 to 28 GW in 2010. **Almost 50% of the capacity is located in China;** the rest is produced in **Taiwan** (over 15%), the **EU** (over 10%), **Japan** (just under 10%) and the **US** (less than 5%). Module production capacities for c-SI are estimated to have been slightly higher and could have ranged between 30 and 32 GW in 2010.
  - The global production capacity for thin film (TF) modules reached around 3.5 GW in 2010. This is likely to increase to more than 5 GW in 2011 and could reach 6 to 8.5 GW in 2012. Today, copper (gallium) indium (di)selenide modules represent about 15% of the total TF capacity, with the remainder equally distributed between cadmium telluride and silicon TF. However, by 2012, EPIA expects that each of the TF technologies will represent an equal share in terms of production capacity. While a large proportion of c-Si modules are assembled in China, most of the TF manufacturing plants are located in other parts of the world, the leaders being the **US**, the **EU**, **Japan** and **Malaysia**.
  - Inverters: 80% of world production is concentrated in Europe.
- Other electrical items: equipment, components and materials (wires, BOS, circuit breakers) may have different countries of origin.
- Structure integration includes the equipment and technologies permitting the interface between the roof and the modules. These are developed mainly in Europe.
- Installation: labour-intensive, carried out by local teams.
- Engineering: carried out locally by local teams.
- Grid connection: connection procedures differ from one country to another; they are linked to local regulations, varying from 2-4 weeks (Germany) to several months (France). They are difficult to delocalise.
- Sales and development: carried out locally by local teams.
- O&M and insurance: local teams for O&M and local insurance companies.

Modules and cells are the main parts for which international competition is heavily present. China and Taiwan have dominated module and cell production since 2007, ahead of Japan and the US. With only small quantities (less than 1 GW annually) of modules shipped and installed during 2000-2003, local markets used to be supplied by local production. From 2004 onwards, however, an increasing number of Japanese modules were imported by the EU in order to supply its rapidly growing market. The same occurred with Chinese modules from 2007 onwards. In 2010, tier 1 and 2 Chinese majors and emerging Asian producers continued to capture foreign market share, benefiting from an average 15% price discount on Japanese/Western producers, with heavy environmental costs.

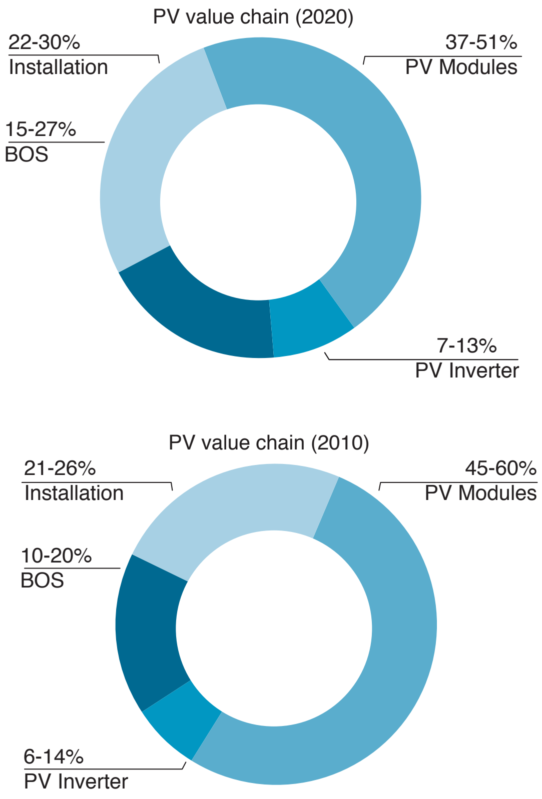
The disparity in terms of installations between the EU and the rest of the world should decrease over the next five years. On the supply side, this imbalance should progressively decline:

- The relative share of transportation in the cost of a PV module will increase, as module prices are decreasing while transport costs are evolving in the opposite direction. This should encourage production closer to the end market.
- **With continuously decreasing prices for PV modules, the share of the module in the total PV system value will further decline in the coming years (figure 10), a rising share of the valued added being captured by local providers (installation and BOS).**

4.4. Consolidating EU strengths

The most valuable PV markets are located in OECD countries, in the US and the EU in particular. The late start from Chinese firms on specific and mature PV segments (cells and modules) has not made the country a high value-added market so far. The strengths of the EU in high-tech and value-added technologies (thin film, CPV) and value chain segments (inverter, BOS) stem from its historical involvement in PV deployment through an original mix of public policies and private sector (secured) investment. Current leadership in BOS and know-how concerning value-added technologies and services (installations) would not have been possible without proactive supply chain public policies over the last 20 years in key EU member countries.

Figure 11. PV value chain, 2010 and 2020



Source: European Photovoltaic Industry Association unpublished data.

In a hypercompetitive environment in any of the value chain segments, from upstream innovation to BOS equipment provision, the emergence of new competitors such as China – publicised by the media because of its rapid and spectacular domination of almost half of a specific technology market (crystalline-silicon cells and modules) – has not occurred at EU expense so far. On the contrary, the sharp reduction in module prices caused by China's leadership in c-Si helped to narrow the gap in EU markets between PV electricity prices and grid parity. This catching up process occurred through classical price competition in non-innovative technology segments of the value chain.

The hypercompetition we observe in the PV supply chain describes much more accurately innovation and innovation deployment in second and third generation cells, where Chinese firms are not the main competitors. Risky technologies where no mass production (and related economies of scale profits) can be envisaged so far are areas where competition is harsh, but emerging country firms, and particularly Chinese ones, are not yet leaders. Hypercompetition means that there is no sustainable leadership or captive market to rely on. Yet with growing renewables (and PV) markets worldwide, any new technology is likely to find its way to the market in the near future (see the case of CPV, where France is positioning itself as a – temporary – leader).

The challenge for the EU is to consolidate its strengths (particularly on thin films and CPV) and to address its protracted weaknesses. Overall political support for PV in the EU is weak, because of limited knowledge on this issue among policy makers, risk averse behaviour towards an allegedly costly technology (when compared to other renewables), the lack of a comprehensive vision at EU level of R&D requirements and industrial needs and, finally, the fallacy of EU firms being doomed to fail because of low-cost competitors worldwide. Mass production for decades-old technologies is no longer conceivable in Europe; this is true for monocrystalline silicon cells as much as for any low-cost, low-value added technology. Education and information are greatly needed in this respect.

A serious concern could be asymmetrical gains from trade and unfair (hyper)competition. The fact that hypercompetition occurs mainly among OECD firms for high-value added, high-tech segments somehow creates a level playing field in terms of cost structures and R&D policy frameworks today. One problem could be that in exchange for importing low-cost cells and modules from other countries, EU firms would be unable to access such countries' domestic markets in a reciprocal manner. Local content requirement, restricted tender to national firms, export-driven public subsidies and technical barriers to trade are more serious concerns than price reduction in conventional PV technologies. Hastening China's signature of the WTO plurilateral Agreement on Government Procurement (GPA) would help to address such concerns.

5. CONCLUSION

In its 2005 Communication on the support of electricity from renewable energy sources, the European Commission asserted that *"the renewable energy sector has a decentralised structure, which leads to employment in the less industrialised areas as well. Unlike other jobs, these jobs cannot be "globalised" to the same extent. Even if a country were to import 100% of its renewable energy technology, a significant number of jobs would be created locally for the sale, installation and maintenance of the systems"*.

The first finding of this study is that the EC assertion is confirmed by the empirical data collected. In the two renewable value chains examined, the majority of value added and jobs are located within the EU, with so far limited entry from foreign firms into significant segments of the chains. EU workers and consumers have enjoyed the benefits of the historical involvement of some key EU firms and countries in the research, development and deployment of innovative wind and PV technologies. The original mix of public incentives, regulations, subsidies and risk-taking behaviour of private companies all result in clear EU leadership of the wind energy sector in most of the global value chain segments, and the majority of business opportunities created worldwide benefiting EU PV firms (BOS, inverter, installation).

Ongoing changes in the respective wind and PV supply chains illustrate two narratives of globalisation. In conventional competition, where early-mover firms gain an advantage over competitors through innovation and economies of scale in an oligopoly market structure, EU firms involved in the wind energy supply chain operate as *sustainable* leaders, gaining and sustaining an edge through their experience curve and captive market shares. This is also the case for foreign firms operating on old and mature technologies (mass production with increasing returns to scale in low-tech mono crystalline silicon by China, for instance). In the second narrative of globalisation, hypercompetition does not isolate sustainable leaders protected by captive markets, trade secrets or patents and economies of scale. Rapid shifts can occur in the production process at various (and increasing numbers of) stages across firms and countries depending on the marginal cost of rapidly evolving technology. Even though hypercompetition unfolding in the PV value chain is currently beneficial to EU firms and jobs (particularly in thin film, third generation PV and inverters), it does not lead to clear and sustainable EU leadership as in the case of wind energy. In this respect, the PV industry seems more fragile and policy-dependent than the wind energy sector.

Contrary to the "threat" allegedly posed by China entering conventional competition (cost advantage) on mc-Si, low-cost imported PV cells and modules seem more likely to have had a positive impact on the EU PV value chain, with a boom in PV installed capacities (leading to downstream value added and jobs) and the indirect incentive for EU firms to enter the market with alternative technologies. Declining costs of PV cells and modules should lead to a rising share of value added captured by downstream activities, whose costs are predictably stable in the EU and related non-tradable jobs worldwide. More and more value added (and related jobs) should therefore be created in Europe in the PV sector.

Even though the current competition structure in wind and PV energy value chains is beneficial to EU firms, this situation might not be stable over time. Hypercompetition could become the dominant narrative in the wind value chain (offshore) along with a progressive worldwide shift towards renewables, while barriers to entry in emerging (and booming) captive markets such as China could mean hypercompetition in the PV sector, which could turn oligopolistic and conventional, to the detriment of EU firms prevented from accessing such markets. In both cases, public policies are at stake; in the EU, through sustained incentives (price policy, technology deployment, public policy predictability and stability) and globally, by levelling the playing field in export competition and government procurement through negotiated (and updated) multilateral agreements in these two key and rather weak areas of global trade governance.

APPENDIX

Annex 1. Top 10 wind turbine manufacturers by annual market share in 2010

1. Danemark Vestas 14.8%	6. Inde Suzlon Group 6.9% (including Suzlon Energy (IN) and RePower (DE)
2. Chine Sinovel 11.1%	7.Chine Dongfang Electric 6.7%
3. États-Unis GE Wind Energy 9.6%	8. Espagne Gamesa 6.6%
4. Chine Goldwind 9.5%	9. Danemark/Allemagne Siemens Wind Power 5.9%
5. Allemagne Enercon 7.2%	10. Chine United Power 4.2%

Source: BTM Consult. Note that figures may differ between sources.

Annex 2. Major OEMs[1] per region

	Onshore	Offshore
Europe	Enercon (EU) Vestas (EU) Gamesa (EU) Nordex (EU) Siemens (EU) GE (US) Acciona (EU) Fuhrländer (EU)	Siemens (EU) Vestas (EU) Both: 95% of the market in 2010 (MW installed). GE Wind (US) Nordex (EU) RePower (EU)[123] Alstom Power (EU) Areva Wind (EU) WinWind (EU)[4] Bard (EU)
North America	GE Wind (US) Vestas (EU) Gamesa (EU) Siemens (EU)	None
Latin America Africa	Enercon (EU) Vestas (EU) Gamesa (EU) Suzlon (IN)	None
Asia-Pacific	Sinovel (CH) Goldwind (CH) Dongfang (CH) United Power (CH) Suzlon (IN)	Sinovel (CH) Goldwind (CH) Suzlon (IN)

Source: European Wind Energy Association and interviews.

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[1] Original equipment manufacturers (OEM).

Annex 3. Typical wind energy job profiles required by different types of industries

Company type	Field of activity	Main job profiles
Wind energy manufacturers	Wind turbine producers, including manufacturers of major sub-components and assembly factories.	Highly qualified chemical, electrical, mechanical & materials engineers dealing with R&D issues, product design, management and quality control of production process. Semi-skilled and non-skilled workers for the production chains. Health and safety experts. Technical staff for the O&M and repair of the wind turbines. Other supporting staff (including administrative, sales managers, marketing and accounting).
Developers	Management of all the tasks related to the development of wind farms (planning, permits, construction etc.).	Project managers (engineers, economists) to coordinate the process. Environmental engineers and other specialists to analyse the environmental impacts of wind farms. Programmers and meteorologists for wind energy forecasts and prediction models. Lawyers and economists to deal with the legal and financial aspects of project development. Other supporting staff (including administrative, sales managers, marketing and accounting).
Construction, repair and O&M	Construction of the wind farm, regular inspection and repair activities.	Technical staff for the O&M and repair of wind turbines. Electrical and civil engineers for the coordination of construction works. Health and safety experts. Specialists in the transport of heavy goods. Electricians. Technical staff specialised in wind turbine installation, including activities in cranes, fitters and nacelles. Semi-skilled and non-skilled workers for the construction process. Other supporting staff (including administrative, sales managers and accounting).
Independent power producers, utilities	Operation of the wind farm and sale of the electricity produced.	Electrical, environmental and civil engineers for the management of plants. Technical staff for the O&M of plants, if this task is not sub-contracted. Health and safety experts. Financiers, sales and marketing staff to deal with the sale of electricity. Other supporting staff (including administrative and accounting).
Consultancies, legal entities, engineering, financial institutions, insurers, R&D centres, others.	Diverse specialised activities linked to the wind energy business.	Programmers and meteorologists for the analysis of wind regimes and output forecasts. Engineers specialised in aerodynamics, computational fluid dynamics and other R&D areas. Environmental engineers. Energy policy experts. Experts in social surveys, training and communication. Financiers and economists. Lawyers specialised in energy and environmental matters. Marketing personnel, event organisers.

Source: European Wind Energy Association and authors

Annex 4. Wind turbine components and raw materials used

Wind turbine component	Raw materials used	Weight ratio/MW installed
Foundation (tower)	Concrete	76-77%
Foundation, tower, nacelle, rotor, gearBox, transformer, generator	Steel, steel plate, cast iron	19-21%
Cabling, rotor, nacelle	Aluminium	1-3%
Cabling, nacelle, generator, transformer	Copper	
Electronics	Lead	
Cast components (e.g. hub)	Nickel	
Blades	Epoxy/polyester resins	1-2%
	Glass fibre	
	Carbon fibre	
	Balsa wood	
	Foam	

Source: Authors.

Annex 5. Material requirements per MW installed

Material	T/MW
Concrete	549
Stainless steel	125/142
Iron/cast iron	14
Glass fibre	8
Epoxy resin	6
Carbon fibre	2
Copper	1
Aluminium	1
Nickel	<0.2
Balsa	<0.01

Source: Authors.

Annex 7. Investment costs (%)

	Onshore	Offshore
Turbine	70%	30-50%
Foundation	5-7%	15-25%
Installation	1-9%	1-30%
Grid connection	8-10%	15-30%
Property/Land rent	2-4%	-
Infrastructure	1-5%	-
Other	-	8%
Total	€1100-1200/kW	€2800-3000/kW

Source: European Wind Energy Association.

Annex 6. Cost structure of a typical 2 MW wind turbine installed in Europe (2006)/ onshore

INMENT	€	%
Turbine (ex works)	928	75.6
Grid connection	109	8.9
Foundation	80	6.5
Land rent	48	3.9
Electric installation	18	1.5
Consultancy	15	1.2
Financial costs	15	1.2
Road construction	11	0.9
Control system	4	0.3

Note: Calculated by the author based on selected data for European wind turbine installations.
Source: European Wind Energy Association.

Annex 8. PV system description

The key parts of a solar energy generation system are:

- Photovoltaic modules to collect sunlight;
- An inverter to transform direct current (DC) into alternating current (AC);
- A set of batteries for stand-alone PV systems;
- Support structures to turn the PV modules towards the Sun.

The system components, excluding the PV modules, are referred to as the balance of system (BOS) components.

PV cells and modules

The solar cell is the basic unit of a PV system. PV cells are generally made from either:

- crystalline silicon, sliced from ingots or castings;
- grown ribbons;
- alternative semiconductor materials deposited in thin layers on a low-cost backing (thin film).

Cells are connected to form larger units called modules. Thin sheets of EVA or PVB (resin type) are used to bind cells together and to provide weather protection. The modules are normally enclosed between a transparent cover (usually glass) and a weatherproof backing sheet (typically made from a thin polymer). Modules can be framed for extra mechanical strength and durability. Thin film modules are usually encapsulated between two sheets of glass, so a frame is not needed.

Modules can be connected to each other in series (known as an array) to increase the total voltage produced by the system. The arrays are connected in parallel to increase the system current. The power generated by PV modules varies from a few watts (typically 20 to 60 Wp) up to 300 to 350 Wp depending on module size and the technology used. Low wattage modules are typically used for stand-alone applications where power demand is generally low. Standard crystalline silicon modules contain about 60 to 72 solar cells and have a nominal power ranging from 120 to 300 Wp depending on size and efficiency. Standard thin film modules have lower nominal power (60 to 120 Wp) and their size is generally smaller. Modules can be sized according to the site where they will be placed and installed quickly. They are robust, reliable and weatherproof. Module producers usually guarantee a power output of 80% of the Wp, even after 20 to 25 years of use. Module lifetime is typically considered to be 25 years, although it can easily exceed 30 years.

Annex 9. PV technologies

PV technologies are classified as first, second or third generation. First generation technology is the basic crystalline silicon (c-Si). Second generation includes thin film technologies, while third generation includes concentrator photovoltaics, organics, and other technologies that have not yet been commercialised on a large scale.

Crystalline silicon technology

Crystalline silicon cells are made from thin slices (wafers) cut from a single crystal or a block of silicon. The type of crystalline cell produced depends on how the wafers are made. The main types of crystalline cells are:

- Monocrystalline (mc-Si);
- Polycrystalline or multicrystalline (pc-Si);
- Ribbon and sheet-defined film growth (ribbon/sheet c-Si).

The single crystal method provides higher efficiency, and therefore higher power generation. Crystalline silicon is the most common and mature technology, representing about 85% of the market today. Cells turn between 14 and 22% of the sunlight that reaches them into electricity. For c-Si modules, efficiency ranges between 12 and 19%. Individual solar cells range from 1 to 15 cm across (0.4 to 6 inches). However, the most common cells are 12.7 x 12.7 cm (5 x 5 inches) or 15 x 15 cm (6 x 6 inches) and produce 3 to 4.5 W – a very small amount of power. A standard c-Si module is made up of about 60 to 72 solar cells and has a nominal power ranging from 120 to 300 Wp depending on size and efficiency. The typical module size is 1.4 to 1.7 m^2 although larger modules are also manufactured (up to 2.5 m^2). These are typically used for building integrated PV applications.

Thin films

Thin film modules are made by depositing extremely thin layers of photosensitive material onto to a low-cost backing such as glass, stainless steel or plastic. Once the deposited material is attached to the backing, it is laser-cut into multiple thin cells. Thin film modules are normally enclosed between two layers of glass and are frameless. If the photosensitive material has been deposited on a thin plastic film, the module is flexible. This creates opportunities to integrate solar power generation into the fabric of a building or end-consumer applications.

Four types of thin film modules are commercially available:

1. Amorphous silicon (a-Si)

The semiconductor layer is only about 1 μm thick. Amorphous silicon can absorb more sunlight than c-Si structures. However, a lower flow of electrons is generated, which leads to very large substrates (up to 5.7 m^2 on glass), reducing in turn manufacturing costs. An increasing number of companies are developing light, flexible a-Si modules that are perfectly suiTable for flat and curved industrial roofs.

2. Multi-junction thin silicon film (a-Si/μc-Si)

This consists of an a-Si cell with additional layers of a-Si and micro-crystalline silicon (μc-Si)

applied to the substrate. The μc-Si layer absorbs more light from the red and near-infrared part of the light spectrum. This increases efficiency by up to 10%. The thickness of the μc-Si layer is in the order of 3 μm, making the cells thicker but also more stable. The current maximum substrate size for this technology is 1.4 m^2, which avoids instability.

3. Cadmium telluride (CdTe)

CdTe thin films cost less to manufacture and have a module efficiency of up to 11%. This makes it the most economical thin film technology currently available. The two main raw materials are cadmium and tellurium. Cadmium is a by-product of zinc mining. Tellurium is a by-product of copper processing. It is produced in far lower quantities than cadmium. Availability in the long-term may depend on whether the copper industry can optimise extraction, refining and recycling yields.

4. Copper, indium, gallium, (di)selenide/ (di) sulphide (CIGS) and copper, indium, (di) selenide/(di)sulphide (CIS)

CIGS and CIS offer the highest efficiencies of all thin film technologies. Efficiencies of 20% have been achieved in the laboratory, close to the levels achieved with c-Si cells. The manufacturing process is more complex and less standardised than for other types of cells.

This tends to increase manufacturing costs. Current module efficiencies are in the range of 7 to 12%. There are no long-term availability issues for selenium and gallium. Indium is available in limited quantities but there are no signs of a forthcoming shortage. While there is a lot of indium in tin and tungsten ores, extracting it could drive the prices higher. A number of industries compete for indium resources: the liquid crystal display (LCD) industry currently accounts for 85% of demand. It is highly likely that indium prices will remain high in the coming years. Typical module power ranges from 60 to 350 W depending on the substrate size and efficiency. There is no common industry agreement on optimal module size for thin film technologies. As a result, they vary from 0.6 to 1.0 m^2 for CIGS and CdTe, and from 1.4 to 5.7 m^2 for silicon-based thin films. Very large modules are of great interest to the building sector as they offer efficiencies in terms of handling and price.

Annex 10. PV – region, total shipments, leading firms and shipments

REGION	TOTAL SHIPMENTS (MWp)	LEADING FIRMS	THEIR SHIPMENTS
Europe	397	Q-cells	128
		Schott Solar	63
		+ 8 other firms	
Japan	635	Sharp	292
		Kyocera	109
		Mitsubishi	77
		Snayo	96
		+ 1 other firm	
United States	119	7 firms	
China	116	Suntech Power	63
		+ 2 other firms: Hingbo Solar Cell and Shenzhen Topray	
Rest of world	133	4 firms, including 2 developing nations firms: Motech (Taiwan) and BP Solar (India)	

Source: Greenpeace and European Photovoltaic Industry Association, *Solar Generation* (April 2006).

Annex 11. Direct and indirect occupations in the PV industry

Direct occupations

Jobs created in the production, installation and maintenance of PV projects, solar silicon, ingots and wafer producers:

- Solar cell and module producers
- Photovoltaic equipment producers
- Balance of systems producers and suppliers
- System integrators and assemblers
- Suppliers and distributors
- Installers
- Service and repair technicians (operations, maintenance and demounting)
- Site surveyors and assessors
- Managers and entrepreneurs
- Sales representatives, marketers and estimators
- Engineers
- Project developers
- Designers
- Researchers and scientists
- Trainers and educators

Indirect occupations

Jobs created in the production of all inputs into the photovoltaic industry on all intermediate levels of production:

- Architects and planners
- Builders
- Commodity suppliers, chemical industry, machinery industry, glass industry, electronic device producers, plastics and polymer industries, equipment suppliers, wire and cable makers, and steel, aluminium, copper, and other metal industries
- Trade and skilled labourers, roofers, electricians, heating, ventilation, and air conditioning installers
- Energy exchange pool, energy authorities and electric power utility employees
- Financers and investors
- Media and publishers
- Policy and programme managers
- Employees in local and regional municipalities

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The Muddle over Green Race

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