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The industrial dynamics of water innovation: A comparison between China and Europe

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Abstract: The expansion of the green economy agenda has increased the attention on eco-innovations globally, with issues related to water stress identified as one of the major bottlenecks for sustainable economic growth. Using evolutionary economic theory, this study investigates the industrial dynamics of the water sector, comparing China and Europe using patent data. This comparison feeds into the "catching up" literature, addressing the challenges of the "green economy" agenda in different regions in various stages of development. We highlight the neglected micro-dynamics of water innovation, investigating the roles of different innovators in the development of water technological trajectories, with a special focus on water innovations closely related to climate change adaptation and mitigation technologies. Public water innovators (universities) were found to be more important in China than in Europe. Similarities were also identified between Europe and China; big companies were found to be the main innovative leaders with no substantial changes documented over the timeframe investigated. Overall, the finding implies a rapid Chinese technological catching up of water technologies in the last three decades, where our research has pointed towards the role of redirection of Chinese policies with a stronger focus on sustainable development. The analysis, overall, sheds light on the state and nature of the globalizing green growth agenda.

Keywords: Water innovation; Eco-innovation; Evolutionary Economics; Knowledge Institutions; Business demography

1. Introduction

Water is designated as a "critical resource" and rising problems with securing water supply and handling of wastewater is turning the water agenda into an area of high corporate and policy attention (OECD, 2011a). According to Organization for Cooperation and Development (OECD) (2012), the total water demand is projected to increase by 55% by 2050 due to growing demand from both manufacturing (+400%) and domestic sectors (+130%). Moreover, this threatens the capacity to find a balance between the right to extract and use water that impacts land-use development as well as water for ecosystems, the latter also being a competitor, in a sense, for this resource (Acreman, 2001). This scenario is likely to increase the competition for this resource among domestic users, industry, and agriculture (OECD, 2012b).

In recent years, the importance of eco-innovation in enabling the transition towards global sustainable development is increasingly being recognized; compare the topical UN sustainable development goals (2012). Thus, eco-innovation has become an important contributor to not only environmental benefits, but also economic development (Kemp & Pearson, 2007; Kemp, 2009; Andersen, 2008; O'Brien et al., 2014). Still more countries are developing strategies for green growth, and while this trend started in the developed economies, many emerging economies like China (since 2005) are increasingly committed to the green growth agenda (OECD, 2011b, 2009; United Nations Environmental Program (UNEP), 2011).

Evolutionary economic theory emphasizes not only the dynamic nature but also the time and space dependencies of economic development(Dosi, 1982; Dosi et al., 1988; Nelson and Sidney, 1982). Within this framework, innovation systems theory argues that despite rising globalization, countries and regions tend to display different innovation patterns (Cooke et al., 1997; Lundvall, 2007; Schaaper, 2009). The objective of this paper is to compare the water innovation patterns of China and Europe. We seek specifically to identify and characterize the key water innovators[1] in both Europe (an early mover on eco-innovation) and China (a late mover on eco-innovation). In comparing Europe and China, we feed into the emerging "green catching up" literature e.g.,(Peuckert, 2013). In this context, the first research question is whether China presents different innovative patterns in the water sector as compared to Europe. Our related hypothesis is that China may perform differently from Europe due to a historic high degree of central planning in the Chinese economy.

Europe has been a pioneer in eco-innovation (Eco-Innovation Observatory (EIO), 2011; United Nations Environmental Program (UNEP), 2011), specially within the water sector (OECD, 2014). In contrast, China has only recently taken on the eco-innovation agenda on a large scale, having developed the necessary policies supporting eco-innovation more widely (Cai and Zhou, 2014; Weng et al., 2015) and noticeably stricter water policies. These policies have come about as the country is facing urgent water challenges, many of which are similar to those Europe has already faced or is still facing but often the magnitude and scale is much larger (China Water Risk, 2017). China's innovation system is influenced by its historically communist political structure. Accordingly, it has very strong planning powers and long-sighted strategizing but weaker market mechanisms, although the latter have been considerably strengthened in recent years (Guan and Yam, 2015; Schaaper, 2009). The strong planning powers may be favorable to environmental policy-making once given priority and particular water innovations that entail strong planning elements due to large investments in infrastructure. A related second hypothesis is that China may become a fast mover on eco-innovation, especially water innovation. This is, however, likely to depend on the degree to which China is willing and

[1] This paper is not able to capture the role of utility companies within the innovative dynamics and also non-patentable innovations that may take place, especially in rural areas.

able to develop its own water companies and related capabilities as opposed to relying on imported goods and services (Deng, 2009).

In order to compare the innovation performance and dynamics of Europe and China, we investigate the micro-dynamics of water innovations underlying the National Innovation System (NIS) co-evolutionary processes, so far little analyzed. Based on evolutionary economics theory, we focus in this paper on identifying who the water innovators are, based on patent data, analyzing the similarities and dissimilarities between Europe and China. We distinguish between private water companies and public knowledge institutions. We further investigate different innovators' role in the development of different water technological trajectories, identifying whether or not companies and knowledge institutions present similar innovative patterns in Europe and China. A secondary research question is hence to inquire into the possible specific characteristics of water innovation. Related to this, the third hypothesis is that public water innovators are more important in China than in Europe. The related hypothesis is that the role of public planning and involvement in water innovation will affect the direction of water innovation by prioritizing specific areas.

In order to develop this analysis, we have divided the water innovations into different categories. We recognize that different taxonomies of eco-innovation exist (Andersen, 2008; Horbach, 2005; Horbach et al., 2005; Kemp and Arundel, 1998) but have departed from them, instead proposing speculatively, to test a new taxonomy specifically directed at water innovations. We suggest two distinct groups: The first group contains those water innovations that are strongly eco-innovative or "green," i.e., innovations that are closely related to climate change adaptations and mitigation technologies[2]. The second grouping contains water innovations defined simply as "general water innovations" and are mainly related to innovations covering water distribution, water supply, and sewage distribution and treatment, that is, more traditional water solutions. We use patent classifications to situate specific water innovations in the different groups.

In a sector that has huge environmental importance, and where all water innovations historically and statistically have been considered as eco-innovations, that is, as a part of the "environmental sector"' (e.g., Eurostat, OECD), this is quite controversial, in part because the suggested delimitation between the green and not-green water innovations is not straightforward. Nonetheless, we investigate whether this division may shed light on important dynamics with respect to the application of detailed patent analysis methodology.

2. Understanding eco-innovation and water innovation

[2] More precisely: Water recovery and recycling technologies, pollution control technologies, water saving technologies, and greywater technologies as defined in the patent classifications we shall return to.

Evolutionary economic studies of eco-innovation have generally been rising in recent years see e.g., (Foxon et al., 2005; Freeman, 1996; Geels and Kemp, 2007; Munch and Munch Andersen, 2012). Water-related studies grounded in this framework are still limited. Case studies do exist, however, with respect to particularly urban water technologies, e.g., from The Netherlands (Hegger et al., 2011; Krozer et al., 2010). Hegger et al. (2011) analyze the consequences of the shifts in relationships among the actors within the water innovation system, focusing particularly on sustainable water supply. Binz et al. (2012) discuss the leapfrogging possibilities in the wastewater treatment in China. Mvulirwenande et al. (2013) focus on the rising knowledge capacity within the water sector as a core element for technological development on the supply side.Peuckert (2013) looks into the strengths and weaknesses of the urban water innovation system, focusing on new types of water innovations as a window of opportunity for newly industrialized countries. We also identified studies analyzing the eco-efficiency of the water sector (Levidow et al., 2016, 2014)), specifically, aspects of water governance (e.g., (Lobina, 2012), and knowledge and capacity development in the water sector e.g.,(De Montalvo and Alaerts, 2013). These studies highlight the need for national strategies to strengthen water-related capacities and capabilities in a coherent, coordinated way, and through a comprehensive and harmonized approach.

Most relevant for this paper, the OECD (2014) report on climate change adaptation identifies global water innovation trends, investigating patents in water-related climate change adaptation technologies. The report summarizes both, the innovation activity as well as the importance of international technology transfer and policies that facilitate the broad diffusion of these technologies in water-stressed countries since 70% of water innovation worldwide happens in countries with low or moderate vulnerability towards water scarcity. It also presents analysis of the relative technology advantage (RTA), showing not only European Countries like Germany, the United Kingdom, and France but also the USA as highly specialized in water technologies, suggesting a market opportunity for these countries to export water technologies. The report stresses that although innovation activity in water-related technologies has been increasing over the last two decades, this growth has been disproportionately concentrated on supply-side technologies, which highlights the lack of attention to handling water after the consumer phase. While the OECD analysis provides insights about important macro global trends of water innovation, little is still known about the micro–dynamics and trajectory developments in water innovations. A micro dynamic analysis can provide insights about the process of knowledge creation, and how the water technologies are developed and diffused. This could help the development of effective policies and direction of investments in the sector.

The water sector is highly consolidated with stagnated employment over the last decade (European Commission, 2016). Being highly capital-intensive with long investment cycles, the water sector has exhibited a low innovation rate with relatively low research and development expenditure, focusing on process and incremental innovation rather than radical innovation(European Commission, 2016). These characteristics are typical of sectors that are traditional and/or infrastructural, which implies that the sector lacks innovation dynamism (EIP WATER, 2014). The water sector has been characterized as an extremely variable sector with many technology domains[3] and levels of intervention (Wehn and Montalvo, 2015). There is, however, a high potential for innovation that has currently not been exploited; the reason can be discerned as the inherent difficulty in increasing investments in the water sector as they are linked with public budgets that can suffer from the influence of economic fluctuations and government instabilities (European Commission, 2016).

Traditional water technologies may have exceeded the limit of sustainable water provision in many places (Peuckert, 2013). Therefore, an opportunity for different innovative solutions that will incorporate environmental concerns, such as climate change and pollution, might be available. This means that countries could catch-up through directed technological change, becoming lead markets for sustainable water technologies and further reinforcing their economic development processes (Walz, 2010). The increasing importance of innovation for catching-up processes has been emphasized by many recent studies e.g., (Fagerberg and Godinho, 2004; Fagerberg and Srholec, 2008; Freeman and Soete, 1997) and a few for green catching–up e.g.,(Peuckert, 2013; Walz, 2010). The critical water situation in many countries including China may lead to a window of opportunity for an internationally emerging market of eco-innovative technologies.

The concept of eco-innovation can be intrinsically connected with policies of "green" growth, symbolizing a rising synergy between environment and innovation policies earlier seen as opposites (Andersen, 2006; Kemp and Andersen, 2004; OECD, 2009). According to OECD, environmental innovations encompass those innovations that generate positive externalities on the environment and can include processes, products, and organizational innovations. Nevertheless, there is still no established and widely accepted consensus for the definition of environmental innovation (Andersen, 2008; Kemp, 2010). In addition, the concept of eco-innovation gets even more imprecise when it comes to the water sector, that is, the strong environmental aspect of handling water makes the attempt to define eco-innovations in the sector difficult.

In an attempt to overcome this issue, this paper proposes to focus not on whether a specific water innovation can generate a positive impact on the environment or not but instead on the scope of their impact. Traditionally, water technologies are divided into two groups: the supply side technologies and the demand side technologies(OECD, 2014). These can be further separated into more specific groupings, such as water extraction technologies, water distribution technologies, and water usage technologies where the latter can again be subdivided to specify urban (domestic) water usage, industrial water usage, and

[3] Water related technologies are present in all industries: in domestic usage, agricultural usage, and energy generation.

agricultural water usage. After consumption, further divisions can be made of technologies related to water treatment (waste water) and/or related waste products (i.e., sludge). The problem with this typical “supply side” and “demand side” technological point of view is that we might be missing important aspects in the water innovation dynamics. The inherent problem in this division is that it marginalizes water technologies from the consumption point in the cycle (OECD, 2014). The biggest consequence of this marginalization is the detachment from the drivers to innovate in water, the green innovation policies, and environmental regulations.

In Table 1, we present a taxonomy of water innovations that we, as mentioned, have divided into two categories. The first category is closely linked with the European Patent Office (EPO) patent classification’s environmental technologies list (the “Y” category)[4]. This category represents technologies that are strongly eco-innovative (Veefkind et al., 2012). In this group we encompass those technologies that deal with climate change adaptation and mitigation, that is, related to water conservation, water availability, water recovery, recycling, and water pollution control technologies.

The second category is based on selected International Patent Classifications (IPC) codes covering all “traditional” water technologies[5]. This group encompasses innovations predominantly related to water supply, water distribution, treatment, and sewage, that is, not directly focusing on mitigating or adapting to climate change, promoting water recycling, or new approaches to improve water efficiency (e.g., traditional irrigation technologies *versus* drip irrigation technologies with emphasis on water saving). The main objective of this division is to investigate whether more accurate innovative patterns in the water sector can be captured. The goal is to capture not only the overall evolution of water innovation trends but also the possible rise of technological trajectories of more (eco)innovative water technologies related to climate change, pollution mitigation, water efficiency, and water recycling. These technologies will be closely related to environmental and eco-innovation policies. This division enables the identification of water innovations that may have close links to the greening of the innovation system.

Table 1: Water technologies per sub-category

Water technologies highly eco-innovative	**General water technologies**
Climate Change Adaptation Technologies	Irrigation technologies
- Water Conservation	Water collection and distribution
- Water availability	Public water supply Extraction and Treatment
- Water recovery and recycle	Ground water extraction

[4] For more information about EPO environmental technology classification see: https://www.epo.org/news-issues/issues/classification/classification.html and (Veefkind et al., 2012)
[5] This study doesn´t cover the field of water for energy or river basins management due to restrictions of research scope; water energy nexus and river basis management are areas with distinct characteristics that require a specific individual analysis.

Climate Change mitigation Technologies - Wastewater treatment **Water Pollution Control Technologies** - Water and wastewater treatment - Fertilizers from wastewater - Oil spill cleanup	Surface water extraction Desalination Water treatment Sewage Industrial waste water treatment Sanitation Domestic water use Sanitary Equipment Storm and rain water extraction

Source: Own elaboration based on OECD (2014), EPO, and WIPO.

Regulations and other policies are well recognized as key drivers of eco-innovation (Foxon and Kemp, 2008; Gregersen and Johnson, 2009; Porter and Linde, 1995). Water innovation has been driven by environmental policies and more recently innovation policies in the form of eco-innovation policies. Eco-innovation development has increasingly come into the spotlight of European innovation policies. In Europe, the investment in eco-innovation represented 69% of all investment in innovation in the water sector in 2010 (EIO, 2011). According to the EIO (2011), not less than 45% of the European companies documented at least one eco-innovation, suggesting that the "eco-innovation market" is becoming mature in Europe. In contrast, China has only recently taken on the environmental and eco-innovation agenda on a large scale, but has developed very strong new water policies as well as policies for eco-innovation in general (see Figure 1 for an overview).

The Chinese government has increasingly emphasized the importance and priority given to innovation as a driver of economic and social development (Gu et al., 2016). The importance of water-related innovations has been realized by Chinese policy makers in recent years and is evident by its increasing inclusion in recent policy and research agendas (Figure 1). Figure 1 provides an overview (timeline) of a number of key environmental regulations, innovations policy, and eco-innovation policy/initiatives for both regions.

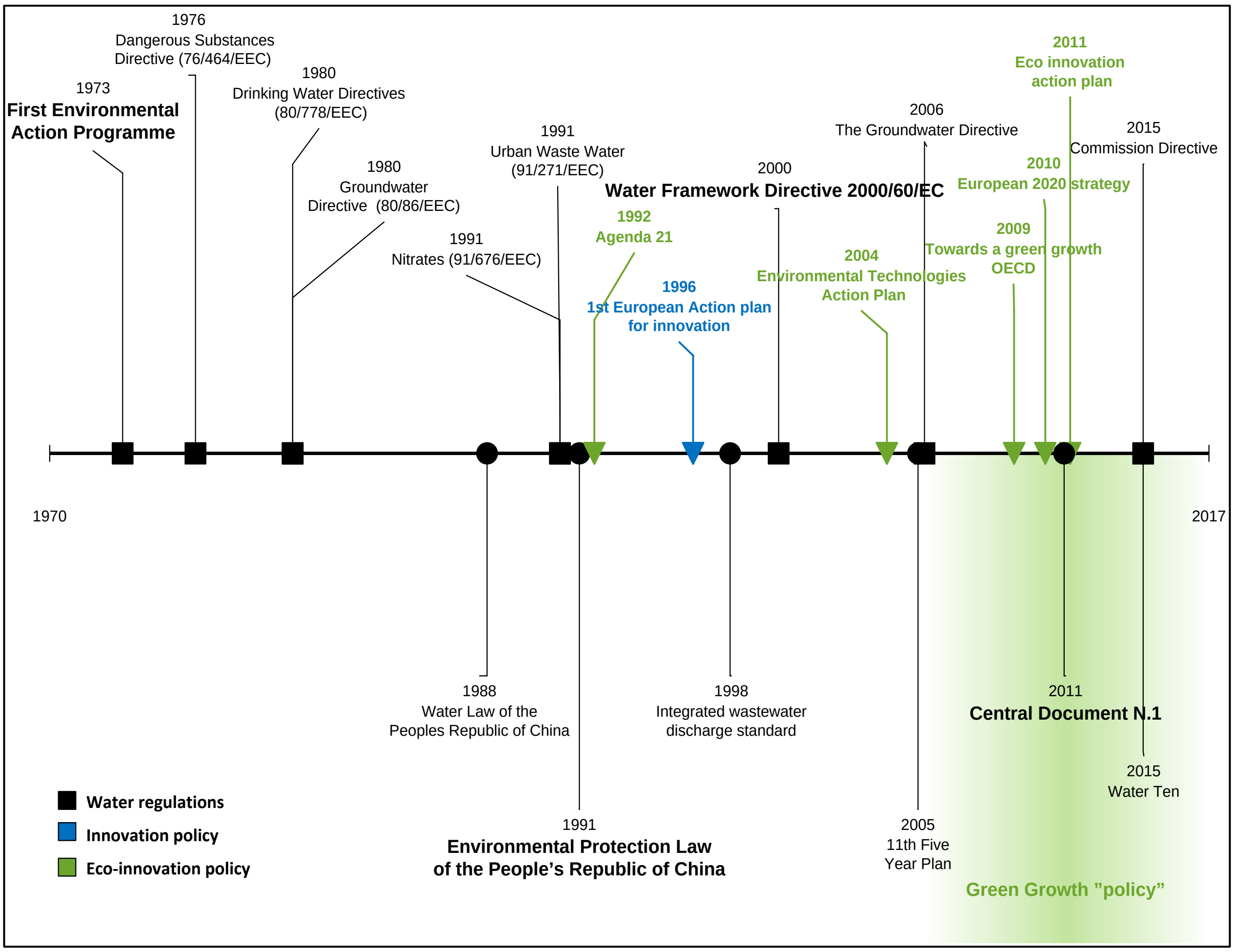


Figure 1: Key water policies and eco-innovation policies.

It shows the introduction of more general eco-innovation policies and beginning of the green economy agenda from the mid-1990s (depicted with green arrows) as pioneered in Europe and picked up later by China in 2005. We can observe different "waves" of environmental regulations and innovation policy. The first wave of European water regulations, marked by the First Environmental Action Programme (1973), established environmental quality standards (Directives). The second European wave is marked by the introduction of the Nitrates and the Urban Waste Directives in 1991. The first Chinese water regulation wave started just prior to this, in 1988, and is marked by the establishment of their first standards for water quality, somewhat following the European trend.

In between the second and third European water regulation waves, came major events marking the beginning of the green economy agenda such as Agenda 21 from the Earth summit in 1992 that led to the implementation of a global action plan for sustainable development, a milestone in the sustainable development discussion. The third European wave milestone is the European Water Framework Directive (WFD) in 2000, a major revision to the overall concept of EU water policy (Jager et al., 2016). The second wave of Chinese water regulations started with the 11th Five Year Plan in 2005. This period marked the beginning of their transition to the green economy agenda, with strong policies and discussions on both circular economy and "green catching up." Probably one of the biggest milestones of this wave is the Central Document No. 1 on water policies, which was developed similarly to the European WFD. Overall, Figure 1 depicts Europe as an early mover compared to China (late mover), especially regarding eco-innovation policy.

Over the last two decades China has been moving towards a new development stage, from imitation-driven (Fu et al., 2013) to self/indigenous innovation-driven development. Furthermore, the government has invested heavily in promotion of sustainable energy sources and environmental technologies. We can observe the first consequences of the recent Chinese regulations, especially in the area of pollution control. For example, it can be seen that the rate of growth of water pollution abatement and control technologies in China has increased four-fold during the period 1999-2004, in contrast to developments elsewhere, with patent counts for most of the other large innovating countries actually decreasing in this period (OECD, 2014). Nevertheless, the greening of Chinese economy will still require fundamental changes in socio-technical regimes and system innovation (Gu et al., 2016).

3. Methods and data

3.1. Data Collection

This study concentrates on the quantitative analysis of water innovations with a strong focus on eco-innovations. Portrayal of this type of analysis can be challenging both methodologically and in terms of data (Fukasaku, 2005; Andersen, 2010; Oltra, Kemp, and De Vries, 2010). We use patents as a *proxy* for (eco) innovative output (Oltra et al., 2010), as they are available at a highly disaggregated level in terms of actor and technology types. This makes it possible to distinguish innovations within the water sector according to specific technologies, whereas R&D investments cannot be easily disaggregated (OECD, 2014). There is an extensive debate about the use of patents to analyze innovation activities, see among others (Pavitt, 1988, 1985; Smith, 2006). Eco-innovation analysis based on patents is still only emerging but rising nonetheless due to recent classification of "environmental technologies" carried out by the European Patent Office (Veefkind et al., 2012).

We used the regional patent data base (REGPAT) -2016 OECD[6] patent database to develop the analysis about water innovation. The advantage of this database is that it is possible to link the patent data with other regionalized data. REGPAT avoids the problem of low quality patents, since it contains only granted patents filed at the EPO, US Patent Office (USPTO) and World Intellectual Property Organization (WIPO). This database allows us to link each patent with the assignee code, name, location, and address. For this study, we use patent grants as a *proxy* for innovative activities. As first step, the innovative activities are measured by selecting the IPC related to water innovations[7] for the period covering 1979-2014. The extracted dataset contains over 41,000 patents (see Table 2).

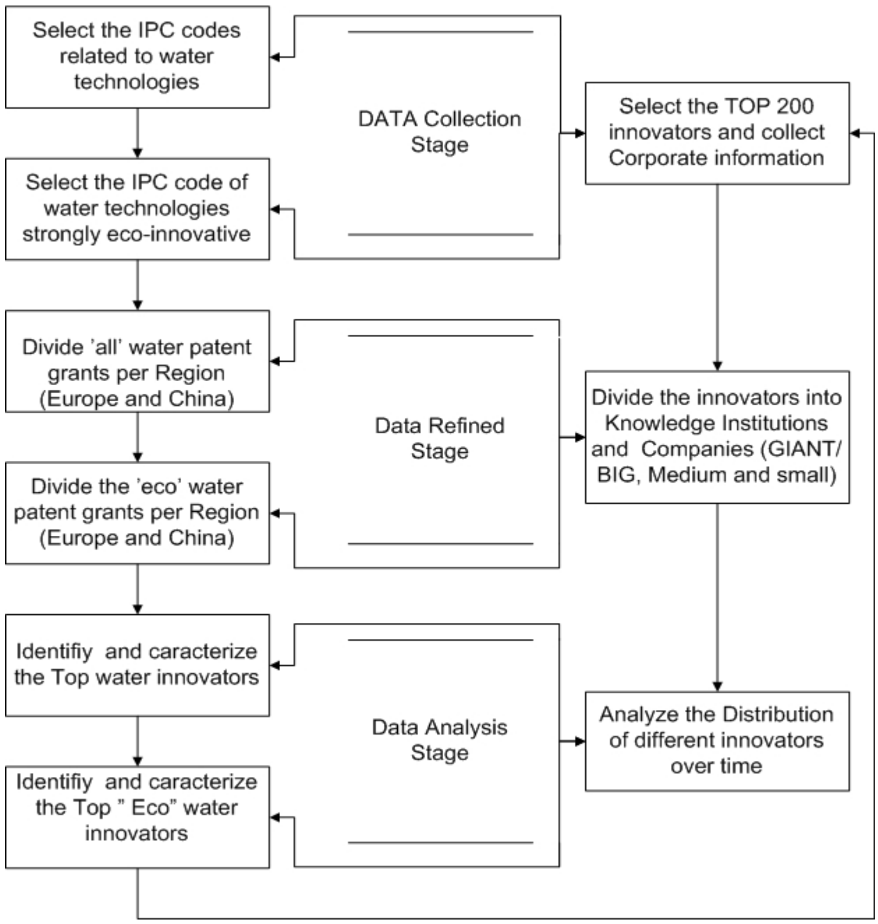
Table 2: Descriptive data.

Type of water patent extracted	Number of extracted patents
Water patents	41,699
European water patents	26,997
European "eco-innovation" water patents	5,753
Chinese water patents	14,702
Chinese "eco-innovation" water patents	1,631

Second, we divided the patents into different water technology categories based on the standard IPC codes and the EPO environmental technologies classification, class "Y." This classification includes

[7] Patents with multiple inventors are counted fractionally. For example, if two assignees from different countries are involved in an invention, then each country is counted as one-half.
[8] For more details regarding the selected IPC codes, please check Appendix 1.

environmental patents that might not have been included had the selection of patents been via keywords (see examples for selection of patents via keywords, e.g., Frenken, Hekkert, and Godfroij, 2004). The "Y" category is mostly used to select the eco-innovation patents, including water technologies related to pollution control, water savings, climate change adaptation, and/or climate change mitigation. The complete list of IPC codes is given in Appendix 1, and the complete list of IPC codes divided according to the technology categories and "eco-innovation" categories is listed in Appendices 2 and 3, respectively. Figure 2 provides an overview of the work flow, that is, methods applied in the paper.



1 **Figure 2: Work flow.**

Next, we selected the top ten water innovators for both taxonomic categories in both regions (i.e., general water innovations and water eco-innovations) based on the count of patent filings and analyzed the evolution of these water innovators over time[8]. This division enables the identification of not only the top water innovators across the entire water sector but also the top innovators within water eco-innovation. Furthermore, we categorized the innovators into knowledge institutions and companies according to their

[9] We checked for co-patenting information to identify any cooperation processes existing between companies and/or knowledge institutions and counted them fractionally.

size classification, that is, giant/big, medium, and small, based on the Orbis database linked with the personal ID of each top innovator for both Europe and China. This division allowed us to analyze the micro-dynamics of the sector, identifying how the different companies' and knowledge institutions' innovative activities evolved over time. Additionally, we used the environmental policy stringency index developed by OECD (see Figure 3) as a *proxy* for the government capacity to drive eco-innovation via regulation and innovation policy to enable an analysis of the role of central planning of the Chinese government in targeting problems and centralizing solutions. The environmental policy stringency index is a composite index approach incorporating market-based policies (taxes, trading schemes certificates) and non-market policies (R&D subsidies and environmental standards). This paper focuses on the analysis of water innovations in both Europe and China over time. In order to better understand its innovative dynamic, the paper tests whether the evolution of patenting activities of Chinese public innovators is related to the evolution of regulations related to water and green growth.

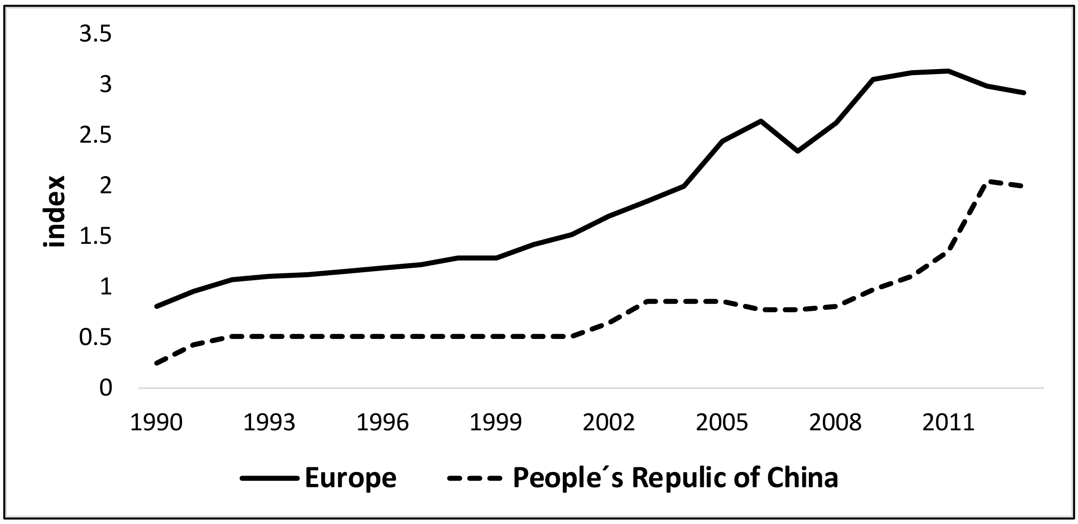


Figure 3: Evolution of the environmental policy stringency index (OECD) for Europe (solid line) and China (dashed line).

3.2. Data treatment

The paper first examines the composition of patents in terms of type of innovators, that is, distinguishing private innovators (companies) from public innovators (knowledge institutions), to determine whether China and Europe have a similar or different composition of actors leading the water innovations and water eco-innovations. This analysis tests whether the public water innovators are more important in China than in Europe with respect to patent filings of eco-innovations. Secondly, we explored the water eco-innovation patents as a function of the environmental policy index for Europe, European knowledge institutions, European Companies, China, Chinese knowledge institutions, and Chinese companies in order to analyze the evolution of patents according to the changes in the environmental policy stringency index over time. Then, using the environmental policy stringency index as a *proxy* for the effect of environment regulations, we performed a one-way ANOVA test using the policy index as a control column to test if Chinese knowledge institutions behave according to the evolution of the environmental policy index. To support the analysis, two linear regressions were developed to test if the role of public planning and public involvement in water innovation will affect the direction of water innovation, prioritizing specific areas. Additionally, a Spearman correlation test was performed to test whether the Chinese knowledge institutions present a strong correlation with the environmental policy index, as well as linear regression. Finally, we performed a Mann-Whitney Rank Sum Test to check if China presents a different trend from Europe.

Table 3: Descriptive data (used in the linear regressions).

	Mean	Std. Dev	Std. Error
China	30.971	33.716	5.699
Chinese Companies	19.371	24.959	4.219
Chinese knowledge Institutions	11.600	11.445	1.934
China policy index	0.541	0.524	0.0885
Europe	1031.276	411.407	69.541
European Companies	1030.400	410.516	69.390
European Knowledge Institution	0.876	2.097	0.355
Europe policy index	1.284	1.101	0.186

4. Analysis and discussion

Figure 4 shows the distribution of water innovation patent grants in China (A) and Europe (C) according to the innovator categories described above (i.e., companies' size [giant/big, medium, and small] and knowledge institutions), as well as specifically for eco-water innovation patent grants in China (B) and Europe (D). The analysis suggests that, in general, innovation within the water sector is carried out predominantly by the big companies in both regions. Big companies, also representing the top 20% of the innovative companies, are responsible for 61.5% and 49% of all water patent grants in Europe and China, respectively. This result is in line with what was stated by European Commission (2016) regarding the characteristics of the water sector, being a strongly infrastructure-oriented sector with almost monopolistic characteristics. It is also in line with the OECD (2014) highlighting that the innovative leadership in water has been historically concentrated in the same countries (in Europe mostly Germany, France, and the UK, which are represented by big companies such as Veolia).

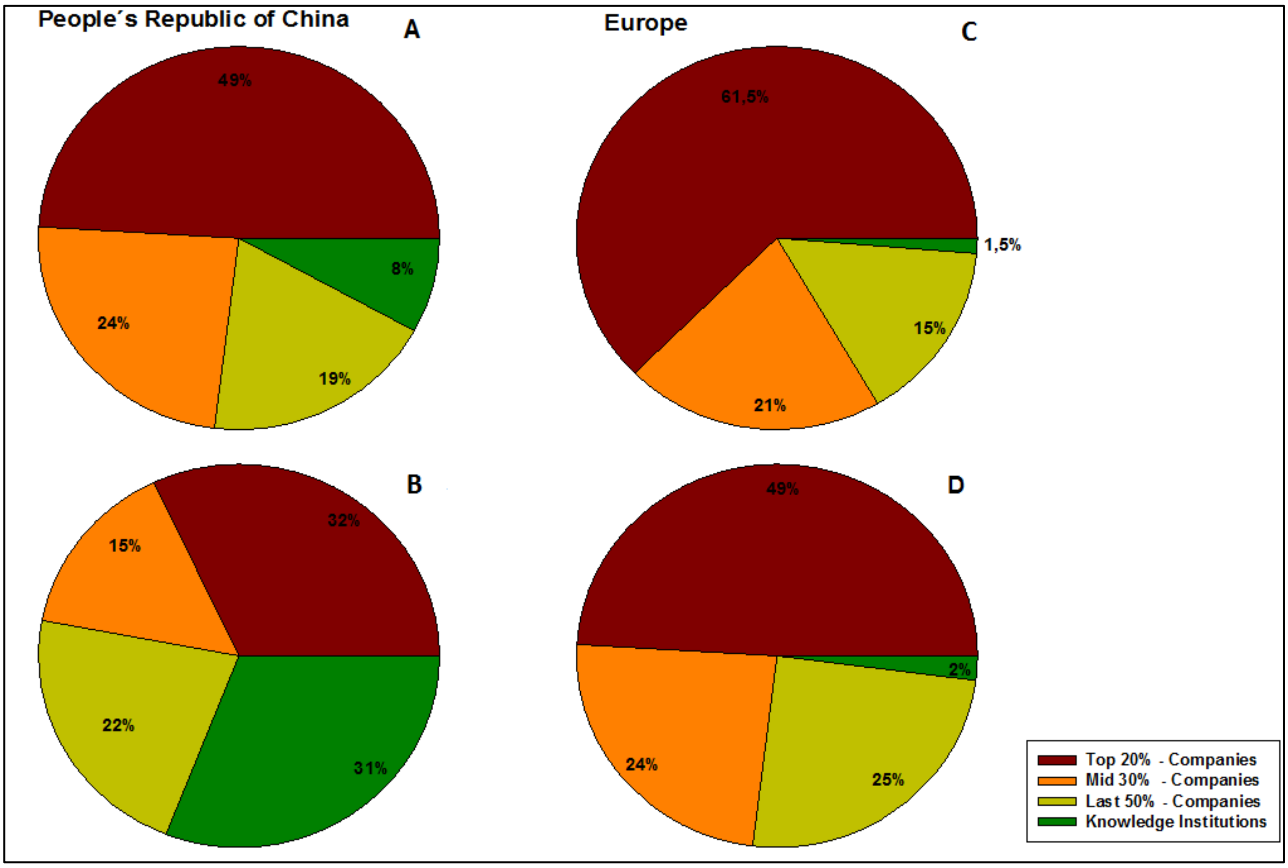


Figure 4: Distribution of companies and knowledge institutions per number of patent filings of all water innovations in China (A) and Europe (C), and water eco-innovations in China (B) and Europe (D), the sum of all years.

The results differ when it comes to the distribution of water (eco)innovation patent grants (Figure 3C, D). The Chinese universities are responsible for 31% of all eco-innovations within the water sector compared to only 2% in Europe, leading to the conclusion that public water innovators play a larger role in China than in Europe according to patent filings in eco-innovation. This result might be a consequence of recent strengthening of water regulations and innovation policies, especially the 5th Five Year Plan and the Central Document No. 1, as discussed previously in Section 2. This is reflected again by the characteristics seen with the knowledge institutions, where China has 8% of patents compared to 1.5% in Europe. This may reflect the influence of the Chinese government; over the past two decades the role of the government has been relatively straightforward—providing infrastructure to complement private investment and allowing open trade and investment policies that encourage technological catch-up.

The European dataset presents a similar distribution of water companies and knowledge institutions when we compare water innovations *versus* eco-innovations. This finding implies that the dynamics of water eco-innovation in Europe is similar to all water innovation, and the "eco-innovation market" is more mature in Europe than in China. This result is in agreement with the OECD water innovation analysis report stating that the level of specialization in water technologies in Europe is higher than in China. In fact, European countries are among the world's top 10 innovative leaders in the water sector (e.g., Germany, the UK, and France) with an Relative Technological Advantage (RTA) higher than the average, especially for technologies that are strongly eco-innovative (OECD, 2014). However, it might be that the influence of knowledge institutions in Europe, especially universities, is hard to document via the patent method used in this study. It could be, for example, that European universities are more likely to partner with European end-users such as companies in the development of (water eco) innovations via large strategic innovation projects, where the companies then take the responsibility of pursuing any potential patents arising from the collaboration, potentially also as spin-off companies. The relevance of the relationship between companies and universities has been widely emphasized in the literature (Cohen et al., 2003; Nelson, 1993; Nelson and Rosenberg, 1993) . Moreover, the difference documented in this study may also reflect that Europe is further developed according to the green economy agenda and/or the patenting activities of the region are better aligned in general with the long-term environmental and eco-innovation policies previously discussed in Section 2.

In order to verify the influence of water regulations on the evolution of patenting activities in China and Europe, we analyzed water eco-innovations as a function of the environmental policy index (see Figure 5). This figure shows the evolution of water eco-innovation patents as a function of the environmental policy stringency index. In general, it can be seen that China performs differently from Europe indicating that European patenting activities display a steady evolution over time that is more in line with the environmental policy, whereas China reflects a changing pattern with respect to the nature of patenting activities.

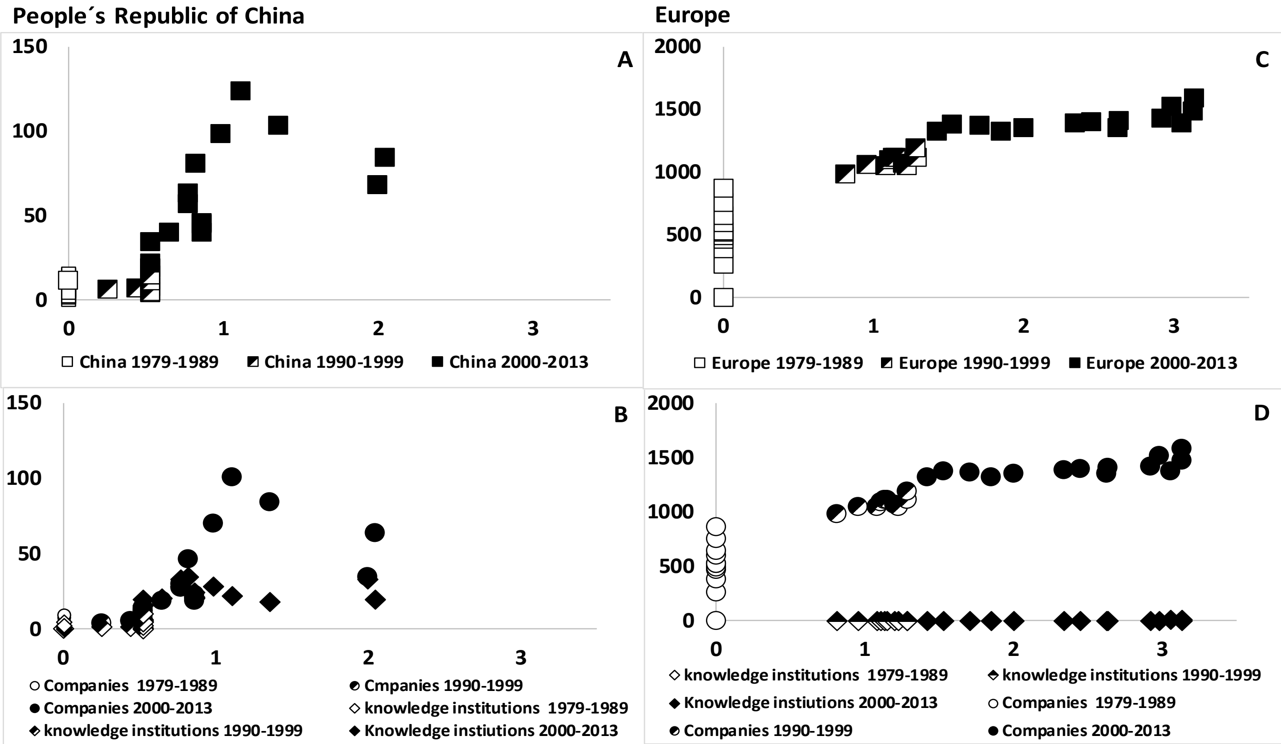


Figure 5: Evolution of water eco-innovation patents over policy index for China (A), Chinese Knowledge institutions and Companies (B), Europe (C), and European Knowledge institutions and Companies (D). Each color represents a specific decade: the period of 1979-1989 is shown by the white symbols, the period of 1990-1999 is shown by the half-white/half-black symbols, and the period of 2000-2014 is shown in black.

Specifically, Figure 5A shows the results for China, where it can be observed that the rise of water eco-innovation in China takes place from the 1990s, reflecting a faster growth from 2000 onwards with a drop in 2013 and 2014, respectively. This fast growth corresponds to a concurrent increase in the environmental policy index (over time), which in China reflects the beginning of the water regulations in 1988 starting with the Water Law of the People´s Republic of China. We observe that in the early years the Chinese patents are not very aligned with environmental policy, but as time progresses the trend indicates they are getting more aligned. Figure 5B presents the same data but separated according to patents filed by Chinese knowledge institutions (represented by diamonds) and those by Chinese companies (circles). We can observe that despite the fact the water companies have more patents in total, the policy index affects the evolution of patents from knowledge institutions more than the level of patents from Chinese companies (even though the policy has an overall positive effect on both patenting activities). We performed a linear regression (see detailed information in Tables A5 and A6 in the Appendix) to confirm if the policy index has a stronger impact on the Chinese knowledge institutions than on the Chinese companies. The results confirmed that an increase in the policy index affects the Chinese knowledge institutions more clearly than the Chinese companies.

Figure 5C shows the results for Europe where it can be observed that the development of eco-innovation closely follows the trend of the environmental policy index. It confirms that the development of eco-innovation in the European water sector has been aligned with the development of green strategies for a longer timeframe. Notably, since the water regulations in the region precede environmental policy index data availability, we cannot capture this relationship before the 1990s despite that Europe's environmental regulations began in 1973 with its first milestone—The Environmental Action Programme (compare Figure 1). These results are in line with the discussion in Section 2 with Europe being the first mover on the green economy agenda, developing water regulations since 1973 onwards, whereas China has its first water regulation milestone in 1989. Figure 5D again presents the same data as in Figure 5C, separating European knowledge institutions (represented by diamonds) from European companies (circles). Here it can be seen that the overall European trend is being led by the European companies, which present the same general European trend. Despite the fact that European knowledge institutions do not represent a significant part of water eco-innovation patenting activities, this might again reflect that the level of interaction between private and public innovators is higher in Europe, as discussed previously.

In general, Figures 5A and B show that China´s innovation dynamics is constantly changing. This is also reflected in the water sector where recent policies may have had a strong impact on the direction of technological development within the Chinese water innovation system. It should be noted that the effects of the latest policies may not yet be captured within the available timeframe. We can also observe that the development of water eco-innovations by Chinese knowledge institutions might become more aligned with the environmental policy index than those developed by Chinese companies, at least according to their patenting activities (see Figure 5B). A one-way ANOVA test was therefore performed to check if the Chinese knowledge institutions' and Chinese companies' patenting activities are more likely to progress according to the policy index (see detailed results in Table A4). The results confirmed that the Chinese knowledge institutions are more likely to progress according to the environmental regulations than the Chinese companies. It additionally confirms the results from the linear regressions. Thus, we can state that the recent investments of the Chinese government within eco-innovation have been reflected by the important role played by the Chinese knowledge institutions, as evidenced by their patenting of water-eco innovations.

The central nature of the Chinese Government may have an impact on how the country is supporting eco-innovation, meaning that ultimately the government is the major eco-innovator driver via the implementation of regulations and investments. China has already signaled that they want to become one of the leaders in eco-innovation, having established new regulations and stricter policies to enforce the transition to a circular economy (see Figure 1, Section 2) This result is in line with the discussion about policy as a major (eco) innovation driver(Foxon and Kemp, 2008; Gregersen and Johnson, 2009; Porter and Linde, 1995). This result also confirms our hypothesis that China may perform differently from Europe due to historic high degree of central planning in the Chinese economy, promoting the development of (eco) innovation in the country.

Additionally, it is important to analyze the distribution among companies and universities over time and also the evolution of number of patent grants in the water sector. Figure 6 shows the moving average (3 years) of water eco-innovations according to patent filing data both in Europe and China while separating both water companies and knowledge institutions.

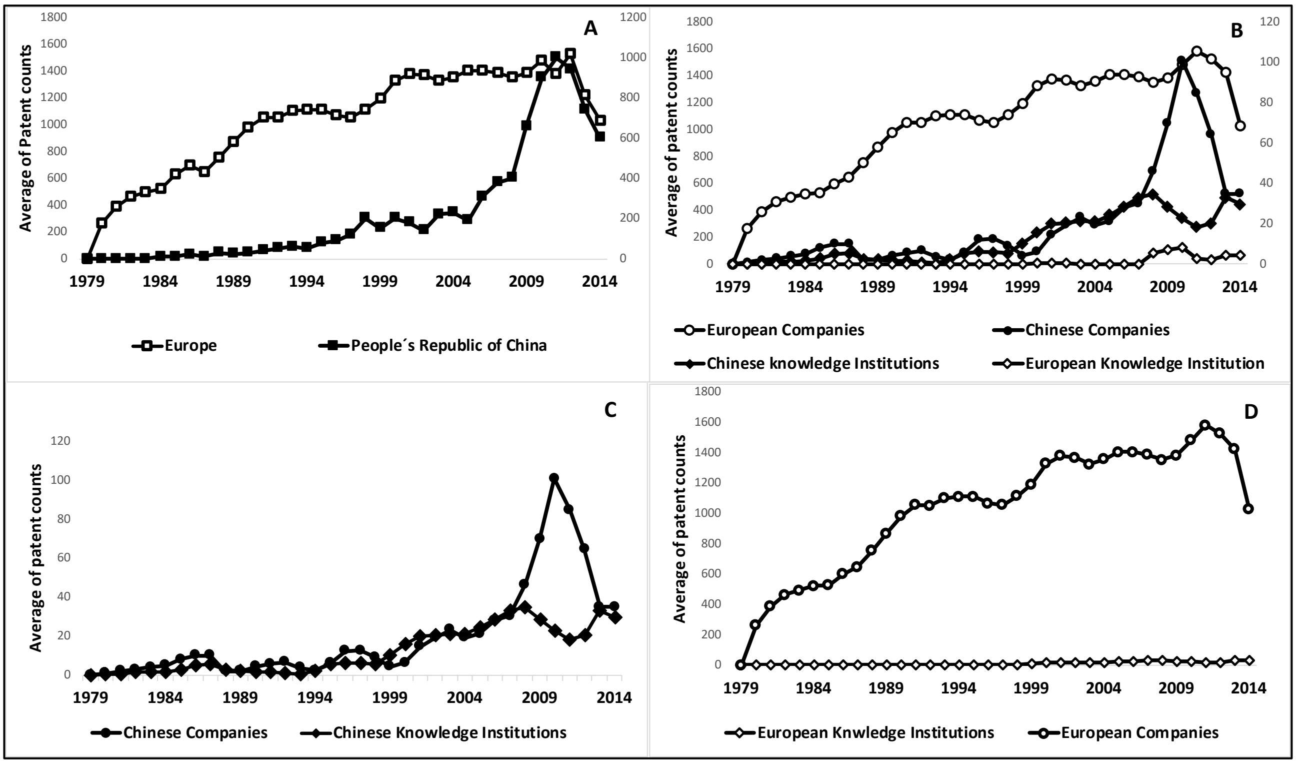


Figure 6: Moving average (3 years) patent indicating the evolution of water eco-innovators for Europe (solid line with white squares) and China (solid line with black squares) (A), both companies and knowledge institutions in Europe and China (B), and for specifically Chinese companies (solid lines with black circles) and knowledge institutions (solid lines with black diamonds) (C), and European companies (solid lines with white circles) and knowledge institutions (solid line with white diamonds) over time (1979–2014).

It can be seen that Europe (solid line with white squares) reflects a steady growth of water eco-innovation patents since 1979 whereas China (solid line with black squares) only recently (from 2006 onwards) presents a significant growth of the same type of patents, indicating a clear difference between the analyzed regions. This was additionally confirmed by the Mann-Whitney Rank Sum Test (see Appendix Table A7), indicating that Europe and China performed with different trends over time. Specifically, Europe shows an early and relatively stable rise in water innovations that starts from the 1990s, that is, the same period when environmental policies really took off in developed economies. We have one of the most important policy milestones in sustainability development—Agenda 21 (1992), the action plan towards a sustainable development (see Figure 1, Section 2). This result thus confirms our hypothesis that China is indeed a late mover as compared to Europe. China shows a long gestation period with very limited water innovation activity, beginning with some activity in the 1990s but starting to move faster only after 2005 and then quickly catching up with Europe. The year of 2005 marks the rapid growth of Chinese patent grants and also the implementation of important Chinese environmental policies such as the central government's 11^{th} 5 Year Plan.

Taken together, these results demonstrate the important role of public institutions in promoting innovation development in the water sector. This result further confirms our hypothesis that the role of public planning and involvement in water innovation will affect the direction of water innovation by prioritizing specific areas. It is also in line with Gu et al. (2016) who discussed that as a consequence of government efforts, many environment-related industries are increasingly becoming new growth sources. The findings also show how vulnerable the sector is to external economic shocks; we can observe a huge drop in patenting activities after 2009 when we had the subprime crises that affected the global economy, even though there were strong environmental policies promoting eco-innovation after that period. This result is in line with what was discussed by European Commission (2016) who suggested that investments in the water sector are linked with local budgets that can suffer from the influence of economic fluctuations. Overall, the results point to the fact that China may soon become a fast mover on water innovation. However, the impact of the latest re-direction of water policies cannot be captured in short-term. This result is in line with the recent "green" catching up literature (Peuckert, 2013; Walz, 2010).

The sub-Figures 6 (B, C and D) show the moving average (3 years) specifically for water-related eco-innovations according to patent filing data, separated to show the trend for both water companies (solid lines with white circles for Europe and black circles for China) and knowledge institutions (solid lines with white diamonds for Europe and black diamonds for China). We can observe fast growth of water eco-innovation technologies over the past three decades. Even though the latter can be considered a late mover, it is moving fast towards the development of eco-innovation in the water sector, especially after 2000. In this context, we can consider that China is catching up very fast, as a consequence of the water regulations and policies that prioritize the development of eco-innovations. Also, we can observe that only recently, the universities represent a large part of innovators in water eco-innovation in China. It reaffirms our hypothesis that this scenario reflects the consequences of the policies and regulations related to the water sector, further elucidating the Chinese government's capacity to prioritize and direct investments to strategic areas.

In this context, we can assume that China is trying to incorporate technologies related to climate change adaptation and mitigation. This result is in line with the OECD report (2011) that shows the strong Chinese focus on developing pollution prevention and mitigation water technologies, as documented previously by the four-fold increase during 1999-2004 (OECD, 2011b). We can assume that the role of regulations via public innovators in water innovation affects the direction of water innovation in China, prioritizing innovations related to the green economy agenda. In contrast, Europe is reaching a more mature stage of eco-innovation development in general. We also identified some similarities between Europe and China with respect to the type of companies leading the innovative activities in the sector. In both cases, the big companies are the main innovative leaders and have remained so with no substantial changes over time within the core of innovators submitting patents.

Finally, we identified a fast and noticeable increase in Chinese water patents over the last three decades, although relative to European water patenting China is still at a lower level. This analysis implies a rapid but recent technological catching-up with respect to water technologies, likely caused by the marked redirection of Chinese policies into sustainable development that is clearly showing a considerable innovation effect. It is undeniable that environmental degradation has been globally identified as an area of strategic importance. Europe has developed strategies to align economic growth and sustainable development via eco-innovation over the last three decades. China, in the past decade, has invested heavily in the promotion of sustainable energy sources and environmental technologies. Water as a pressure area, representing a real challenge to growth, may constitute a window of opportunity for developing countries to perform an economic catching-up via eco-innovation development. However, the greening of the Chinese economy will still require fundamental changes in socio-technical regimes and system innovation.

5. Conclusions

The global water problems related to water pollution, water scarcity, and floods in a climate change context challenge the capacity of both developed and developing countries to sustain their economic development and growth. In this context, eco-innovations play a major role in securing sustainable economic growth. The paper has proposed to address the neglected micro-dynamics of water innovation, investigating the roles of different innovators in development of water technological trajectories. Using evolutionary economic theory, this paper has compared the water innovation dynamics of Europe and China, feeding into the green "catching-up" literature and highlighting the "green economy agenda" in different regions in various stages of development. This comparison sheds light on understanding how countries in different stages of development support water innovations and more widely eco-innovations. In order to analyze the innovation dynamics in the water sector, the paper has proposed to test a new taxonomy of water technologies that enables a more detailed analysis of green technological trajectories in the water sector. The taxonomy enables the separation and characterization of a smaller sub-group of environmental water technologies (termed "water eco-innovations") from the overall category of water technologies with the purpose of supporting the identification of water technologies that are closely related to the green economy agenda. It has been shown that the development of technologies fitting the eco-innovation classification results in a better alignment among companies and knowledge institutions in relation to respective water regulations and innovation policies. We propose therefore that the rise and diffusion of water eco-innovations can be used as a "thermometer" for measuring the greening of the water innovation system, departing from traditional water measurements targeting the growth of the entire water sector.

China and Europe were compared in the paper, the green growth agenda being regarded highly in both regions, with Europe typically characterized as a first mover and China as a late mover. The analysis identified the actors leading the development of respective "water eco-innovations" and "all water innovations." The most remarkable difference was found in the role of Chinese knowledge institutions that, along with the big companies, are leading the development of eco-innovations in the water sector within China, in contrast to Europe where the knowledge institutions play a much smaller role, and big companies are the main water eco-innovators. The paper suggested the following hypotheses, which have been confirmed: i) China performs differently from Europe due to historic high degree of central planning in the Chinese economy; ii) the public water innovators are more important in China than in Europe with respect to patent filings of eco-innovations; iii) the role of public planning and public involvement in water innovation affects the direction of water innovation by prioritizing specific areas. Since China is currently going through a process of major changes with respect to its environmental policy agenda, strongly increasing the importance of sustainable development as well as water policies within its economic development long-term strategy, it is likely they will move faster as regards water eco-innovations in the near future. However, the actual effects of this recent political change are not yet strongly evident in the patent activities.

We identified a surge in Chinese water patent filings over the last three decades implying the beginning of a technological catching up of water technologies and highlighting the redirection of Chinese policies with a stronger focus on sustainable development. We conclude that the public innovators play a larger role in China than in Europe with respect to the development of eco-innovation in the water sector. This may, though, be seen both as a result of a different institutional set up as well as a sign of less green market maturity in China relative to Europe. Clearly, the green growth dynamics differ between the two regions, which has not been documented before. The analysis presented here thus sheds light on the green catching-up agenda, demonstrating the important role of the institutional set-up for this, fitting well within an evolutionary innovation system analytical perspective.

This paper represents a first attempt to analyze the micro-innovation dynamics in the water sector, which has proven a valuable explanatory perspective, considering that existing research has been mainly macro level of single case studies. There are some limitations regarding patent analysis that have prevented a more in-depth analysis of the possible role of water utilities in water innovations as well as excluded non-patentable innovations especially in the rural areas. Moreover, a follow up analysis is required to capture the long-term effects of recent political changes in China. These results also indicate the necessity for further analysis with a focus on various socio-economic factors that may have an impact on how water technologies are developed and diffused. However, such an analysis is beyond the scope of this paper.

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Appendix

Table A1. IPC code – Water technologies.

Agricultural Domain	**Municipal and Industrial**			**Urban Domain**					**Industrial Domain**		
Irrigation technologies	**groundwater extraction**	**Surface water extraction**	**desalination**	**Water collection and distribution**	**Domestic Water use Sanitary Equipment**	**Water Treatment**	**Sanitation***	**Collecting and Distributing Storm and Rain water**	**Domestic and public water supply Extraction & Treatment**	**Industrial Waste water Treatment**	**Sewege**
A01G 25/02	E03B 3/06	E03B 3/04	C02F 103/08	E03B*	A47K 1*	B63J 4/00	E03D*	E03B 3/02	E03B 1/02	B01D	E03F *
A01G 25/09	E03B 3/34	E03B 3/36	B63J 1/00	E03C*	A47K 3*	C02F 1*	A47K 1*	E03B 3/03	E03B 1/04	B01D 67/00	B63J 4/00
A01G 25/06	E03B 11/14	E03B 9		not	A47K 4*	C02F 3*	A47K 3*			B01D 71/00	
A01G 25/16		E03B 3/28		E03B 3/02	A47K 11*	C02F 5*	A47K 4*			B63J 1/00	
A01G 27/00		E03B 3/38		E03B 3/03		C02F 9*	A47K 11*			B63J 4/00	
A01G 27/02				E03B 3/04		C02F 11*				C02F 103*	
A01G 27/04				E03B 3/36		C02F 103*				not	
A01G 27/06				E03B 9		not				C02F 103/08	
				E03B 3/28		C02F 103/08				C02F 103/16	
				E03B 3/38						C02F 103/18	
										C02F 103/20	
										C02F 103/22	
										C02F 103/24	
										C02F 103/26	
										C02F 103/28	
										C02F 103/30	
										C02F 103/32	
										C02F 103/34	
										C02F 103/36	
										C02F 103/38	
										C02F 103/40	
										C02F 103/42	

										C02F 103/44	
										C05F 7/02	
										C05F 7/04	

Table A2. IPC codes - Water eco-innovations.

	WATER POLLUTION ABATEMENT		CLIMATE CHANGE ADAPTATION TECHNOLOGIES				
efficiency	**water and wastewater treatment**	**wastewater treatment or waste management**	**water conservation (indoors)**	**water conservation (outdoor)**	**water distribution**	**water availability**	**water storage**
Y02B 30/12	B63J4	Y02W 10*	F16K21/06-12	A01G 25/02	F17D5/02 and E03	E03B 5	E03B 11
Y02B 30/18	C02F		F16K21/12	A01G 25/06	F16L55/16 and E03	E03B 3/06-26	
Y02B 30/566	C09K3/32		F16K 21/16	A01G 25/16	G01M 3/08 or	E03B 3/26	
Y02B 40/46	E03C1/12		F16K 21/20	C12N15/8273	G01M 3/14 or		
	E03F		F16L 55/07	Y02P 60/122	G01M 3/18 or		
Y02B 40/56	C05F7		E03C 1/084	Y02P 60/141	G01M 3/22 or		
	E02B15/04-10		E03D 3/12	Y02P 60/524	G01M 3/28 and E03		
	B63B35/32		E03D 1/14				
			A47K 11/12				
			A47K 11/02				
			E03D13/007				
			E03D5/016				
			E03B1/041				
			Y02B 40/46				
			Y02B 40/56				
			A01G 25/02				
			A01G 25/06				
			A01G 25/16				

			C12N15/8273				

Table A3. IPC code – Water technologies per technological category.

Traditional water technologies			
Irrigation technologies	Public water supply Extraction and Treatment	Sewage	Industrial waste water treatment
Ground water extraction	Desalination	Storm and rain water extraction	Sanitation
Surface water extraction	Water treatment	Domestic water use Sanitary Equipment	Water collection and distribution
Climate change adaptation technologies			
Water Conservation	Water availability	Water recovery and recycle	
Climate change mitigation technologies			
Wastewater treatment			
Water pollution control technologies			
Water and wastewater treatment	Fertilizers from wastewater	Oil spill cleanup	

Table A4. ANOVA TEST.

ANOVA summary					
F	22.01				
P value	< 0.0001				
P value summary	****				
Are differences among means statistically significant? (P < 0.05)	Yes				
R square	0.3794				
Brown-Forsythe test					
F (DFn, DFd)	18.71 (2, 72)				
P value	< 0.0001				
P value summary	****				
Significantly different standard deviations? (P < 0.05)	Yes				
Bartlett's test					
Bartlett's statistic (corrected)	223.9				
P value	< 0.0001				
P value summary	****				
Significantly different standard deviations? (P < 0.05)	Yes				
ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Treatment (between columns)	10823	2	5412	F (2, 72) = 22.01	P < 0.0001
Residual (within columns)	17702	72	245.9		
Total	28525	74			
Data summary					
Number of treatments (columns)	3				
Number of values (total)	75				

Dunnett's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
China policy vs. Chinese Companies	-25.72	-35.73 to -15.71	Yes	****
China policy vs. Chinese Knowledge Institutions	-0.4800	-10.49 to 9.527	No	ns

Table A5. linear regression Chinese Companies vs policy index.

Linear Regression Friday, January 19, 2018, 6:05:32 PM

Data source: Data 1 in Notebook2

Chinese Companies = 2.891 + (16.103 * Col 2)

N = 35 Missing Observations = 1

R = 0.737 Rsqr = 0.543 Adj Rsqr = 0.529

Standard Error of Estimate = 7.851

	Coefficient	**Std. Error**	**t**	**P**
Constant	2.891	1.922	1.504	0.142
Policy Index	16.103	2.570	6.265	<0.001

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	1	2419.336	2419.336	39.253	<0.001
Residual	33	2033.953	61.635		
Total	34	4453.289	130.979		

Normality Test (Shapiro-Wilk) Passed (P = 0.387)

Constant Variance Test: Failed (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

Table A6. Linear regression Chinese knowledge institutions vs policy index.

Linear Regression Friday, January 19, 2018, 6:07:58 PM

Data source: Data 1 in data with statistical analysis

Chinese knowledge institutions = 3.549 + (50.704 * Col 2)

N = 35 Missing Observations = 2

R = 0.788 Rsqr = 0.621 Adj Rsqr = 0.609

Standard Error of Estimate = 21.079

	Coefficient	Std. Error	t	P
Constant	3.549	5.160	0.688	0.496
Policy Index	50.704	6.901	7.347	<0.001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	23987.442	23987.442	53.984	<0.001
Residual	33	14663.308	444.343		
Total	34	38650.749	1136.787		

Normality Test (Shapiro-Wilk) Failed (P = 0.026)

Constant Variance Test: Failed (P = <0.001)

Power of performed test with alpha = 0.050: 1.000

TABLE A7- t-test comparing the patenting behaviour from Europe and China

Mann-Whitney Rank Sum Test

Group	N	Missing	Median	25%	75%
China (People's republic of)	36	0	15.167	5.667	45.167
Europe	36	0	1105.333	701.000	1372.833

Mann-Whitney U Statistic= 35.500

$T = 701.500$ n(small)= 36 n(big)= 36 ($P = <0.001$)

Table A8. Correlation: knowledge institutions vs policy index.

Spearman Rank Order Correlation Friday, January 19, 2018, 6:08:45 PM

Data source: Data 1 in data with statistical analysis

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	Chinese knowledge institutions
Policy Index	0.806
	0.000000200
	35

Chinese Knowledge Institutions

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.