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An Evolutionary Approach to Water Innovation: Comparing the Water Innovation Systems in China and Europe

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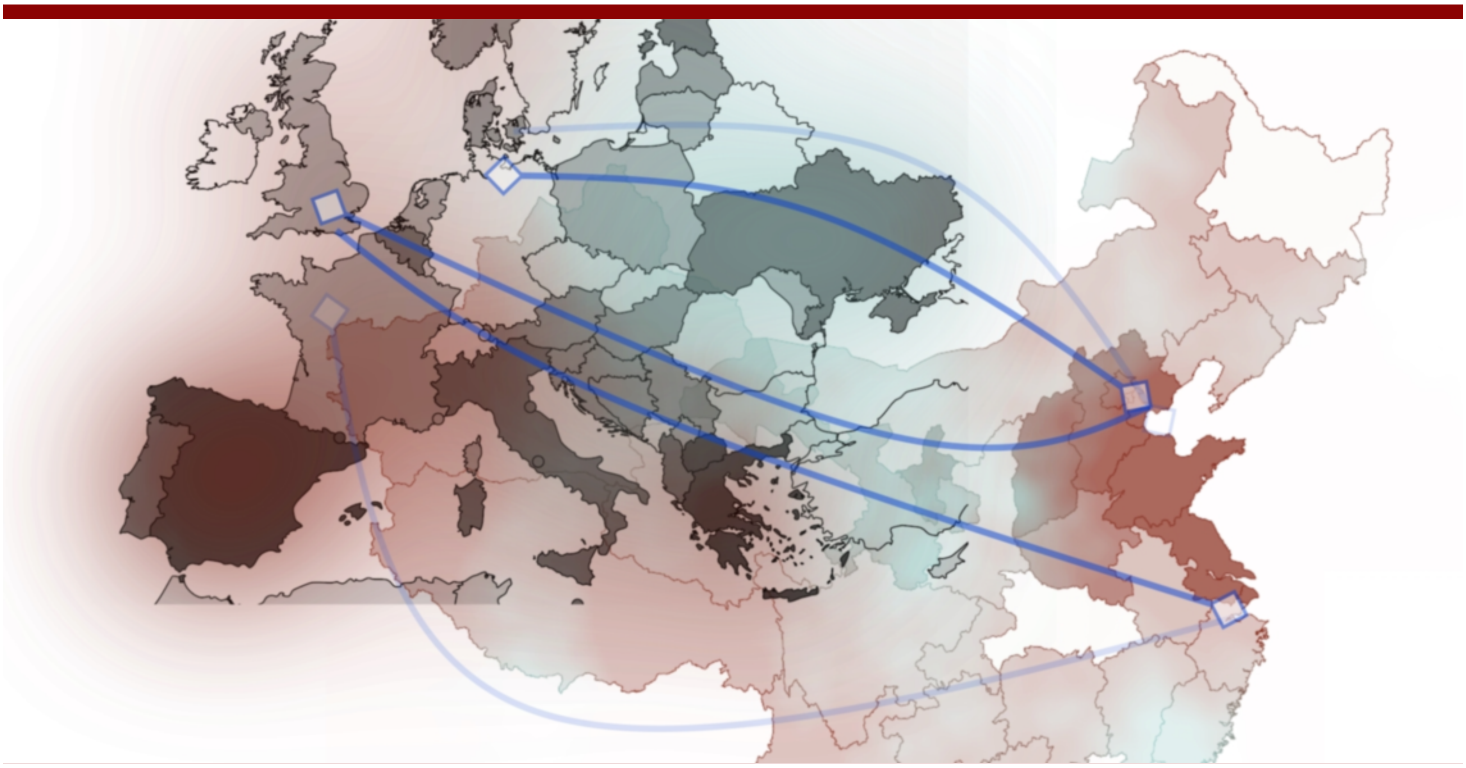

Mariú Abritta Moro
PhD Thesis
March 2018

DTU Miljø
Institut for Vand og Miljøteknologi

An evolutionary approach to water innovation: comparing the water innovation systems in China and Europe

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May 2018

DTU Environment

Department of Environmental Engineering

Technical University of Denmark

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The synopsis part of this thesis is available as a pdf-file for download from the DTU research database ORBIT: http://www.orbit.dtu.dk.

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Preface

The work reported in this PhD thesis, entitled "An evolutionary approach to water innovation: Comparing the water innovation systems in China and Europe", was conducted at the Department of Environmental Engineering (DTU Environment) and the Department of Management Engineering (DTU Management), Technical University of Denmark, from December 2014 to March 2018, to meet the requirements for obtaining the PhD degree. The research was carried out under the supervision of Prof. Barth F. Smets and Assistant Prof. Ursula S. McKnight from DTU Environment, and by Senior Researcher Maj M. Andersen from DTU Management. An external stay at the Department of Water Quality, Research Center for Eco-Environmental Science, Chinese Academy of Sciences, China, was included in collaboration with Prof. Yang Min.

The project was funded by the Sino-Danish Center for Higher Education and Research, in association with the University of the Chinese Academy of Sciences, as well as by DTU Environment. The work reported in this PhD thesis has been closely aligned with the EU Project: 'Policies, Innovation And Networks for enhancing Opportunities for China Europe water' (PIANO; www.project-piano.net), funded by the European Commission within the Horizon 2020 Programme under Grant agreement number 642433.

The content of this thesis is based on three scientific journal papers and one report. The articles and report were prepared in collaboration with researchers from Denmark and China (paper I only). At the time of writing, one of the journal papers is in press, one is submitted and one is a manuscript in preparation for submission as listed below:

I. M.A. Moro, U.S. McKnight, M. Yang, B.F. Smets, M.M. Andersen, 2018. The industrial dynamics of water innovations. An analysis for Europe and China. International Journal of Innovation Studies. Accepted, in Press.

II.M.A. Moro, B.F. Smets, M.M. Andersen, U.S. McKnight. Analyzing the national innovative capacity in the water sector for China and Europe. (Submitted)

III. M.A. Moro, U.S. McKnight, B.F. Smets, M.M. Andersen Green catching-up and Economic Development - An Evolutionary Analysis of Water Innovation for China and Europe. (Manuscript).

IV. M.A. Moro, U.S. McKnight, B.F. Smets, M.M. Andersen. What aggregate data does not tell.Surveys and interviews with water innovators in the Chinese context. Report.

Acknowledgements

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Secondly, I would like to thank my colleagues in the Section of Technology and Innovation management and the Section of Water Technologies for the support and creative environment they have provided. I would especially like to thank Herle and Jieru for sharing the experience of being an interdisciplinary researcher. I would also like to thank my office colleagues Celine, Meiken, Sabrina, JJ and Sophie, for sharing the office and supporting me during these my PhD. I would also like to thank the nice inputs provided by Lars, Lourenco, Francesco and Anne.

Thirdly, I would like to acknowledge the help from all who have assisted me during my external research stay in China, without you I would have never be able to conduct my studies in Beijing. I would like to thank the Sino-Danish Center for high education and Research and the Department of Environmental Engineering for providing the financing of this PhD.

Additional support provided by members of the PIANO project in facilitating contacts within China is gratefully acknowledged, including especially Josh Weinberg (Stockholm International Water Institute, Sweden). I would also like to express my gratitude to Ole Olsen from Danish Statistics that provided me first insights of “green water goods”.

Finally, I thank my family and friends for their support and love throughout these years, specially to my Aunt Marcia for helping me to keep up when this work was overwhelming. I would like to thank my friends in Denmark, specially Natalia and Søren, you were my family away from home.

Sincerely

Mariú Abritta Moro

Kgs. Lyngby, May 2018

Summary

The recent rise of the ‘green economy’ agenda has increased the attention to eco-innovations globally, with issues related to water stress identified as one of the major bottlenecks for sustainable economic growth. Water being a critical resource, more and more countries worldwide are recognizing the need for increasing their innovative capacity within the water sector. Using evolutionary economic theory, this thesis undertakes a longitudinal and comparative analysis of the water innovation dynamics in Europe and China, representing respectively a developed, green early mover economy, and a centrally-planned economy and green late mover. The thesis aims to assess the similarities and differences in the mechanisms applied across these two regions, with a focus on outlining what drives eco-innovation development in the water sector.

The thesis builds more specifically on the innovation system framework within evolutionary economic theory, as well as draws on eco-innovation and water specific literature. The analysis seeks to contribute to the still limited water innovation dynamics research, as well as the green economy and to some degree the ‘catching up’ literature, highlighting the innovation conditions of the green economy in regions with different stages of development. The empirical analysis is based primarily on patent data but also draws in trade data for some of the analysis. These data have been little used in water innovation studies and even less situated within an evolutionary economic theoretical perspective.

The thesis compares and contrasts the elements and dynamics of the Chinese and European water innovation systems, working on multiple levels. The thesis identifies and characterizes: a) the actors of the water innovation system, b) trends in innovative capacity and the driving forces of the technological development, and c) the degree of Chinese catching up to Europe, both in general as well as related to different technological patterns of eco-innovation in the water sector.

The main findings of the thesis are related to the clear differences in the dynamics of water innovation versus water eco-innovations in the Chinese context, where public innovators (universities and knowledge institutions) are found to have a more important role than in Europe in the development of eco-innovation – as opposed to the development of “general” water innovations. This points towards a better association among the actors involved in performing eco-innovation and the water regulations and innovation policies. This

alignment is expected given the planned economy of China, but which has not been previously documented or discussed for the water sector.

Additionally, the thesis identified and analysed the drivers for the overall (eco) innovative capacity development of the water sector in the two regions, and found them to be similar and strongly related to the national innovative strategy, as well as to public budgets, environmental regulations and R&D development. Generally, Europe presents a higher water (eco) innovative capacity; nevertheless, the thesis also indicates that China is increasing its innovative capacity in the water sector relative to Europe. In particular it could be seen that China is in the process of a "market" technological catch-up while remaining at a much lower patenting innovative performance level than Europe. Both regions present similar eco-innovative patterns, with a strong remaining focus on traditional water pollution technologies and wastewater treatment. This demonstrates there is still a huge potential for green business development related to water conservation and water recovery in both regions that hasn't been explored yet and may become crucial to the future transition towards sustainability.

Overall, the analysis of the thesis contributes to a more nuanced understanding of water innovation dynamics, as well as global water innovation trends than has been conducted to-date. Novel contributions include the combined analysis of the micro aspects of water innovation dynamics, the econometric analysis of innovative capacity drivers, as well as the longitudinal catch-up analysis of combined patent and trade data, including the discussion of the development of different water technological trajectories. The suggested taxonomy for water (eco-) innovations and the trade data list of water technologies can be used as novel indicators to analyse eco-innovation developments and diffusion in the water sector.

Given the limited prior research to draw on and limitations regarding data availability, as well as the many very recent green water policy tendencies in China whose effects are yet to be seen, the empirical results of this thesis are not that clear cut. In some respects, China is catching up in water innovations, in other respects not. Further analyses are needed to provide a more thorough understanding of the water innovation performances and dynamics of the European and Chinese water innovation systems.

Dansk sammenfatning

Den stigende interesse for den "grønne økonomi" som politiske agenda, har øget den globale opmærksomhed for øko-innovation, med problematikker relateret til vandstress identificeret som en af de største flaskehalse, for at opnå bæredygtig økonomisk udvikling og vækst. Vand er en kritisk ressource, og globalt indser flere og flere lande nødvendigheden, af at øge deres innovative kapacitet indenfor vand-sektoren. Med udgangspunkt i evolutionær økonomisk teori sigter denne afhandling på, at udføre en longitudinal og komparativ analyse af vand innovationsdynamikkerne i henholdsvis Kina og Europa. Afhandlingens mål er at vurdere ligheder og forskellige imellem de tendenser og mekanismer, som foregår i de to regioner, med et fokus på at identificere de faktorer, som driver øko-innovationsudvikling indenfor vand-sektoren. Mere specifikt bygger denne afhandling på *innovations system* begrebsrammen indenfor evolutionær økonomisk teori og inddrager tillige øko-innovation og vand-specifik litteratur. Forskningen føder ind til den stadig meget begrænsede vand innovationsforskning, så vel som *grøn økonomi (green economy)* og til dels 'catching up' litteraturen. Vi sætter fokus på at belyse de innovative betingelser for grøn økonomi i regioner, som befinder sig på forskellige udviklingstrin. Den empiriske analyse er baseret primært på patentdata, men inddrager også handelsdata i nogle af analyserne. Denne slags data er tidligere, kun i begrænset omfang, blevet anvendt indenfor vand innovationsstudier og endnu mindre indenfor et evolutionært økonomisk teoretisk perspektiv.

Afhandlingen sammenligner og analyserer elementerne og dynamikkerne i henholdsvis det kinesiske og det europæiske vand- innovationssystem, fra tre forskellige vinkler. Først identificeres og karakteriseres; a) aktørerne indenfor vand innovations systemer, dernæst b) de drivende kræfter for den teknologiske udvikling og trends i den innovative kapacitet, og endeligt c) i hvilken grad Kina, som en centralt styret planøkonomi og late-mover indenfor grøn økonomi, har indhentet Europa, som er en veludviklet early mover indenfor grøn økonomi.

Hovedfundene i denne afhandling er relateret til de klare forskellige i dynamikken indenfor vand innovations kontra øko-innovation i Kinesisk kontekst, hvor offentlige innovatører (universiteter og videns-institutioner) blev fundet til at spille en vigtigere rolle end i Europa indenfor øko-innovation end er tilfældet generelt indenfor vand-innovation. Dette indikerer en bedre association imellem de involverede aktører indenfor øko-innovations og vand- og innova-

tions-lovgivning. Dette er et forventet fund på grund af den kinesiske planøkonomi, men det er ikke tidligere blevet dokumenteret eller diskuteret i analyser af vandsektoren.

Derudover, identificeres og analyseres trends og drivkræfter for den samlede (øko) innovative kapacitetsudvikling for vandsektoren i de to regioner. Disse drivers blev fundet at være sammenlignelige og stærkt relateret til både dn nationale innovative strategier, såvel som de nationale budgetter, miljølovgivningen i regionen og udviklingen af R&D i sektoren. Generelt har Europa en højere (øko) innovativ kapacitet, men afhandlingen indikerer, at Kina i stigende grad øger sin innovative kapacitet i vandsektoren relativt til Europa. Specifikt blev det fundet at Kina er ved at indhente Europa på markedsplan, på trods af at de stadig på patentmæssigt ligger på et væsentligt lavere niveau end Europa. Begge regioner udviser sammenlignelige øko-innovative mønstre, med et vedvarende stærkt fokus på traditionelle vandforurenings- og spildevandsrensnings teknologier. Dette demonstrerer, at der stadig findes et stort uudforsket potentiale for grøn forretningsudvikling relateret til vandbesparelse og vand genindvinding i begge regioner som vil være vigtige for at sikre en fremtidig bæredygtig udvikling på vandområdet.

Sammenfattende bidrager afhandlingens analyse til en mere nuanceret forståelse af vandinnovationsdynamikker såvel som globale vandinnovationstrends end hidtil. Nye bidrag til innovationssystemforskningen er den kombinerede belysning af mikroaspekter af vand innovationsdynamikkenerne (aktørerne), den økonometriske analyse af drivkræfter for innovations kapaciteten såvel som den longitudinale analyse af catch-up baseret på kombinerede patent og handelsdata indenfor forskellige teknologiske udviklingsspor. Den udviklede taxonomi for vand innovation samt listen over vandhandelsdata kan anvendes som nye indikatorer for øko-innovationsudviklingen og diffusionen i vandsektoren.

På grund af emnets kompleksitet og den begrænsede forskning hidtil indenfor området og visse datamæssige begrænsninger, samt det forhold at mange nye grønne vand politiske tiltag i Kina endnu ikke reflekteres i de anvendte data, er resultaterne af de empiriske analyser ikke helt entydige. På nogle områder bevæger Kina sig imod Europæiske niveauer, hvorimod andre indikatorer er uændrede. Yderligere analyser er nødvendige for at opnå en mere komplet forståelse af dynamikkerne i vandinnovationssystemerne i både Kina og Europa.

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Abbreviations

ANOVA- Analysis of variance

CIS- Community innovation survey

CN- Combined Nomenclature

EPS-Environmental Policy Stringency Index

EU- Europe

GDP- Growth Domestic Product

H- Harmonized code

ICTs- Information and communications technologies

IPC- International Patent Classification

NIC- National Innovative Capacity

OECD – Organization for economic cooperation and development

PRC- China (People´s Republic of)

R&D- Research and Development

UN- United Nations

UNEP- United Nations Environmental Programme

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1 Introduction

1.1 Background and motivation

The study of water innovation dynamics is fairly recent and can be traced back to the late 1990s. The analysis of how water innovations take place, highlighting the role of innovative actors in the water sector to promote innovations, is extremely important to the development of innovative capacity to meet rising water challenges. The global demand for water is expected to increase by more than 50% over the next 40 years, and by the year 2050 more than one third of the global population may be living in river basins experiencing severe water stress (OECD, 2012a). This scenario is likely to increase competition for this resource among domestic users, electricity generation, industry and agriculture (OECD, 2012b). In this context, the development of new and more efficient water technologies can be considered a key element in the transition towards a sustainable pathway in which eco-innovation is becoming a still more important driver of economic development, globally (Foxon and Andersen, 2009)

Innovation system research within the field of evolutionary economics indicates that despite rapid globalization, nations still display very different patterns in their mode of innovation (Lundvall, 2007; Schaaper, 2009) which is also true for eco-innovation (Andersen, 2010a). This PhD thesis compares aspects of the European and Chinese water innovation systems. Europe has been a pioneer in eco-innovation, particularly within the water sector and has developed many advanced water technology solutions of both curative and preventive nature (OECD, 2012b). Europe is also a global reference among regions that have started to incorporate the green growth agenda where the focus has been on reducing the risk of negative shocks to growth related to resource restraints, the opening/expansion of green(er) markets, creating incentives for enhancing the demand for both “green” products and technologies as well as green business opportunities via improved governmental support in dealing with major environmental issues(OECD, 2011a). Each country should adapt the green growth agenda to fit specific needs related to international policy and institutional settings, their level of development, social structures, resource endowments and particular environmental pressure points. Advanced, emerging, and developing countries will face different challenges and opportunities. While national plans will differ, in all cases green growth strategies need to go hand-in-hand with the main pillars of action to promote social equity: more intensive human capital investment, inclusive employment promotion, and well-designed tax/transfer redistribution policies. and business that is related to into their economic development strategies and are moving towards a “green economy” (OECD, 2012b). Notably, the European Innovation Partnership (EIP) Water stated in 2012 that while Europe is very strong on water research, it often fails to turn knowledge into added value for society and markets.

China, on the other hand, has only more recently taken on the eco-innovation agenda on a larger scale, having just developed quite strong policies for eco-innovation in general and specifically for water innovation. This has been the primary institutional response to a country still facing many urgent water challenges (see Chapter 2.2). China is also one of the largest and most important developing economies in the world, with an important participation of “heavy” industry – which entails the heavy use of natural resources including water. Even though China has undertaken significant investment in research and innovation in the water sector over the last few decades, knowledge on its outcome is fragmented (Liu and Yang, 2012).

1.2 Objectives

It is recognized that the ability to develop eco-innovation can determine the capacity of a nation to socio-economically sustain itself in the long run. In this context, eco-technological development is a crucial element in the process of aligning economic change with sustainability goals. The purpose of this PhD thesis is to assess the similarities and differences in the mechanisms applied across China and Europe, with a focus on outlining what drives eco-innovation development in the water sector. To this end, the elements and dynamics of the Chinese and European water innovation systems are compared and contrasted in order to analyze how countries in different stages of development are performing with respect to achieving a high overall innovative capacity in water innovation.

The four specific objectives of this thesis are thus to:

- Identify and characterize the actors of the water innovation system, investigating the nature and innovative performance of the core actors in the water “innovation dynamo” **(Article I)**;
- Delineate the framework conditions for water innovation, with a focus on defining eco-innovation in the water sector **(Article II)**;
- Outline the nature of the interactions between the water innovation infrastructure and cluster-specific environment, which determines the

driving forces for the technological development and the overall innovative capacity of the water innovation system **(Article II; III);**

- Evaluate the degree of catching up of China in relation to Europe, as well as different technological patterns of eco-innovation for each region in the water sector **(Article III)**.

The scope of this thesis has been limited to focusing on technologies related to three water domains: municipal water management, industrial water management and agricultural water management.

1.3 Structure of the thesis

This thesis is article-based and is comprised of a synopsis containing six chapters, followed by three articles (papers I-III, provided in the appendix), and a report (IV), also provided in the appendix. Chapter 2 presents the conceptual framing, describing the research relevance, the theoretical background that basis this study's objectives. Chapter 3 presents research problem and the research gaps and data sources of the thesis. Chapter 4 discusses the water innovators for both Europe and China, the determinants of water innovation capacity, as well as the evolution of water innovation dynamics and innovative patterns. Finally, Chapter 5 presents the conclusions and Chapter 5 presents future perspectives. Figure 1 below provides an overview of the thesis structure and the relationship among the chapters.

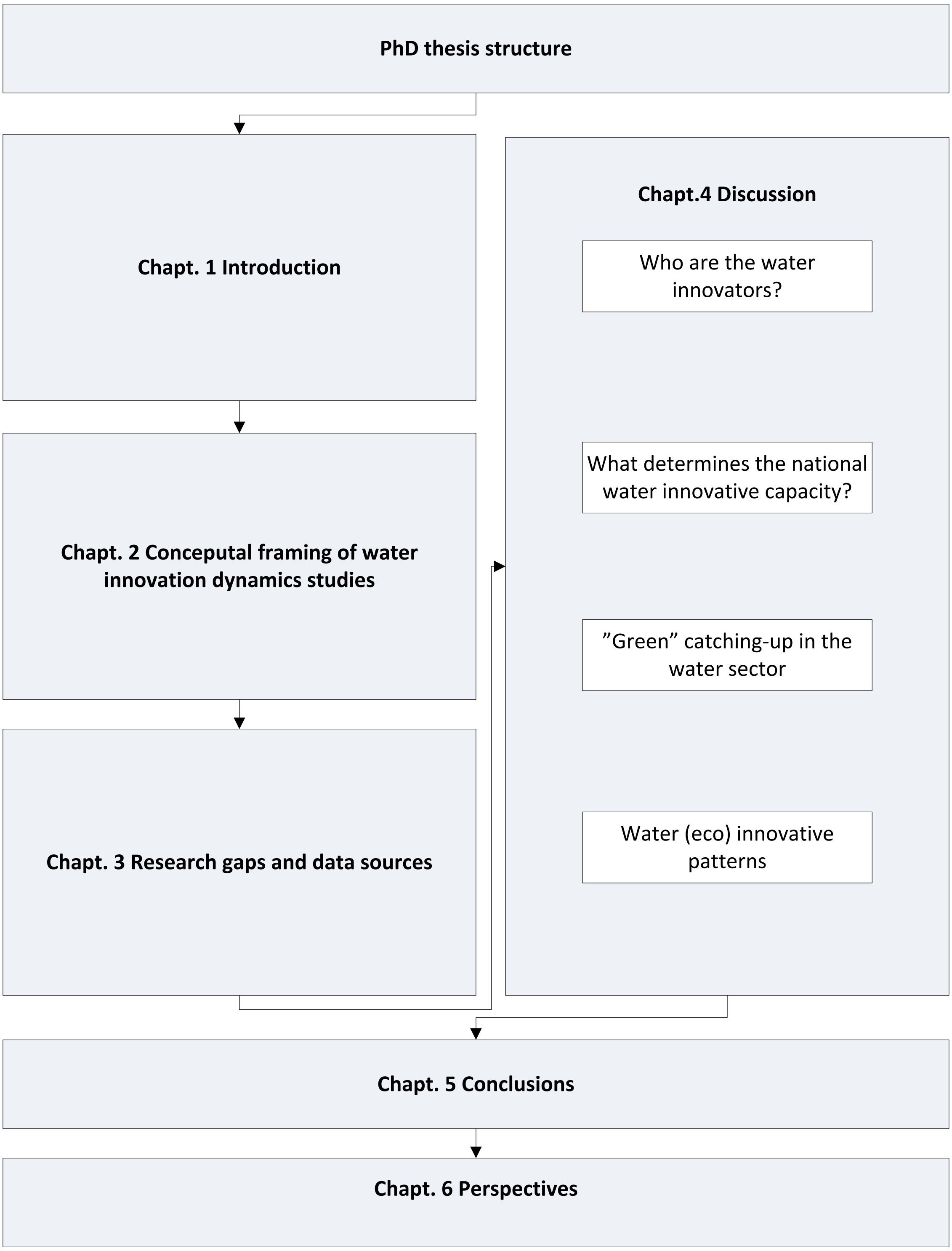

Figure 1: Thesis structure and relationship among chapters.

2 Conceptual Framing of water innovation dynamics studies

This chapter is dedicated to explaining elements and background information that form the basis of the thesis. The purpose of the chapter is to contextualize the key discussions surrounding the thesis. The first section entitled "contextualizing water innovation studies" explains the background motivation of the thesis and highlights its overall scientific relevance. The subsequent section presents the water issues pertaining to Europe and China at a general level. The section focuses on bringing information regarding the three main water problems: water scarcity, water pollution and floods. The last section entitled "conceptual framing" is dedicated to the ideas behind the theoretical background of the thesis. The purpose of this section is to highlight the most important elements in each background that shaped the direction, findings and contribution of the thesis.

2.1 Contextualizing water innovation studies

The development of eco-innovations is central to achieving sustainable development and understanding how these innovations are developed and diffused are crucial to increase the level of eco-innovative activities in the water sector. The area of diffusion is particularly crucial to the understanding of technological trajectories towards sustainable development (Andersen, 2010b). In this context, the analysis of water innovation dynamics and evolution is important for understanding the knowledge creation, interactions, the capacity building of water technologies, and the diffusion and direction of water technologies. The analysis of the mechanisms of knowledge creation and interaction and diffusion of water innovations have not been widely explored so far. To date the these mechanism behind the development of water innovations and more specific eco-innovations are not explicit on the literature is water innovations.

The further development of such studies may contribute to improving water resource management globally, by providing incentives for technological development in specific areas, as well as the most appropriate incentives for strategic actors in the water innovation system. Understanding how these innovations take place might also answer the questions related to the level of innovative activities in the water sector. Despite being a strategic sector for sustainable development, the water sector lags behind when compared to other infrastructural sectors, such as energy. Water is a crucial resource and the misuse of water resources linked with technological progress and population growth leads to increasing water issues that affect both developing and developed countries. The development of water innovations, focusing on water resource efficiency and water problem mitigations is key for assuring sustained socio-economic growth (the failure to develop smarter water technologies may become a barrier to achieving sustainable development).

This thesis thus contributes to building the literature-base for water innovations, presenting an initial discussion about the leading actors in the water system with respect to their nature (private innovators *versus* public innovators) and size (small, medium and big). The thesis also contributes to the national innovative capacity analytical framework, showing elements that impact the level of innovative capacity in the water sector across Europe and China, highlighting the role of regulations and level of economic activities on the process of technological development in the water sector. The thesis also contributes to the emerging green catching-up literature, focusing on the discussion about knowledge creation and interaction and evolution among Europe and China. The thesis also contributes to the analysis of the innovative patterns in the water sector, providing a comparison between Europe and China, starting the discussion about knowledge base and knowledge creation. Methodologically, the thesis contributes with new quantitative tools, such as the water technology list and the water eco-innovation list, that enable a better understanding of water technologies classification and can provide a basis for future analysis in water innovation studies. This thesis contributes to the policy point of view to support policy makers' decisions to prioritize strategic water eco-innovations closely related to the concept of the circular economy[1], that can be understood in more general terms, it promotes resource minimization and the adoption of cleaner technologies (Andersen, 1999), highlighting how the innovative actors in the water sector respond to water regulations with potential to promote eco-innovations. Europe and China presents an unique comparison, since Europe can be considered an early mover into the green agenda and China a transitional

[1] The concept of a circular economy – currently widely promoted in Asia – has its conceptual roots in industrial ecology, which envisions a form of material symbiosis between otherwise very different companies and production processes. Industrial ecology emphasises the benefits of recycling residual waste materials and by-products through, for example, the development of complex interlinkages, such as those in the renowned industrial symbiosis projects (see Jacobsen 2006).

economy, with a strong central- planned government that is currently re-directing the national development strategy with a strong focus on circular economy.

2.2 Water Challenges

Water challenges are globally recognized as one of the most pressing concerns that could hinder socioeconomic development. Approximately 78% of the global workforce are, to varying degrees, dependent on water (United Nations, 2016). These water challenges can be roughly translated into the three **T´s**: **T**oo little (water availability related to water scarcity), **T**oo dirty (related to pollution levels and wastewater management), and **T**oo much (related to floods and rise of sea levels). Water shortage is a serious problem, and these problems are aggravated by climate change[2].. Currently, approximately 1.2 billion people suffer the impacts of water scarcity (UN-Water & FAO, 2007). In Europe and China, these challenges can vary with respect to type and magnitude. Figure 2 provides a map with the level of water scarcity in China (A) and Europe (B). We can observe that in China, the highest level of water scarcity is concentrated in the area with the biggest population (cities such as Beijing and Shanghai), and that in general water stress (orange to red colors in Fig. 2) predominantly affects northern and central east China. In Europe, we observe that the extreme water scarcity is concentrated in two countries (Spain and Greece), although currently, 16 European countries are affected in general by water stress is much higher among them important leading economies (within the G 10) such as United Kingdom, France, Italy, Belgium, and Netherlands, emphasizing the great impact of a restrain on water can cause on the economy, not just local, but global, since the globalization process linked local economies into a global value chain and intensive the effects of local crisis into the global economy.

[2] The effects of climate change on the environment as economic activities is perceived as one of the most global pressing concerns.

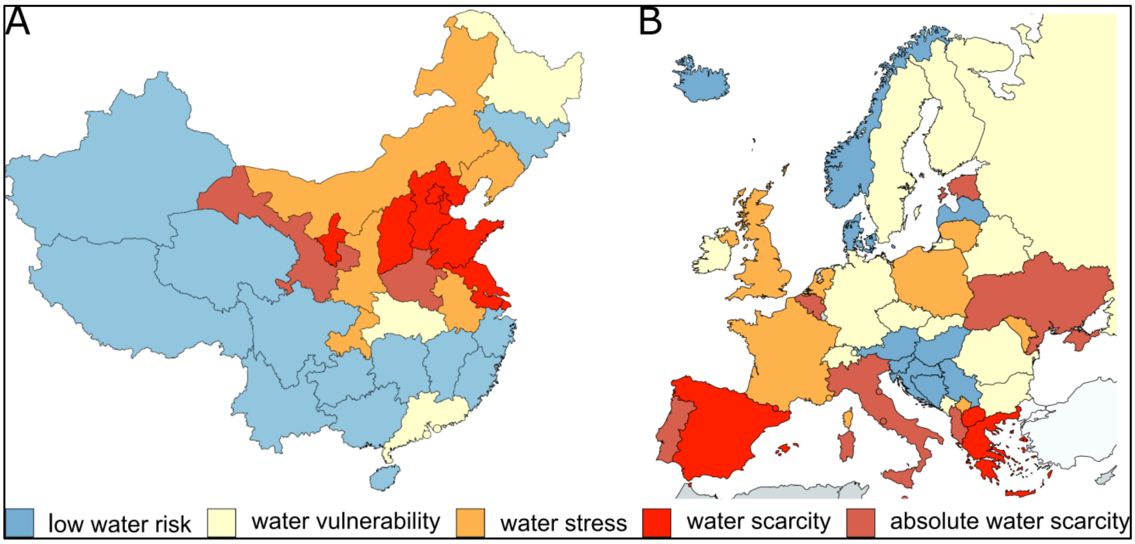

Figure 2: Map of (A) China´s water-scarce provinces, and (B) European countries. Source: own elaboration based on World Resource Institute[3]

The water challenges are found on an even bigger scale for China, with the country having only 6% of the (global) freshwater resources, but over 20% of the world´s population. Moreover, China is still undergoing a rapid urbanization and industrialization process that altogether causes severe water restraints and increasing pressure on water resources, such as decreasing groundwater table levels (depleting at ca. 1 m/yr) and high levels of water pollution (e.g. Davidsen et al., 2015). Currently, the agriculture sector is responsible for 65% of China's total water usage (RobecoSAM, 2015). However, a shift in the water usage is expected to take place where industrial and domestic domains will be responsible for the majority of demand growth by 2030 (OECD, 2012a). Figure 3 presents the expected demand by 2030 for water across the three analyzed domains (municipal, industrial and agricultural water). We can observe that there is generally a higher increase in the demand for water in China as opposed to Europe, which highlights the severity of China's water problems.

[3] Available at: http://www.wri.org/resources/maps/aqueduct-country-and-river-basin-rankings

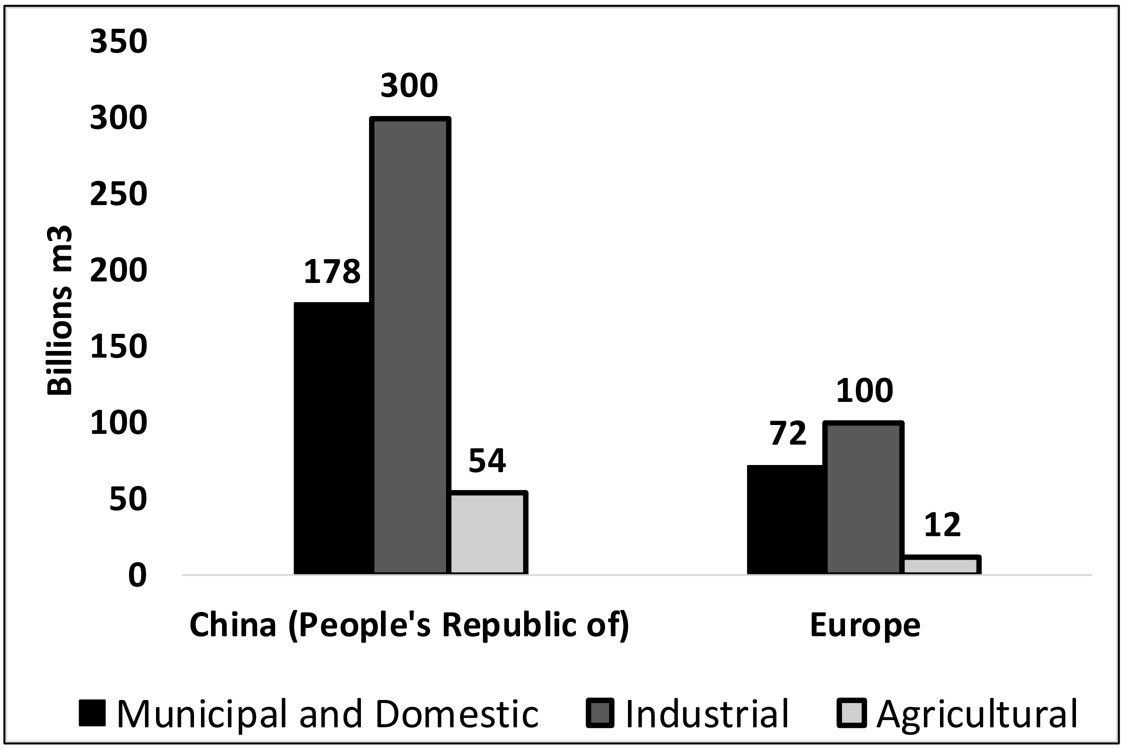

Figure 3: Expected demand for water in China and Europe (2030) in billions of cubic meters.

Too much water can also pose a challenge. Floods have impacted China over the decades and the country is still facing challenges associated with flood protection and water resources management. Despite the strong focus on flood protection over the last decades, the current urban drainage infrastructure fails to handle the scale of urban floods, with around 60% failing to meet minimum standards for flood prevention (PIANO, 2015). The incapacity to handle urban floods represented a loss of over 120 billion yuan from the period of 1991–2011(PIANO, 2015). China has also experienced an increase in the level of water pollution, and has depleted the natural water system capacity for-self-purification; discharges of both point and non-point source pollutants has caused vast ecological destruction that ranges from xenobiotic organic and inorganic pollution to eutrophication (Miao et. al., 2012).

The need to increase resource productivity has been globally recognized, with water comprising a particularly pressing resource. The key to increasing environmental resource productivity lies in the development of environmental technologies (OECD, 2011). Figure 4 illustrates the so-called Kondratiev cycles, which highlight the most important areas related to economic prosperity. It is suggested that the next wave (or cycle) of prosperity is starting now and is intrinsically related to the ability to increase resource productivity via the development of eco-innovations.

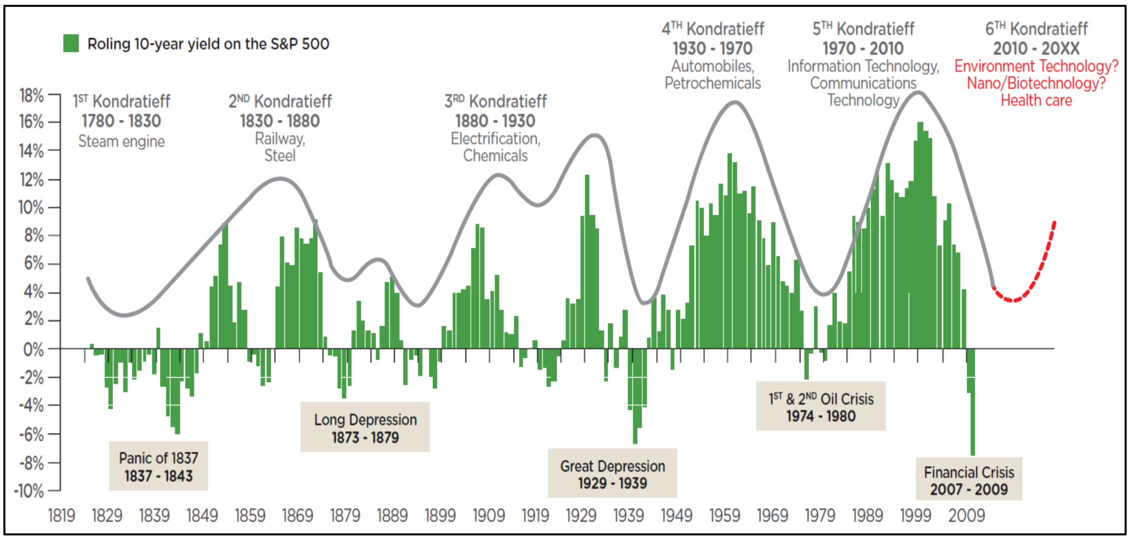

Figure 4: Kondratiev cycles. Source: OECD (2016) from: Allianz Global Investors "The Sixth Kondratieff" – Long waves of prosperity, 2010. The description of the sixth Kondratieff suggests that resource productivity could become the overarching characteristic of the new cycle.

Based on the Kondratiev cycles, we observe that the level of economic prosperity is transitioning from a strong infrastructure aspect, such as steam engines related to industry, transport, electric energy, and communication and technology infrastructures to different aspects focused more on technological development with strong links to sustainable development goals, that for water are related to the improving access to water, specially, improving drinking water access and quality and sanitation.

The challenges related with water resource management are clearly complex, involving different levels of interventions and aspects (De Montalvo and Alaerts, 2013; Wehn and Montalvo, 2018). Macroeconomic, local and individual decisions can affect to a certain degree the dynamics of the water system. At the macroeconomic level you have the set up for investments and overall regulations that affects the level of investments and focus on water resources, at the local level there are the specific regulatory framework and specific group companies and utilities involved in the process of water management, from the individual level you have examples of the adoption of portable water-reuse technologies (Binz et al., 2016). Water has many aspects (cultural, ethical, economic, and environmental) which affect how we perceive water that also involves socioeconomic (increased demand for water, via economic growth, population growth), as well as technological (barriers related to the water infrastructure and regulatory framework) challenges related to water management therefore, varies from its type and magnitude (Lincklaen Arriëns and De Montalvo, 2013).

2.3 Conceptual framing

This thesis aims to contribute to the evolutionary economy theoretical approach and to the understanding of water innovation dynamics seen as an example of eco-innovation. The thesis is based on the evolutionary theory that states that exist an important link between the dynamics of economic growth and technological change (Nelson and Sidney, 1982; Perez, 1983; Schumpeter, 1942), meaning that technological development is crucial for economic development and growth and in turn the economic set up impacts the level of technological development of nations. The thesis feeds into the green economy and green catching-up literature, that states the "creation of windows of opportunities" (Perez and Soete, 1988) for countries in development to achieve a higher level of economic development via technological progress of eco-innovations. In this context, the thesis, via a comparison of the role of Europe and China in the water innovation domain, analyse how countries in different stage of development perform eco-innovations, specific water eco-innovations. The thesis develops this analysis based on the evolutionary economy focusing on the study of water innovations development and evolutions that are related to the eco-innovation concept. Figure 5 shows the positioning of the thesis within the literature.

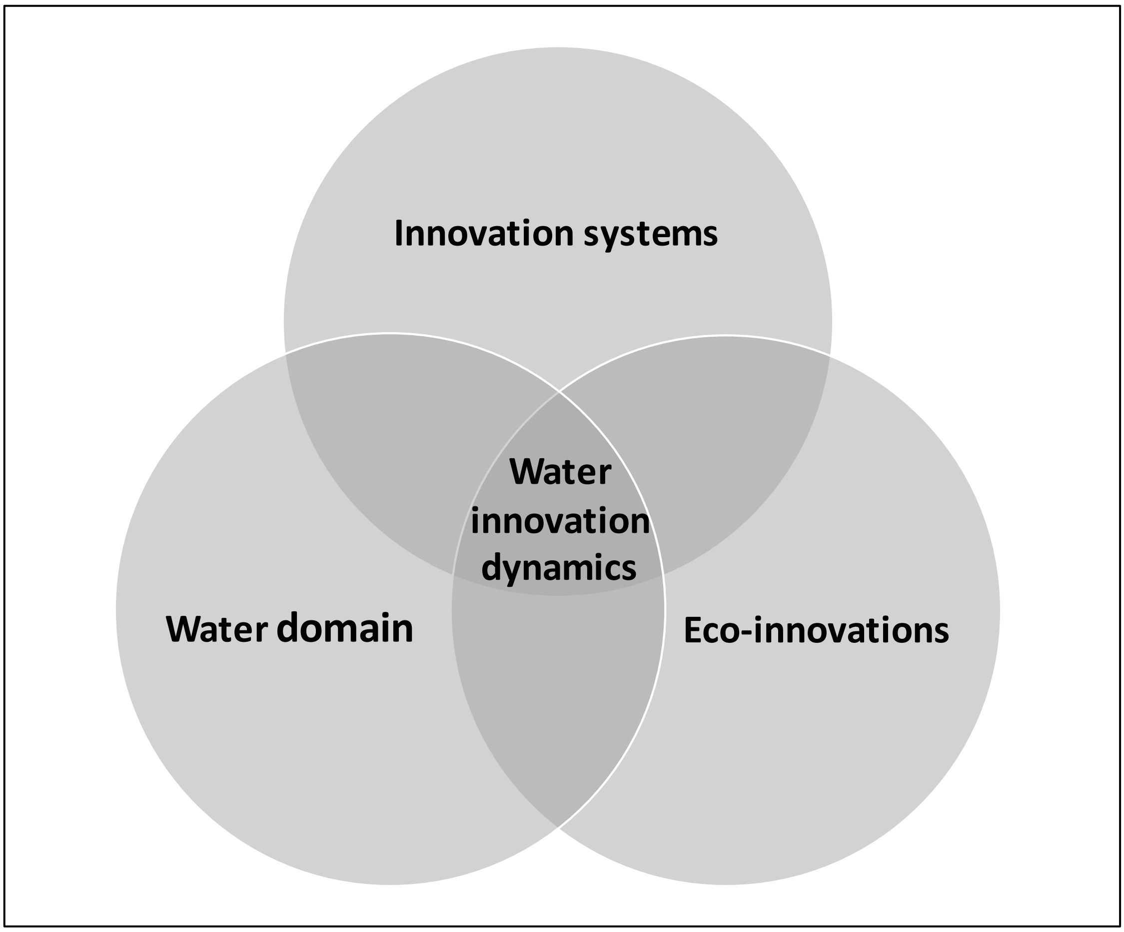

Figure 5: Positioning of the thesis.

2.3.1 Technological development from an evolutionary perspective

Technological development is an evolutionary process linked with the states of the dynamics of economic growth (Schumpeter, 1942, Nelson and Winter, 1982; Perez, 1983). Technological change impacts the level of economic growth and both co-evolve over time, affecting each other in a systemic process. In this process, there are main actors involved in the process of creation of innovations (companies and knowledge institutions), the stage of knowledge base (the overall knowledge accumulated over the years), and the framework conditions (norms, regulations, and characteristics of a nation that will shape how the country supports technological development). The success or failure of developing new technologies is related to the level and type of interaction among the actors in order to create new knowledge and the framework conditions that will support technological development.

The innovation system theoretical approach understands the process of economic growth as an evolutionary process intrinsically related to technological development and institutional change. Moreover, it is considered that the economy and technological development are complex and endogenous to the economic system, affecting and being affected by the system at the same time in a co-evolutionary framework (Lundvall, 2007, 1992). In addition, the technological development process is non-linear and dependent on knowledge previously accumulated over time by setting technological paths. According to Perez (1985), technology is the "how" and "what" of production and, thus, is subject to determinations of social and economic order. Moving forward in this perspective, the concepts of product and process technologies (which later give rise to product and process innovations) are pointed out, the first being the stock of knowledge about how to create or improve products and the second being the stock of knowledge about how to produce them.

According to Dosi (2006), technology is "a set of knowledge mix of know-how, methods, procedures, experiences, successes and failures and also, of course, physical devices and equipment." In this sense, this definition also includes in the concept the "perception about future technology alternatives, composed of the technological solutions from the past along with the knowledge and achievements of the state of art of a given technology". In a complementary way, Rosenberg (2006) defines technology as the knowledge of techniques and methods that work in certain ways and with certain consequences, even when such processes cannot be clearly explained. The ability of a country to perform innovation and maintain the level of technological development over the years can lead them to a high or low level of economic development and competitiveness in the global market.

The process of globalization of production has brought a more active participation of some developing countries that have used the possibilities of technological advances to achieve a higher level of economic development, as described by Freeman and Perez (1988) and Pérez (1992, 2001). However, the fact that there are such “windows of opportunity” does not mean that the process of technological absorption and economic development is taken for granted. According to Perez (1992), beyond opportunity conditions, such countries should be able to appropriate from such technological advancements, which depends greatly on the institutional arrangements in the country, given that "[...] the biggest leap in development probably will not happen in the more advanced countries, but in those which can have the better match between the technological potential, social consensus and institutional framework " (Perez, 1992, p. 40). Further, developing countries tend to benefit from the latecomer's advantage by following a development path adopted by others. This path makes the role of government relatively straightforward—providing roads, railways, energy, and other infrastructure to complement private investment, allowing open trade and investment policies that encourage technological catch-up, and implementing industrial policies when market and coordination failures inhibit the development of internationally competitive industries consistent with the country's comparative advantages. The globalization of production generates competitive pressures and accelerates the demand for new, differentiated technologies. Thus, the development of innovations has become faster and more widespread in the economy (Malerba, 2010).

2.3.2 Eco-innovation: definition and development.

The relationship between economic growth and environmental preservation is complex, involving a relationship of mutual causality, because the economic system is based on the use of natural resources to develop and grow (Kemp and Soete, 1992). This process, in its current pathway, causes degradation and large-scale exploitation of finite resources, reaching the limits of the biophysical capacity of the planet, compromising their availability in the long run, with negative, continuous effects on economic growth (Venkatachalam, 2006). In recent years, the concern of society about the effects of human action on the environment has intensified. Much of this concern arises because of works such as Limits to Growth (Meadows et al., 1972) the Brundtland Report (Brundtland, 1987) and the alarming reports of agencies such as the Intergovernmental Panel on Climate Change (Bernstein et al., 2008), as well as several other smaller studies.

The industry is seen as largely responsible for this phenomenon: the process technologies and product identity used currently require natural resources at a rate that nature can no longer reset, while most modern technologies are not environmentally friendly. On the other hand, the development of more efficient technologies could be considered as a key instrument to reduce environmental impact.

The complexity involved in the process of technological development goes beyond the technology itself to the entire system of technological development involved in this process (Geels, 2004, 2002; Kemp and Arundel, 1998). Understanding the interaction among the various actors in the technological development process is essential for understanding the development of environmental innovations, since the cooperation among those involved in innovative activities is an important channel of knowledge generation and learning that support the formation of a Sectoral Innovation System (Lundvall, 1992; Malerba, 2006, 2002; Nelson, 1982). The many actors involved in the technological development process have different skills and therefore the exchange of knowledge through cooperation becomes essential for innovative activities, since the agents do not innovate in isolation, but do so in a context of a system of networks made of direct and indirect relationships (Freeman, 1995; Lundvall, 2007, 1992; Nelson, 2006).

In this context, eco-innovation is seen as part of the process of technological and economic change in which paradigmatic changes happen in an evolutionary process (Andersen, 2010c). Hence, we consider eco-innovation as a process of technological and economic change, and seek to understand its relevance to the greening of the economy. This thesis understands that eco-innovations are new or modified products, services that generate positive externalities[4] on the environment, and are intrinsically connected with the policies of "green" growth, symbolizing a synergy between environment and innovation policies (Kemp & Andersen, 2004, Andersen, 2006; OECD, 2009) and the creation of green business opportunities (Andersen, 2010c). The rules applied for the technological development are also applied for the eco-innovation developments, only that environmental and innovations policies have a larger role. However, there is still no consensus established nor wide acceptance of environmental innovation definitions (Andersen 2006, 2008, EIO 2012, OECD 1992).

The development of eco-innovation as the core element to enable the transition to a sustainable path has been globally recognized. According to the OECD (1997), environmental innovations include all kinds of innovations that generate positive externalities on the environment, whether intentional or not, which includes processes, products and organizational innovations. Furthermore, the

[4] The creation of positive externalities is related to promote positive impacts/ effects on the environment, such as technologies that reduce the use of a natural resource and technologies related to pollution remediation and mitigation.

distinction between eco-innovation and innovation that create no reduction of environmental impacts is not clear. But whatever the term, environmental innovations are generally distinguished from innovation in general and so are studied separately. Why such a distinction? Is it just because environmental innovations have initially been studied by researchers coming from the field of environmental economics? Or is it motivated by a real specificity of environmental innovations which calls for specific concepts and analytical tools? The answer to these questions requires a clarification of the definition of environmental innovations, as well as thorough analysis of their properties and determinants (Oltra, 2008, p.4).

In general, the "traditional" technologies have experienced a long period of adaptation and incremental innovation, which makes them superior in many aspects (cost of production, performance, price) when compared to the new "clean" technologies. This scenario discourages the adoption of these new technologies, which in turn reduces the investment opportunities for their incremental development (that could eventually reduce the performance differential between them), configuring a problem of lack of incentives to incur in changes in the system. It is also important to adopt an analysis that encompasses all relationships involved in the development process of environmental technologies, so we can identify changes that take place in the system that encourages environmental technology development.

Although there are several challenges related to an environmental technology development process, there are also motivations for their development. As mentioned earlier, the option of developing an eco-innovation is not exclusively based on the search for reduced production costs and increased efficiency or product performance. Therefore, other actors involved in the technological development process have major roles, namely, when consumers express their preferences for green products and institutions that create incentives and indicate the direction of technology development. The elements that influence the eco-innovation development also differ among those who are related to the development of processes and those related to the development of products, the last one being influenced to a greater degree by consumers and the availability to pay for environmentally friendly goods, since the environmental process innovations are more influenced by the innovation strategies of each firm (Lustosa, 1999).

It is widely recognized that regulation is a major driver of eco-innovations once it can "indicate" for firms which path should be followed, breaking the lock-in of certain technological paths (Porter and Linde, 1995). The form how it "indicates" and acts can foster the development of end-of-pipe technologies, or new technologies that also generate competitive advantages. In other words, it can characterize a “win-win” scenario as defined by the "Porter hypothesis" (Porter and Linde, 1995). According to these authors, the eco-innovations induced by stricter regulations can generate economic and environmental benefits at the same time, breaking with the idea of trade-offs between the search for private profit and environmental improvements.

The outcome of regulation depends therefore on the type of regulatory instrument used, beyond the structure and context in which it is placed. Depending on how this regulation is developed, it cannot generate any incentive to develop cleaner processes and products, nor create any positive impact on the environment (Kemp and Arundel, 1998). Furthermore, it is necessary that the regulation has taken into account all environmental problems related to each type of technology, which is difficult to analyze, once the development of modern technology is complex, involving several elements, in a way that it is not possible to foresee the externalities that each one of them generates for the environment (Kemp and Soete, 1992).

Therefore, we can infer that eco-innovations are not limited to a direct response to current regulations; it is something more complex that requires additional efforts and research studies for its understanding (Oltra, 2008; Oltra et al., 2010). The technological regime has significant influence on a technological path, with the basic principle being that “technological and environmental regimes” shape sectoral patterns of technological innovation. Not all firms of the industry necessarily follow the same pattern because they may have different technological paths. Moreover, there are technological determinants that must be taken into account in a sectoral analysis, which include: technological opportunities related to the environment, technological barriers to entry, appropriability conditions, cumulativeness, knowledge base, etc. (Oltra, 2008).

The work of the United Nations Environment Programme (OECD, 2011b) focuses on studying the contribution of cleaner technologies towards sustainable development. Among them, the idea of decoupling stands out, in which the adoption of "green" technologies rather than traditional technologies would be able to generate the decoupling between economic growth and environmental degradation, enabling the continued growth of the economy without incurring higher levels of pollution or increased demand for natural resources. In this way, all developing countries could, by adopting "green" technologies, continue the expansion of their production processes without "bumping" the biophysical limits of the Earth.

UNEP's initiative "towards green economy" was released after the economic crisis in 2008, with the aim of promoting sustainable economic growth that would occur through a decoupling process in two ways: i) by decoupling the economic growth from environmental pressures arising from the demand for natural resources (inputs); and ii) decoupling economic growth from pollution generation (outputs). The "flagship" for achieving this process would be growth-oriented rules and regulations that would encourage the development and adoption of "green" technologies in key sectors such as: agriculture, buildings, energy, fisheries, forestry, industry, tourism, transport, water and waste management. In the water sector , decoupling opportunities were identified within the following areas: i) changes from building dams to sustainable ground-water exploitation and management (including storage and aquifer replenishment) ii) Invest in reducing water loss from leakages to below 10%; iii) reduce domestic water consumption by 40% via mandatory use of water efficient household fittings, grey water, recycling and rainwater harvesting; iv)Build neighborhood-level plants that recycle grey water for toilet flushing, capture methane gas for energy generation and capture nutrients for reuse in food production and greening and v)Invest in technology innovations to reverse the qualitative degradation of national water resources (OECD, 2011b).

According to UNEP (2011), the main barrier to achieving decoupling processes lies in the fact that most of the eco-innovations identified by UNEP hitherto focus on "impact decoupling" (e.g. prioritizing development of technological solutions for reducing the impact on pollution levels) and that fundamental to the decoupling process is the development of technologies that increase the efficiency in the use of natural resources (resource decoupling). The innovations that have been developed so far have contributed to an "extraordinary" increase in productivity (production), consumption, economic activity, and higher levels of quality lifetime. However, this has been an unsustainable path and, therefore, the innovations need to be directed towards increasing the productivity of natural resources used in production processes and environmental restoration. Also, according to UNEP (2011), such imbalance took place because the first generation of innovation investments focused on labor productivity, better efficiency and performance of the products. Because of this, the second generation of technologies will need to focus on the productivity of natural resources for the successful transition to a green economy.

Finally, the major “bottleneck” in order to achieve sustainable development with economic growth lies in the ability to create environmental technological innovations that increase resource productivity. In this sense, coordination among the different actors involved in the process of technological development is needed to foster these types of technologies. Thus, government should be considered the key coordination agent through the implementation of a regulatory framework, assigning functions to direct financial resources for this purpose. Moreover, the government should lead the finance of innovative activities and developing, therefore, "sustainable innovation systems" or "systems of sustainability-oriented innovation" (UNEP, 2011). In these systems, the coordination among agents, mediated by the government, support the development of a "green technology" with the necessary features to facilitate the decoupling process between economic growth and environmental degradation. This can be an alternative economic development model, particularly for developing countries, which could take advantage of the opportunity to do the "catching up" towards a green economy, as is defined by UNEP (2011).

The relationship between technological progress and the environment is complex, because human damage to the environment can be attributed to modern technologies, which were gradually developed and improved over decades without taking into account the environmental issues. On the other hand, the development of more efficient technologies is certainly one of the greatest allies in the search for reductions in environmental impact. In this sense, it is increasingly accepted that, in order to more efficiently use natural resources and significantly reduce their impact on the environment, it would be required to conduct radical changes in the current product and process technologies. Therefore, because of the high complexity existent in the current process of technological development, studies about technology preferably take into account their creative processes, selection and development. As such, such studies should not be limited to technology development itself (i.e focusing on the technology per se), but in its socio-technical relations (how is the environment in which this technology is being developed), also consider the role of society and its actors, such as the structure of supply and demand, infrastructure, among others; because the technology used must be in balance with these factors (Kemp and Soete, 1992).

Sector that are highly polluter can expect to have higher pressures to adopt eco-innovations (such as the automotive sector, electronic sector). Additionally, the degree of “eco-innovativeness” can be expected to differ across sectors

(López, 2008; Montalvo, 2008) and therefore different sectors (such as the water sector, the energy sector) may present different levels of eco-innovativeness. The degree of sectorial "eco-innovativeness" can be related to the level R&D investments, organizational set-up, level of path dependency of current dominant technological trajectories (Norberg-Bohm, 2000) a strong characteristic in the water sector. Other factors may also affect the level of eco-innovativeness, such as the existence of technological opportunities, the properties of innovative processes, the market structure, the maturity of the sector, the environmental impact and the exposure to societal pressures(Bleda and Del Rio, 2013).

2.3.3 Framing water innovations

The definition of "what is the water sector" it is still up to debate. From a "market perspective" the water sector is composed by water utilities (mix of public and private companies) the water companies that are related to the supply of technologies and manufactured equipments. (Arup 2015; Deloitte 2012). Departing from the "market perspective" and adopting a water resources view the UN (United Nations, 2008) divides the water sector into three functional categories (When and Montalvo, 2018) Water resource management; water infrastructure and water services. The division reflects that water innovations will be "place" within these three groups: i) water resource management, which includes technologies related to the protection of ecosystems, as well as to the sustainable use of water resources; ii) water infrastructure, which is related to the industrial, urban and agricultural water infrastructure (pipes, canals, etc.); and iii) water services related to water extraction, distribution, treatment before and after water usage, and the use of water for energy (Wehn and Montalvo, 2018).

There are overlaps among these three categories. However, these categories do not present a clear relation between the innovation itself and the discussion of innovation development and do not discuss the relation of these technologies in a systemic approach in which technologies are part of the process of economic and technological change. To overcome this limitation the thesis propose a new (category/ taxonomy) for water innovations. Firstly, the thesis frames water innovation as all new and/or modified processes, products and organizational innovations, related to the handling of water resources before, during and after its usage. These water technologies can be divided into those which are highly eco-innovative and those which are not (see data source in section 2.3 and Moro et al., (I) for detailed information related to the classification of water innovations). We do not recognize all water innovation as environmental technologies and also we do not recognize all water innovations as being eco-innovations. We understand water environmental technologies based on the OECD definition that environmental innovations are all kinds of innovations that generate positive externalities on the environment, whether intentional or not. So, why is water innovation not necessarily associated with environmental technologies? Firstly, not all water innovations create positive externalities to the environment. Some innovations improve the access and distribution of water that can be linked with the rebound effect. This effect involves an increase in efficiency which does not ensure a reduction in consumption (Brookes, 1990; Khazzoom, 1980; Saunders, 1992). The rebound effect is present for technologies that are believed will impact the environment in a positive way, but instead they make it easier to have more access to a specific environmental resource, consequently contributing to its overexploitation, creating negative externalities to the environment.

Currently, most of water innovations “falls” into the environmental technologies group, since in theory they comprise new or modified inventions, processes or services to avoid or reduce environmental impacts. However, this classification is not accurate, since some water innovations are not those designed to fit an environmental purpose, but to increase the access and usage of water. Additionally, part of water technologies, especially those related to increase water resource efficiency may be linked with rebound effects since it increases the availability of water resources and its exploitation, an example of this scenario are the drip irrigation methods used e.g. in greenhouses, since they are related to increased efficiency but not necessarily guaranteeing environmental sustainability (unless used and documented correctly).

We therefore understand water eco-innovations as new or modified products, services, that generate positive externalities on the environment, and are intrinsically connected with the policies of "green" growth, symbolizing a synergy between environment and innovation policies (Andersen, 2006; Kemp and Andersen, 2004; OECD, 2009) and the creation of green business opportunities related to climate change mitigation, adaptation technologies, water conservation, water efficiency, pollution control and mitigation, water recycle, and water re-use. In this context, the water eco-innovations evolve to mature stages along with the greening of the economy in a co-evolutionary process, meaning that more you adopt eco-innovations in the water sector the more it affects the stage of green of a given economy that in turn, redirect even more the technological development towards the creation of green business opportunities. It is expected that research will also expand in scope and complexity. As water eco-innovation evolves, factors beyond the regulatory framework will increase the importance of explaining why firms engage in eco-innovation, some of which may also be sector specific, including the role of differences and similarities in technological regimes, sectoral institutions, demand, and market structures (Oltra, 2008). For instance, the "fit" between existing technological competences and environmental goals might be subject to sectoral specificities, and such a fit might well be unstable over time, since both industrial characteristics and environmental sensitivity are in constant change. The role of institutional stimuli, including national and regional regulations and standards, in influencing the timing and direction of eco-innovation has been widely acknowledged in the literature (Penna and Geels, 2014; Budde et al., 2012; Dijk and Yarime, 2010; Frenken et al., 2004). Overall, there is still a significant gap in the studies of water innovation dynamics, and the following section is thus dedicated to the discussion of research coverage and gaps in the field.

3 Research gaps and data sources

This chapter is dedicated to summarizing the current state of research coverage on water innovation, the existing research gaps, and how this thesis positioned itself to fill these gaps and contribute to the literature of water innovation dynamics. The purpose of this section is to present the relation among the research gaps and the objectives of the thesis. The section covers the important findings and approaches used by other researchers in the field.

3.1 Research gaps in water innovation studies

The study of water innovations dynamics is fairly recent (see table A1). However, a significant increase on academic research took place from 2010 onwards, Figure 6 provides an overview of the evolution of studies related to water innovations based on findings via “key word search” from google scholar search[5]. The figure shows that until 2009 there were 27 results related to water innovations and up to this date there are circa 1.150 results related to water innovation. The results for the search for “water innovation system” is even smaller, currently there are 29 results, being two European union project, one special call, and three relevant academic papers, the other results weren´t classified as relevant within the scope of this PhD. The first time an academic paper uses the terminology “water innovation” with a non-technical purpose was the paper entitled “Water works” by Cramer et al. (1999). The first time a special call specific for water innovation dynamics was made was in 2014 by the *Journal of Cleaner Production* aiming to reduce the research gap in water innovation studies.

[5] The study wants to highlight that this number might be lower since, there were some repetitions and some non-academic research related to the keyword search.

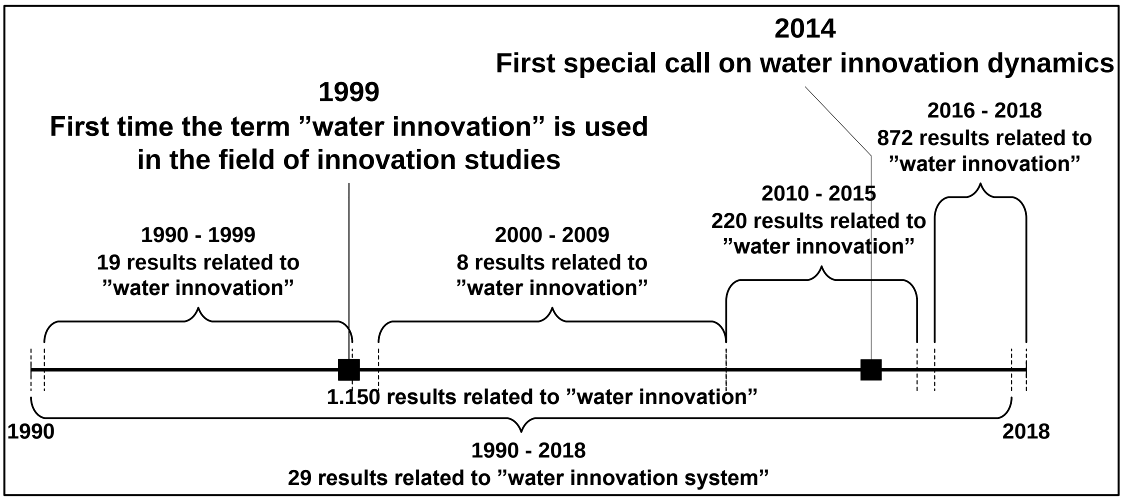

Figure 6:Timeline for the evolution of water innovation studies

Moreover, the majority of the research studies focused on water innovation are mainly related to a specific type of water-innovation, either water supply technologies or wastewater management technologies, which are adopted in a specific geographical area with specific actors and mechanism. Research that covers a larger scope (being at national level or global level) are still mainly lead by international organization such as UN and OECD with strong focus on policy orientations but fails to discuss the evolution and direction of water technologies overtime.

Overall, the current papers highlight the knowledge leadership development to increase the level of innovative activities, the role of the government (if and how) can set up the stage for innovations in the water sector, additionally, there are discussion on the technological shift in the water sector due to the increase of the pressures related to water resource the study of the role of water utilities in the process of technological development. Binz et. al. (2012) discuss the potential leapfrog in the Chinese wastewater treatment plants placing the discussion of water innovation development into the green growth agenda. Peuckert (2013) states that traditional water technologies may be reaching critical point in which they won´t be able to support the necessary technological development, this moment will constitute a paradigmatic change (Dosi, 1982) in which eco-innovation represent the alternative solution leading to the creation of a “green window of opportunities” that transitional economies like china might benefit from.

However, these studies represent an exception on the water innovation literature. Little is known about how these innovations take place and which actors in the innovation system are responsible for bringing these eco-innovations to the market. The water sector is a "quasi-monopolistic" sector, with mixed public/private actors, moreover the sector has close relations with public investments being affected in the period of economic crisis. Also, the investments increased due to the necessity of catching up with infrastructure investment lagging in southern and eastern European Countries. All European countries (expect Greece) are characterized by less than proportional efficiency in converting innovation inputs into innovation outputs.

The European Commission (2016) developed a report about innovation and structural change in different sectors of the economy and highlighted the lack of innovativeness of the water sector, despite the significant potential to innovate; the reason why the sector does not innovate has been related to the level of investments in the sector. However, De Montalvo and Alaerts, (2013) argue that innovativeness in the water sector is not hindered by a lack of investments, but by the incapacity to develop new capabilities, with governance in the water sector identified as the main barrier to the development of such capabilities, which is related to problems regarding the interaction among different actors in the water sector to create and diffuse new knowledge. The importance of knowledge and in particular of the creation, use, and diffusion of knowledge in the current economy has been emphasized by many scholars (Foray, 2004; Lundvall, 1992; Lundvall et al., 2002) and is considered to be central to technological change (Dosi, 1988, 1982).

Additionally, the sector is also highly regulated; Figure 7 provides an overview (timeline) of a number of key environmental regulations, innovations policy and eco-innovation policy/initiatives for both regions, which depicts Europe as an early mover compared to China (late mover), particularly regarding eco-innovation policy. It furthermore shows the introduction of the more general eco-innovation policies and beginning of the green growth agenda from the mid-1990s (depicted with green arrows) as pioneered in Europe, and picked up later in China in 2011.

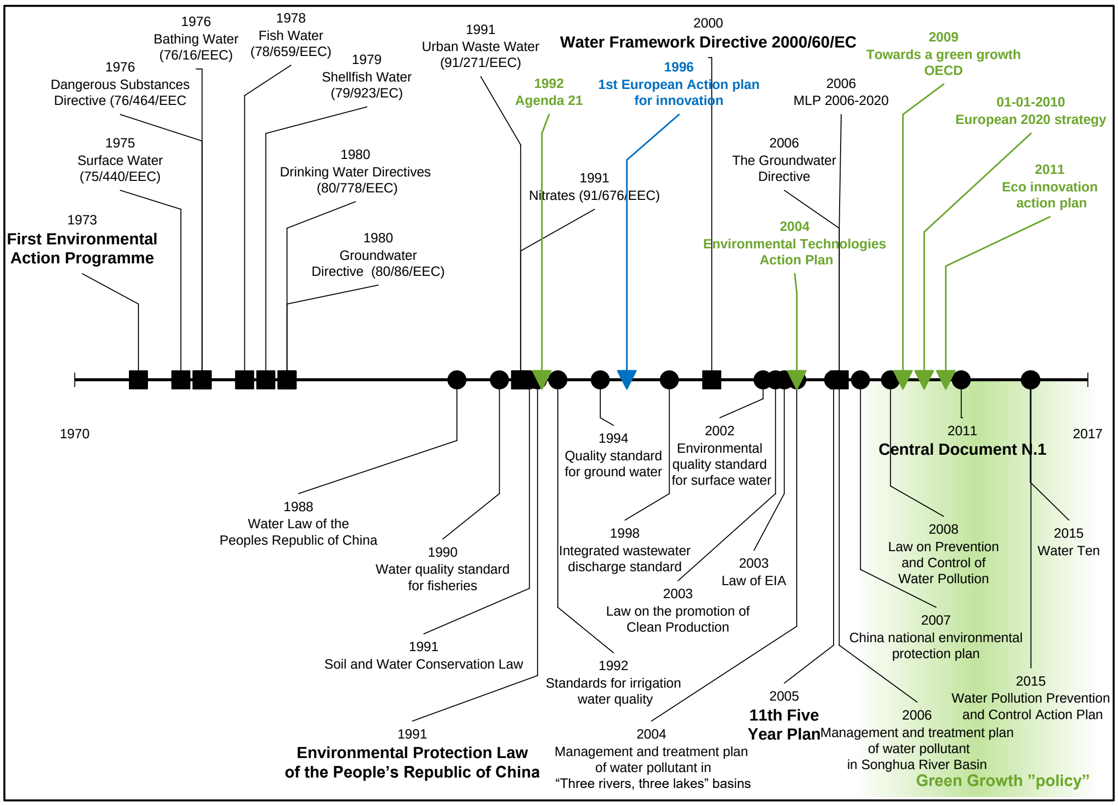

Figure 7: Water regulations in China and Europe. Source: adapted from Moro et al. (I).

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 (91/676/EEC) and Urban Waste Directives (91/271/EEC) 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. However, the Chinese regulations were more "political" than effective, since the water law from 1988 was only fully implemented in 2002 (China Water Risk, 2014). In between the second and third European water regulation waves, came the major events marking the beginning of the green growth agenda.

The passing of the European Water Framework Directive (WFD) marked the beginning of the third European wave, and really set the stage for major revisions to the overall concept of EU water policy, working in particular to reduce the fragmentation of the existing regulatory system. The second wave of Chinese water regulations started with the 11th Five Year Plan in 2005. Probably one of the most important regulations of this wave is the 2011 Central Document Nr. 1, which was somewhat developed on the basis of the European WFD.

It also marked the beginning of their transition to the green growth agenda, with strong policies and discussions on both circular economy and "green catching up".

The analysis of the relationships among innovative actors in the water sector and regulatory framework for the development of technologies is even more recent, with studies in this field starting to appear in the literature after the 2000s and are still rather rare. The majority of studies in the field focused on specific study cases with limited application elsewhere. Recent studies from the OECD (2014) discussed the development of environmental-related water technologies based on patent analyses, indicating that the market for water technologies has been dominated by few countries (USA, Germany, France, United Kingdom and recently Japan) with no substantial changes over time, suggesting a lack of dynamics in the water sector.

Technological development faces match and mismatches and are conditions for the path dependency from knowledge accumulated over the years. The match and mismatches of technological development is related to alignment of technological capabilities, institutional set- up, infrastructure and demand. The existence of path-dependencies tends to be higher in sectors with strong infrastructure characteristics, such as the water sector. The sector is dependent on technologies provided from other sectors such as the ICTs. This means that the core technological development is outside the water sector boundaries. Also, the problem with new radical innovations in the water sector is that it many times requires large structural changes that incur high capital costs, with funds not being available since the investment in water infrastructure is linked with local budgets that suffer from macroeconomic instabilities and fluctuations.

There is a clear signal to the sector towards the adoption of water eco-innovation from the regulatory framework. However, how the innovative actors respond to those regulations is still debated. Furthermore, the stage of "how green" the water sector is, is still unanswered. Do companies perceive a potential/new market for eco-innovations in the water sector? Is the creation and development of a green market of water technologies on the run? In order to answer these questions, it is necessary to first overcome the major and most basic research gaps in the water innovation dynamics field. These gaps are divided into four areas: i) analysis involving the micro dynamics of water innovations; ii) the analysis of the water innovation framework conditions; iii) lack of analysis involving the process of innovative capacity in the water sector; and iv) systemic cross-country analysis to understand the different degree of catching-up, as well as different technological patterns in the water sector. The thesis attempts to contribute to the discussion of these current research gaps via a comparative analysis between Europe and China. Figure 08 provides an overview of the linkages of the research questions with the overall scope of the PhD.

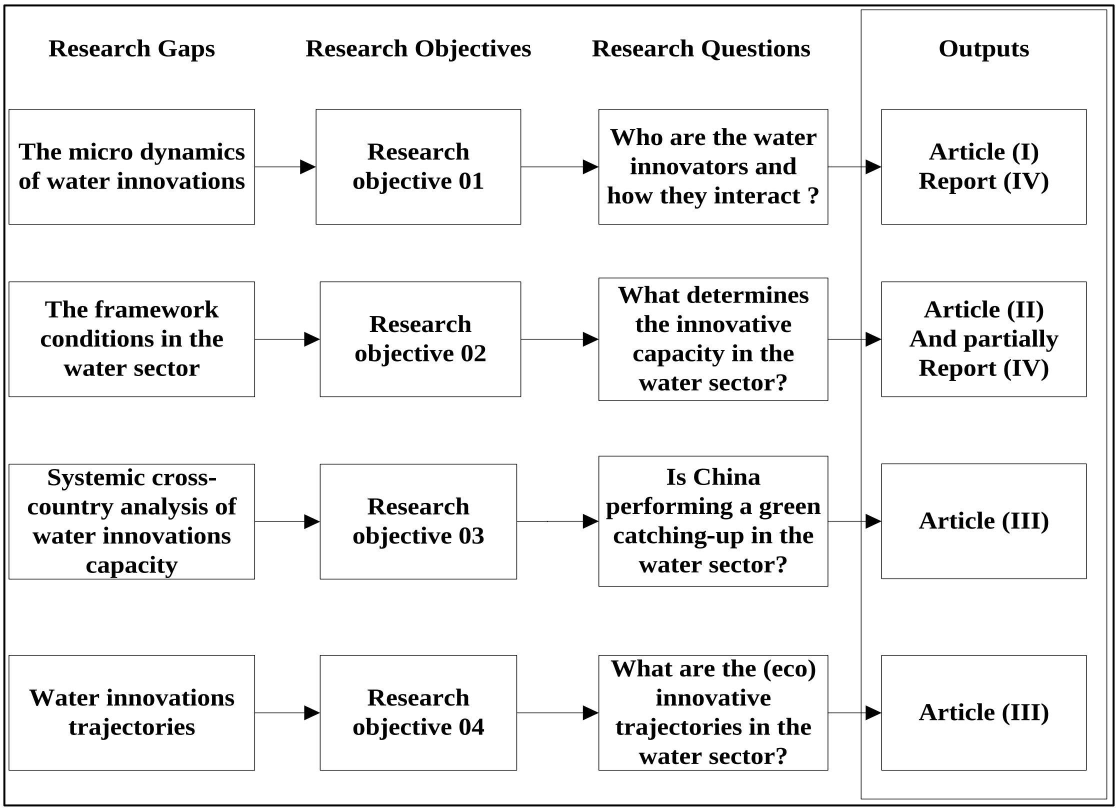

Figure 8: Linkages between research gaps, research objectives, research questions and papers

3.2 Methodological approaches and data sources

The first methodological approach used in this thesis involved the collection of patent data from different databases REGPAT, PATSTAT, OECD. The core indicator used in this thesis to express innovative activities in the water sector is therefore patents. The key challenge in using patents is related to the definition of water technologies and the international patent classification (IPC) codes. The water technologies were spread among different areas of IPC code, and hence not directly related to the domain separation studied here in part because some technological solutions may (technically) fit requirements related to more than one of the studied domains.

There were two assessments of the IPC related to water technologies with water experts. After the first assessment level, the IPC codes had divided the associated water technologies among the different water domains studied here: agricultural water management, industrial water management and urban and drinking water management. In the second assessment, the water technologies were further divided into 12 categories, which were based on the PIANO project assessment for technological water innovation (TWI), see also WP2 Deliverable 2.1 (available on the PIANO webpage). In the third assessment, the water technologies could be subsequently divided into water eco-innovations and general water technologies. This division was made based on the environmental technologies classified by the EPO and OECD water technologies list. Table 1 presents the water technologies divided by highly eco-innovative water technologies and general water technologies.

Table 1: Final list of water technology categories .

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

Source: Moro et. al. (2018).

The aim of this division is to capture whether there are differences in the dynamics regarding the development of eco-innovation in the water sector as opposed to general water innovations. The complexity lies in the taxonomy itself (how to classify water eco-innovations and why it is relevant). The main argument for making this division is that it is necessary in order to capture changes in water innovation dynamics towards a sustainable economy. This division further highlights the water innovations that are closer to the circular economy concept, which requires a combined effort from actors and institutions to change the innovative trajectory.

The second methodological approach used in the thesis was related to general economics and innovation indicators related to R&D investments, size of population, high education investments, among others. These indicators were collected from OECD, and UNEP GEODATA to analyze the innovative capacity of water innovations. The aggregate indicators were used to determine whether the innovative capacity of the water sector is related to the overall innovative capacity of a country, or whether there are differences among the different levels of the innovation systems (national to sectoral). The indicators were selected based on the NIC analytical framework developed by Furman et.al. (2002). Additionally, we added indicators believed to be important for the water sector. The EPS index was used as a proxy for regulations, pollution levels, quality of water and water dependency ratio. These water-related variables were chosen due to the availability within the analyzed timeframe (1990–2013). The third methodological approach used trade date related to a list of "green water technologies" collected from Comtrade and water patents collected via IPC to analyze a possible catching-up process of water eco-innovations from China compared to Europe.

The fourth methodology used in the thesis is based on a survey and semi-structure interviews, developed with the purpose of overcoming the limitations in using aggregate indicators in water innovation dynamics analysis. The thesis developed semi-structured interviews focusing on three important actors: i) water companies; ii) knowledge institutions and iv) water authorities. Additionally, the thesis developed a survey based on CIS. The purpose of the survey and interview to collect information related to the innovative pattern of interaction among the actors in the water innovation system to develop innovations, as well as the barriers and drivers of the technological development in the field.

4 Analyzing water innovation dynamics

This section begins by discussing the findings related to the water innovators within the water sector, along with their interactive patterns for Europe and China. The level of innovative capacity is discussed next, including the associated drive to increase the innovative capacity in the water sector and a comparative analysis of the levels of innovative capacity between Europe and China, which is important for understanding whether China exhibits a pattern of 'catching–up'. Finally, an analysis of the innovative patterns in the water sector is presented, which are linked with the eco-innovation literature.

4.1 Characterizing the water innovators and their interactive patterns

Historically, it is known that forerunners in water technology, such as the United States, Germany, and the United Kingdom have been leading the water technology market with no substantial changes documented over a prolonged period of time. Thus, the innovative knowledge, and consequently the leaders in water technologies are highly concentrated among these few countries. However, local water issues are not necessarily directly resolved by the technologies developed in association with these countries, and thus may require solutions made with technologies that can be locally supported. Additionally, traditional water technologies might reach a stagnation point, due to restrictions inhibiting sustained economic growth and development (Peuckert, 2013). Indeed, literature on the dynamics of water innovations are scarce and thus questions such as "Who are the water innovators?" and "Are they also leading eco-innovations in the water sector?" remain unanswered. As the dynamics of eco-innovations may differ from traditional technologies, this difference gets blurred further when it comes to water technologies due to the difficult to define n what is or is not eco-innovation in the water sector. This thesis proposes to test a new taxonomy of water technologies that enable to differentiate the water eco-innovations from the overall water innovations and consequently, reducing the lack of a definitive answer that tends to bleed into the definition of eco-innovations itself (see section 1.2.2). Answering the first research questions (discussed on chapter 3) "Who are the water innovators, are they in the private or public sector, and if they are in the private sector, what is the size of their company? Secondly, are the water innovators leaders also leading eco-innovations in the water sector?

The investigation related to the first group of questions showed that firstly, innovation leaders in the water sector are mainly private innovators, specifically belonging to the larger companies (more than 500 employees). Public innovators (universities and other knowledge institutions) are responsible for 2% of water innovations in Europe and 8% in China, over the timeframe analyzed (Moro et al., 2018). However, the distribution of water innovators (private *versus* public) changes when it comes to the development of eco-innovations in the water sector, with the role of public innovators in China increasing drastically. This reflects the level of maturity of the green market within water technologies, along with the national innovation strategy of China versus Europe. This is accompanied by a view of the development stages of the various regions. It is understood that environmental innovation (or eco-innovation) results from a dynamic and interactive process between institutions, technology and the industry, reflecting a systemic and sectoral character (Oltra, 2008; Oltra and Saint Jean, 2009). In the water sector, the institutions that govern water generally present a strong relation with regards to the level of innovative activities from major water innovators Moro et al., (2018). The major innovators in the water sector are large companies, specifically in China, large firms with a foreign controlling interest (Hampton report 2012).

The second dimension to be analyzed is the interactive patterns among the innovative actors. Innovation in general is characterized by a collective process which depends on interactions for knowledge diffusion. The several actors involved in the technological development process have varied skills and thus the exchange of knowledge through cooperation becomes essential for innovative activities, Each companies produces and has specific knowledge that are crucial to the innovative process, and you boost the innovative process when you share the your knowledge with other companies and vice versa, meaning, the companies do not innovate in isolation, but do so within the context of a system of networks made from direct and indirect relationships (Cassiolato & Stallivieri, 2010). Therefore, in order to understand the process of eco-innovation development in the water sector, we selected each source of cooperation and attributed a degree of importance to them through looking at firms that performed the innovations with cooperative relations.

According to the survey results available at Moro et al., (IV), the most valuable type of cooperation for the water companies are the suppliers of the e.g. equipment, materials, components or software. This indicates that the vertical cooperation is a form of cooperation that stands out as innovative efforts of companies in the water sector are concentrated generally in the acquisition of machinery and equipment. This has been proven by several empirical studies in other sectors (see: Stallivieri & Souza 2008; Britto & vargas, 2004). This type of cooperation is the consequence of the disintegration of the production due to the globalization of markets and also the very important in first stages of the innovation system, reflecting that in china the stage of the water innovation system is quite recent as compared to Europe that is known to foment interaction among companies via the promotion of strong network platforms.

Moreover, clients and customers were also pointed out as a major source of cooperation in water innovations. The customers in this case come primarily from the water utilities and related industries. This shows the important role of the consumer in the promotion of eco-innovations; by revealing their preferences and needs, it can drive technological development (Malerba, 2002; 2006). In addition, several authors (e.g. RIP & Kemp, 1998; Geels, 2002; Geels 2004) claim that for eco-innovations, the role of the consumer can create niche markets that contribute to the improvement of the eco-innovations, playing the role of "incubators" for this type of technology.

Wagner (2008), from a review of authors who have addressed the issue of the influence of the selective environment in the decisions of agents, highlights that "green consumers" represent a major boost in demand generation and/or adoption of eco-innovations. The assessment of the preferences of these consumers, through market research, indicates that the provision of information to consumers regarding the environmental quality of products and processes of a firm (whether through certifications or other mechanisms) may be considered similar to the relevance of regulation (Cleff & Rennings, 1999; Wagner, 2008). In the water sector the utilities are at the same time consumers and providers, so this relationship between water companies and water utilities presents a special link in the water sector. The water utilities also meet barriers for technological developments and these barriers may differ from those met by water companies (Luken and Van Rompaey, 2008). The water utilities barriers to innovate may have high relation with the level of local investments that are linked with local budgets and local regulatory framework. However, the specific study of water utilities weren´t address in the scope of the thesis.

According to Moro et.al (IV) the business opportunities in the Chinese market were related to water re-use and recycling, since the companies targeting the Chinese market were mainly offering products related to these areas. Finally, universities were also pointed out as important avenues for collaboration in the development of new technologies. The relevance of the relationship between companies and the university is widely emphasized in certain literature (Nelson, 1993; Lall, 1992, Nelson & Rosenberg, 1993; Cohen, Nelson & Walsh, 2003). With respect to the geographical location of these cooperative endeavors, the majority of the interviewees were mainly from their own country or other European Country. Conferences, fairs and networking platforms appear to be of medium importance, showing that association with a group or network is viewed as a positive driver for eco-innovation, emphasizing the importance of "horizontal economies of scale" and cooperative strategies for this type of innovation (Mazzanti & Zoboli, 2006; Horbach, 2006). Overall, the innovative patterns in the water sector (within the scope of the survey target) reflects that the sector is still at early stage of the green growth agenda, whereas the opportunities of green business are starting be visible but there still a strong important role of the government to enforce the path towards the adoptions of eco-innovations.

4.2 Determining the water innovative capacity

The water innovative capacity can be understood as the ability to promote and sustain innovative activities in the water sector over the long run. In the water sector the promotion of innovation and more specific of eco-innovation is mainly lead by environmental regulations, (Moro et. al. 2018; II). This reflect the current stage of the water sector into the greening of the economy, that can be understood as "*the degree to which environmental issues are becoming integrated into the economic process. Fundamentally this means that environmental parameters are included in the selection processes on the market*" (Andersen p.10, 2010). This scenario is therefore related with the level of "eco innovativeness" in a given sector. However, the development of eco-innovation and consequently the capacity to sustain this development over the long period should not be understood as a simple response to regulations (Oltra, 2002). As mentioned in the previous section, the interaction patterns play an equally vital role, along with the framework conditions. Indeed, the water sector is highly regulated and presents different dimensions and levels of interactions. However, despite this variety, all of them are, to a certain degree, linked with the national strategy. Further links can be made with water infrastructure investments and local budgets, alongside the usage of water within urban, rural and industrial areas being linked with a water regulatory framework. Consequently, these elements are subject to changes over time, due to the environmental concerns and the national strategy of development during that particular time.

In the water sector the innovative capacity is more related to the set-up of the framework conditions than to the interaction among actors Moro et al. (II). This reflect the great challenge the water sector has to overcome to increase the interactions among actors, crucial to increase the capacity to perform eco-innovations. Additionally, looking into the innovative capacity of the water sector (intra-Europe), it is possible to observe that within Europe, there is a clear difference among the level of innovative capacity in northern and central Europe *versus* Eastern and southern Europe (see Fig. 9). Similar trends are found on the overall innovative performance in Europe where "*The first group of Innovation Leaders includes Member States where performance is more than 20% above the EU average. The Innovation Leaders are Denmark, Finland, Germany, the Netherlands, Sweden, and the United Kingdom*" (European Innovation Scoreboard, p14, 2017). Figure 8 provides an overview of the evolution of water patenting per capita with time.

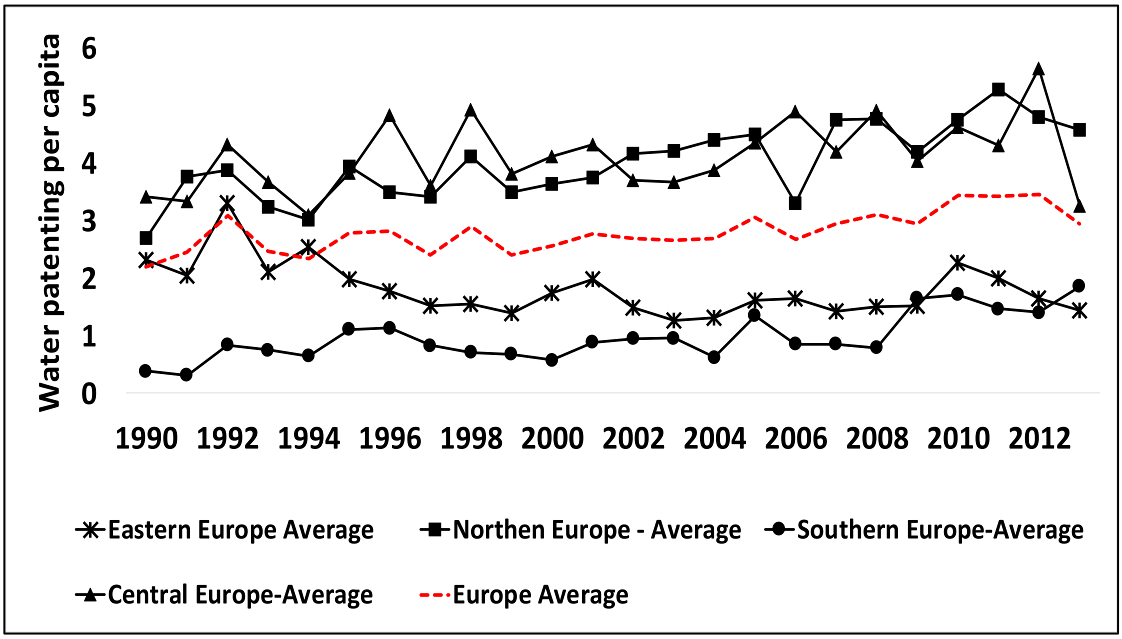

Figure 9-Evolution of water patenting per capita in European regions (average).

If we take a look at the Figures 9, we can see a marked division between northern and central Europe as compared to eastern and southern Europe. In order to analyze how marked is this division a one–way ANOVA test were conducted, Figure 10 presents the results from the ANOVA test. We observe that Central Europe presents a similar trend of European average, whereas Eastern Europe and Southern Europe presents lower trend, suggesting that central Europe leads the overall European trend although northern Europe presents the highest trends in water patenting.

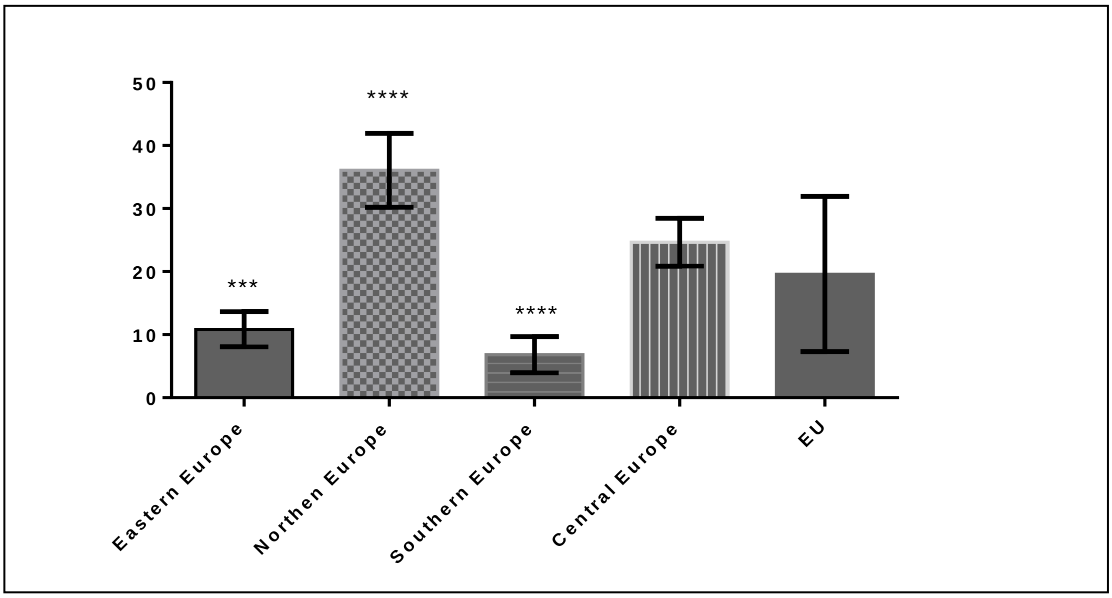

Figure 10 - Means and deviations of water patenting per capita European regions.

This results shows that despite recent European policies driving for a homogenous Europe, there are remarkable differences across Europe in terms of water innovations and water innovative capacity. The water innovative capacity is higher in northern Europe and Central Europe, reflecting the findings from Moro et. al II, which stated that the water innovative capacity is intrinsically related to the national innovative strategy. This means that countries that are known to be highly innovative are also highly innovative in water eco-innovations. Following this, a high ratio of patenting per capita seen in Nordic countries like Finland, Denmark, Norway, and Sweden, alongside countries historically known as water innovators like Germany, the Netherlands and France. The United Kingdom, despite being historically known as a water innovator, is just below the European average.

The number of water patents *per capita* can be considered a *proxy* for the level of innovative capacity in the water sector, and Figure 11 displays the evolution of water per capita among European Countries and China It is interesting to notice that despite the fact that Germany is a European innovation leader in water technologies, the evolution of water innovative capacity translates to water patents per capita. As such Germany appears to present a declining trend, suggesting that there are few significant improvements on the water innovation front Moro et. al (II).

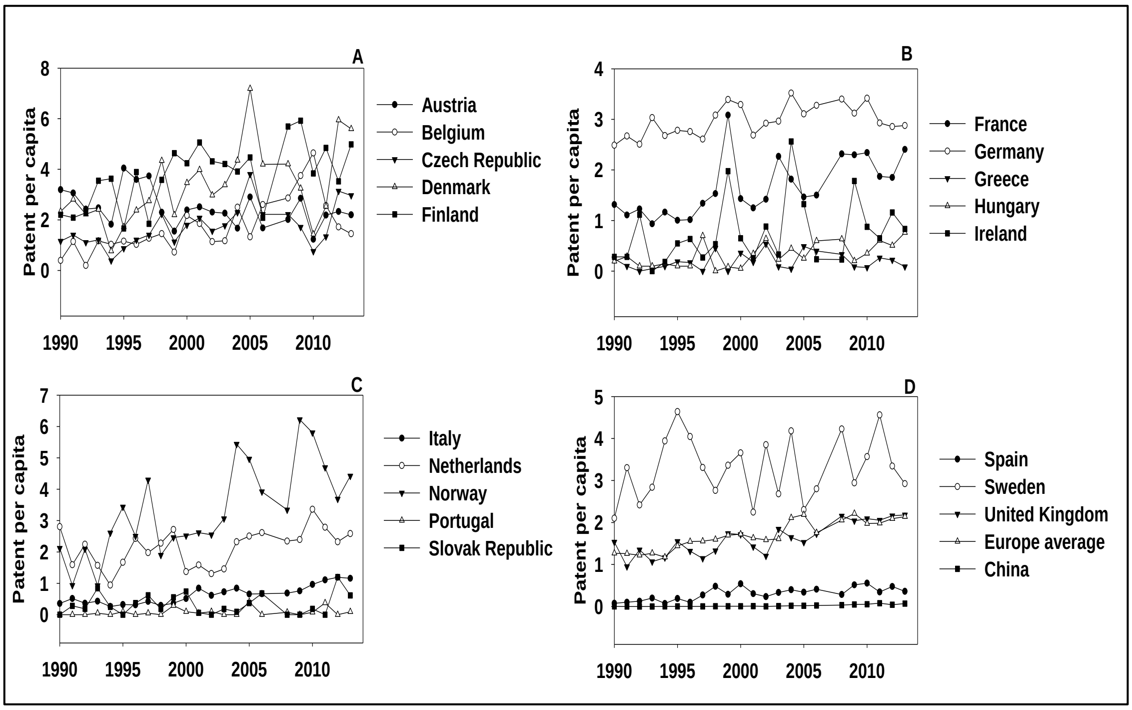

Figure 11:Evolution of water patents per capita among European Countries and China.

The same trend can be found in France and the United Kingdom. We can also see the heterogeneity among European countries; this result is in line with what was found by the European Commission (2013) and Faber and Hesen (2004). The Nordic Countries are the ones presenting higher rates for water patenting per capita, suggesting a higher innovative capacity to develop water technologies. China, on the other hand, presents low rates of water patents per capita when compared to water patents, showing a gap between the European average and China (Moro et. al II). This demonstrates that a large volume of patents does not necessarily translate into innovative capacity. We can also observe how the mean and deviations follow a trend, showing that countries with low means and low deviations have historically been less innovative.

Overall, Moro et. al (II) provides insights related to how the national strategy can affect the sectorial dynamics of the water sector, highlighting water as a sub-system of the national innovation systems. The water innovation dynamics presents similarities with the national dynamics, but this is not always the case for other sector, since it is known that sectorial patterns of innovation may present specific characteristics, based on the sector-specific characteristics the firms share (Breschi & Malerba, 1997; Klevorick et al., 1995; Malerba & Orsenigo, 1993, 1997; Malerba, 2002; Nelson & Winter, 1982; Pavitt, 1984; Winter, 1984, Dosi, 1988). In the water sector, country and region-specific elements may also overlap, thus reducing the effect of sector specific elements

(Barney, 1991; Clausen, 2013; Cohen and Levinthal, 1990; Dosi et al., 1997; Fagerberg, 2003; Leiponen and Drejer, 2007; Peneder, 2010; Teece and Pisano, 1994; Teece, 1980).

4.3 Analyzing the technological "catching- up" process and innovative patterns in the water sector

The Chinese government, with a strong focus on circular economy alongside water recycling technology, can be seen as starting a trajectory change in their water sector dynamics. This might entail supporting companies to seek potential for green business opportunities in the sector for local companies (Moro et. al., 2018). While the previous section mainly utilized patents as a barometer for analysis, this section looks to trade data to analyze the Chinese performance on the global market, as opposed to Europe. It can be seen that where the patents showed low innovative activities over time, the trade data showed a steady increase in the market share of Chinese technologies, indicating that China is indeed in the process of a technological catch-up in this sector. However, there are ambiguities in the results, as from the patents it looks like China is starting to increase its innovative capacity but is still at a very early stage and lower level compared to Europe. However, from the trade data analysis, China is seen as more advanced, having significantly increased their market-share of water technologies **(**Moro et. al III**)**.

In addition, the level of the specialization index of different technological fields within the water sector has been analyzed. Figure 12 reflects the general patterns for water eco-innovations in both regions. Both regions present similar water technological patterns with a strong focus on pollution control - related to industrial waste water management. In theory, these are considered "end-of–pipe" (Kemp and Pearson, 2007) water technologies that do not necessarily bring radical changes to water infrastructure and water resources management. However, while the water sector does not contribute to water pollution in the same magnitude as the other sectors, technologies from the water sector are expected to be responsible for overcoming the challenges related to a high level of water misuse and pollution.

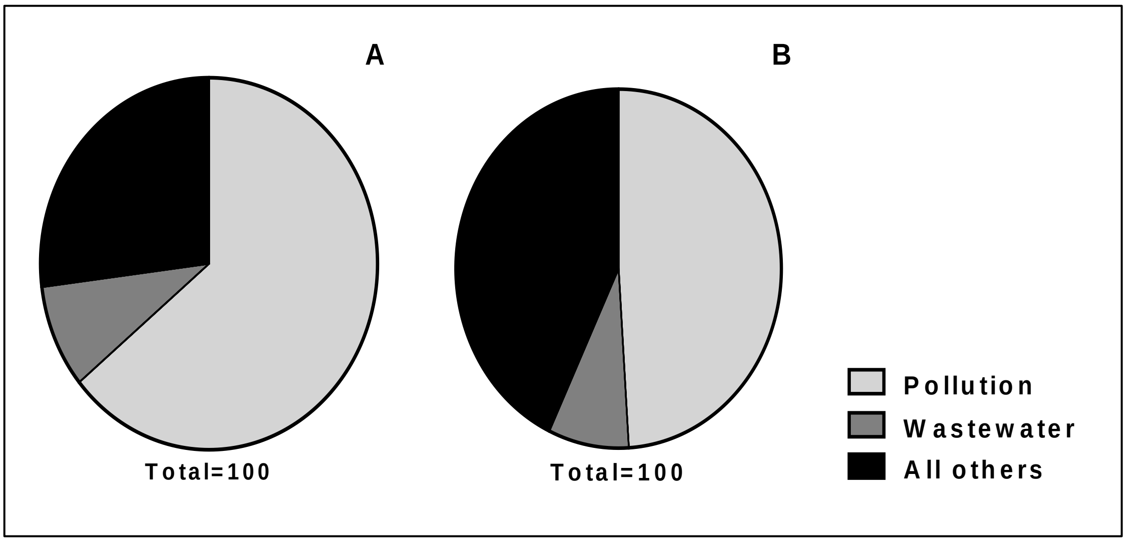

Figure 12: Innovative patter in water eco-innovation for China (A) and Europe (B) adapted from Moro et. al. (III).

Moreover, it can be said that the evolution and interaction of these types of technologies, revealing that China has increased their interactive learning of water technologies via both an increasing number of internal co-inventions (i.e. Chinese actors interacting with Chinese actors in order to create new knowledge), as well as increasing the level of external co-inventions (i.e. number of Chinese actors involved with international actors in order to create new knowledge). The results indicate that China is on the move towards a 'greening' of their water innovation systems, relying on external knowledge while simultaneously developing internal sources and capabilities. As a result, the Chinese water innovation system is transitioning in two ways: it is performing a technological 'catching-up', following the dominant trend similar to the European, while also departing from the dominant technological trajectory by adopting and developing new ones. China uses the aforementioned latecomer advantage (fewer costs in terms of infrastructure), since they have an ongoing process of (rapid) urbanization and infrastructure development. They can thus use this to their advantage to adopt more radical disruptive water technologies. This advantages may also be favorable for a fast advance in the process of greening the water sector that is related to the increase of green business opportunities constituting a green market in which eco-innovations are the central.

In general, we can understand the rise of the greening of markets as an element related to the techno-economic paradigm change (Kemp and Soete 1990; Freeman 1992, Andersen, 1999, 2002, 2008b). Theories and studies of innovation cycles argue that some changes in technology have so pervasive impacts on the economy that they will entail a techno-economic paradigm change (Dosi, 1982; Freeman and Perez, 1988; Perez, 2000, 2002). It is her argued that the greening of the economy is of such a nature and scope that it has come to act as such an engine of economic growth and transformation (Andersen 2010). Figure 13 present the schematic illustration of "green markets" and where the China and European water sector and energy sector can be placed within the different phases of this evolutionary process.

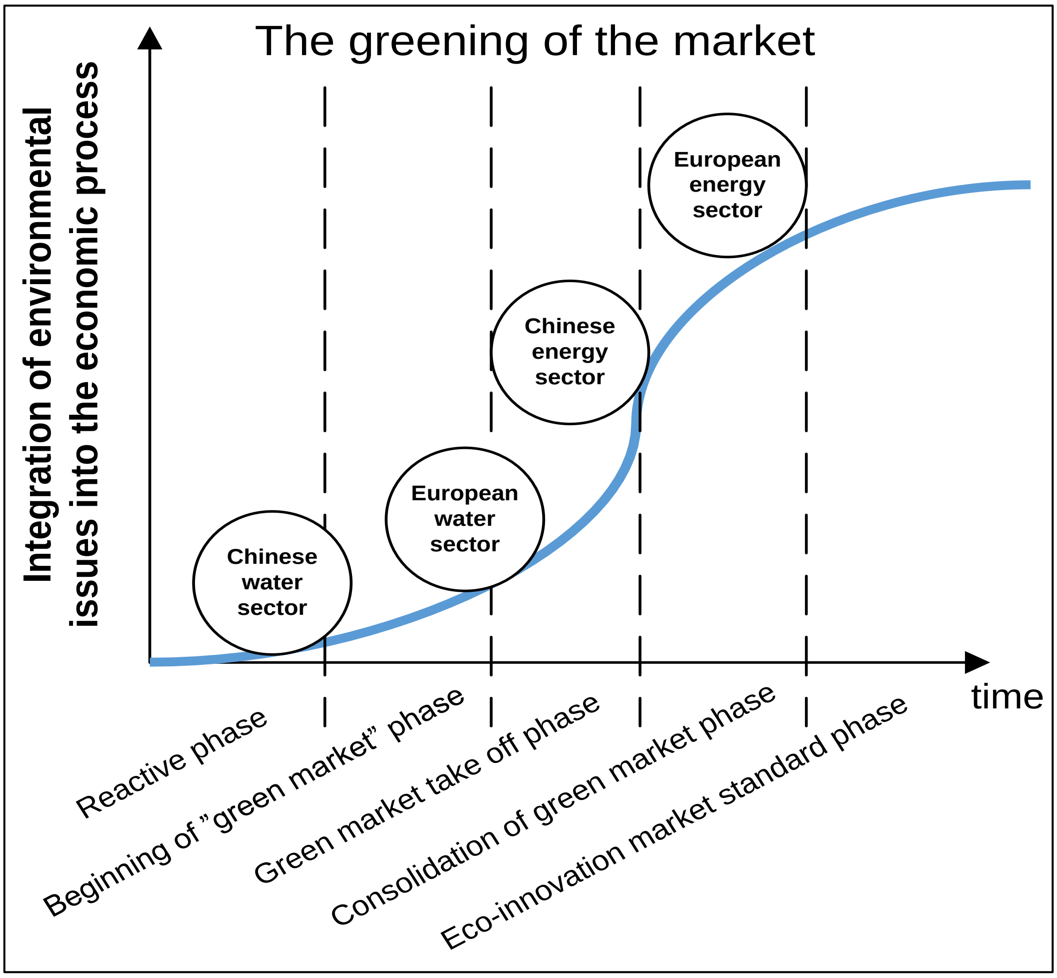

Figure 13: Schematic figure illustrating the thematic of green markets. Source: Own elaboration based on Andersen (2010).

Evolutionary economists pointed to the rise of the greening of markets as an element related to the techno-economic paradigm change (Kemp and Soete 1990; Freeman 1992, Andersen, 1999, 2002, 2008b). Theories and studies of innovation cycles argue that some changes in technology have so pervasive impacts on the economy that they will entail a techno-economic paradigm change (Dosi, 1982; Freeman and Perez, 1988; Perez, 2000, 2002). Therefore, the greening of the economy is of such a nature and scope that it has come to act as such an engine of economic growth and transformation (Andersen 2010). The greening of the economy is, however not about systemic technological change in a classical sense. The process of the greening of markets resembles more the pervasive changes of the economy associated with the rise of general purpose technologies such as ICT, biotechnology and nanotechnology (see figure 3 chapter 01). The greening of the markets is related to the degree that environmental issues are integrated into the economic process, based on the environmental parameter that are included in the selection process of the market. Taking this general idea into account, scholar may assume that the water sector is at an advanced stage of "the greening of the market" due to the strong environmental elements related to the sector. Contrarily to this apparent indication, the water sector can be considered a late mover into the greening of the market.

The evolution of water eco-innovation in both Europe and China is relatively low when compared to other sector, such as the water sector, both sectors are related with infrastructure (cities, nations, regions), both sectors are related to the search for resource productivities and both sector present strong regulations. Why they present different performances? Some might argue that the reason lies on the fact that innovations in the water sector are not patentable (When, 2014), at least not as much as the energy sector. This reason may partially explain the different levels of patenting activities of eco-innovation between the two sector. Figure 14 shows the evolution of eco-innovation patenting activities in the water sector and the energy sector for both Europe and China. Both regions present similar trends over time, but Europe at a much higher level[6]. The reason for this difference is beyond the likelihood of patenting activities per sector, it is a reflection of the level of maturity of "green opportunities" in the water sector *versus* energy sector.

[6] Please notice the break on the Y axis.

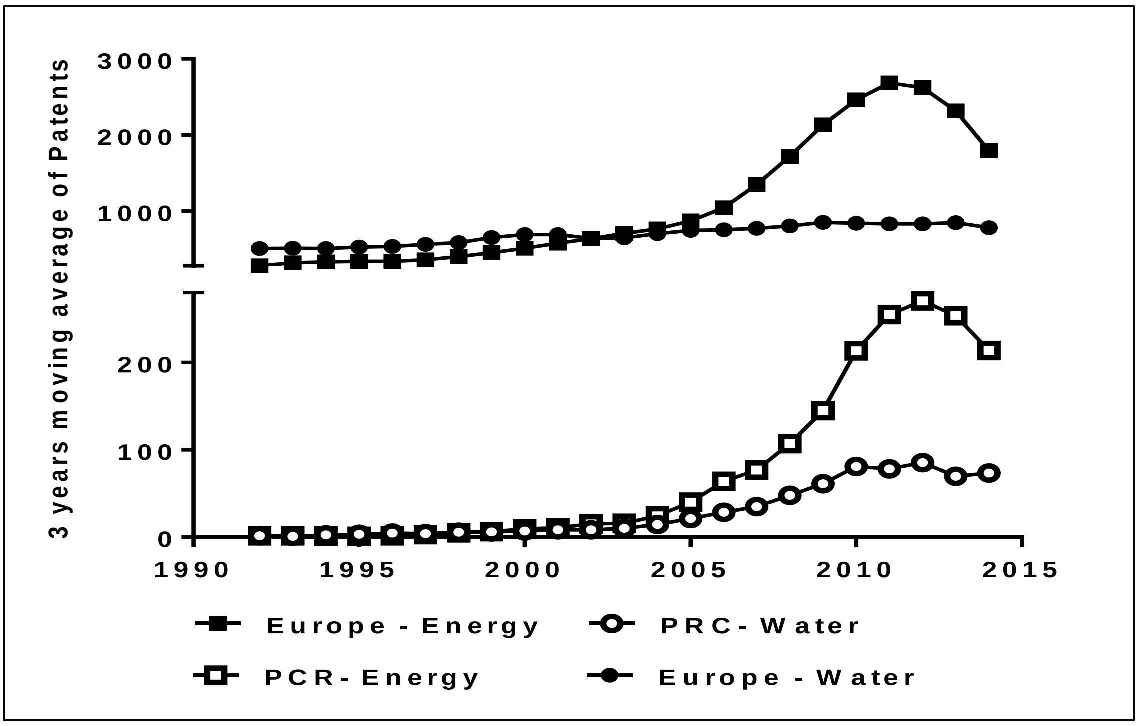

Figure 14: Evolution on patenting activities in the water sector and the energy sector for China and Europe from 1992-2014

However, this does not mean that the environmental concerns related to water started later than other sectors. On the contrary, due to the quintessential importance of water, there are various complexities related to performing radical changes with respect to water infrastructure and water resources management, thus making the cost of change markedly higher than for other sectors. To better understand this, we have to look at the three main aspects of water: 1) **social aspects of water;** water is required for everyone, thus there is a relation to the price of water and the coverage of water that in turn is related to water resources management. **2) Environmental aspects of water**, where this relates to the ability to sustain different ecosystems and thus also relates to the resource efficiency. **3) Economic aspects of water;** this aspect is related to sustaining the production of goods in general, and the associated usage of water by urban (municipal; industrial) and agricultural activities. Consequently, this is related to the pricing resource efficiency aspects of water.

Moreover, the creation of green business opportunities lies in the combination of the regulatory and overall framework conditions, and the perception and interactions among companies, reflecting the stage in the "greening of the market". In the water sector the elements related to the creation of green business opportunities change and evolve to meet challenges related to the path dependency of water infrastructure and costs - the older the water infrastructure, the higher the cost to radically change it. Additionally, the water sector is considered quite "traditional" with historically big companies in a highly concentrated market that has big entrance barriers. This might also explain to a certain degree why the water sector is lagging behind in the greening of the sector when compared to other sectors such as energy. The stage of the green market is also reflected on the innovative patterns in the European and Chinese water sector. As mentioned earlier (see figure 12) Europe and China presents quite similar water eco-innovation patterns, presenting a higher level of specialization on wastewater treatment technologies related to pollution control and overall wastewater treatment that fall into the "end of pipe" type of water technologies.

5 Conclusions

While the development of eco-innovation has become increasingly recognized (globally) as a core element in securing sustainable economic growth we still need a further understanding of the different dynamics and trends in countries at different stages of economic development. This is particularly interesting in the water area, water being a critical resource for any economies. The rising water stresses globally threatens a sustainable economic development and growth. Through evolutionary economic theory, that stress the key role of innovations for the process of economic change, this thesis has aimed to investigate the similarities and differences in the water innovation mechanisms in China and Europe, with a focus on outlining what drives eco-innovation development in the water sector in these two regions. Europe representing respectively a developed, green early mover economy, and China a centrally-planned large transition economy and green late mover. The major conclusion of the thesis are:

- There are important differences in the dynamics of general water innovation *versus* water eco-innovations particularly in China. Looking into the micro dynamics we have found that in China public innovators (universities and knowledge institutions) have a very important role for the development of 'water eco-innovations' as opposed to the development of "general" water innovations. The latter is dominated by a few big incumbent companies. There seems to be a better association among actors performing eco-innovation with the water regulations and innovation policies. We may conclude that the dynamics of water eco-innovations in China differ from Europe due to the high historic degree of central planning in the Chinese economy, where the role of public planning and public involvement in water innovation still affects the direction of water innovation importantly, prioritizing specific areas more than others.
- The Chinese innovation infrastructure over time has evolved to levels similar to European levels. This evolution is visible in the drivers identified for increasing the innovative capacity in the water sector. Our results show that the drivers for their water (eco) innovative capacity in China and Europe are quite similar; they are strongly related to their respective national strategies of development. The water regulations are still the core driver for eco-innovations in the water sector in both re-

gions, but water eco-innovations are not a simply respond to these regulations. The level of R&D investments and public budgets for water infrastructure also impact the level of innovative capacity of water eco-innovation.

- Analyzing the degree of catching up of China in relation to Europe the thesis concludes that China is on the move towards a 'greening' of their water innovation system, a trend that is likely to continue and increase in the near future given the strong political priority to water in recent policies and investments. China is still relying on external knowledge to a high degree while simultaneously developing internal sources and capabilities though so far still showing a much lower water innovative performance than Europe.
- The thesis concludes that both regions present similar technological pattern of eco-innovation, pursuing mainly a traditional End of Pipe trajectory in the form of pollution control water technologies and wastewater treatment technologies. This result indicates the great potential for "green" business opportunities related to the development of water recovery and water conservation technologies that are more aligned with more preventive and circular solutions that are likely to characterize the green economy agenda. We do see some early signs, though, that China is starting to deviate somewhat from the End of Pipe dominant technological trajectory. China uses the latecomer advantage (fewer costs in terms of infrastructure), since they have an ongoing process of (rapid) urbanization and infrastructure development, where they can use this to their advantage to adopt more radical disruptive water technologies. Further analysis is needed to investigate the scope and dynamics of this.
- Based on a smaller qualitative analysis of the knowledge collaboration patterns in the water sector in China. We find strong vertical relationships, i.e. among water companies, their costumers (water utilities) and suppliers (ICT sector and manufactures). This is indicative that the water (eco) innovation system is still at a relatively early stage of development with somewhat limited interactive learning patterns. Further studies are needed on the nature of these interactive patterns.
- The analysis of the thesis has contributed to a more nuanced understanding of water innovation dynamics and trends than has been conducted up to this date, concerning both actors and technological trajectories. The limitations of the study are recognized, none the least because of

the limited previous studies to draw on, where only aspects of the very complex theme of water innovation systems has been investigated. We argue, though, that important aspects have been highlighted and that these may form a good basis for further empirical analysis of water innovation dynamics as well a theoretical discussions of water innovation systems and the green economy. Although these findings contribute to the understanding of the water innovation landscape, the underlying mechanisms behind the development of eco-innovation in the water sector also raises further questions that must be looked at before we can claim to have a satisfactory understanding of water innovation dynamics.

6 Perspectives

The thesis has contributed to the analysis of water innovation dynamics and trends in the European and Chinese water innovation systems, still limited researched. The rising global water problems are likely to create increasing attention to innovation in the water sector; hence much more policies and research in this area may emerge in the coming years. Future promising research could be looking into, first, the development of water technological trajectories in the respective regions, investigating none the least whether China, and other developing and transition economies, may depart from the trajectories of the early mover green economies.

A second important theme is examining the collaboration patterns within the innovation systems among the core actors in the water 'innovation dynamo' (water-companies and knowledge institutions) but including the specific role of the water utilities. The analysis specific to utility companies' green innovation movement has generated a growing body of theoretical and empirical contributions from quantitative and qualitative perspectives in recent years.

A third promising line of research is investigating the collaborating patterns internationally in depth, looking into how China positions itself in the international water innovation landscape. A forth interesting area is analyzing the framework conditions more deeply, none the least, there are planning advantages in a county like China. Fifth, a comparative analysis between the water sector and the somewhat similar energy sector, could be highly interesting. Both are characterized by a strong public involvement in the form of policies, planning and investments, and with a strong link to eco-innovations, but we need to know more about their similarities and differences.

There are important policy implications of the thesis. In order to meet the rising severe global water challenges, there is a need to support the development of more radical and eco-innovative technologies in both regions. It requires a strong effort from the policy makers and the innovative actors not only from the regulatory framework but also to incentivize and coordinate interactions among innovative actors to create a high eco-innovative capacity across the actors. Deep insights into the innovation system dynamics of important water innovation regions such as China and Europe may help this process.

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8 Appendix

Table A 1- Academic research in water innovation dynamics

Year	Author	Contribution to the field of water innovation dynamics
1998	Chen	Highlight the role of innovations to increase innovative capacity of water companies.
1999	Cramer et. al.	First time to discuss present the concept of water innovation in a paper.
2004	Barrip et. al.	First paper to refer "water innovations" to discuss leadership in achieve higher levels of water resource management
2005	Thomas and ford	Discuss the lack of innovation in water and wastewater treatment.
2009	Partzsch	Analyzes how/if governments can set the stage for industrial innovation, new and improved products, and the implementation of new, cleaner processes, products and services.
2010	Krozer et. al.	Analyzes evidences that suggest that markets for high-value water use invoke innovations and low cost technology adaptations.
2011	Hegger et. al.	Analyzes the consequence of the contemporary shifts in the relationships between water utilities, their competitors and domestic end users.
2012	Peuckert	Discuss the role of water technologies into the catching-up process of urban wastewater technologies, highlighting the need to adopt green technologies and the different potential among BRIC countries to do perform such transition
2012	Lobina	Analyzes the social factors enabling and inhibiting paradigms shifts as radical changes in the metabolism of urban water services
2012	Binz et. al.	Discuss that the leapfrogging in the Chinese wastewater sector might develop in either an integrated “international innovation system” trajectory, where Chinese and international actors closely interact, or in an “international competition” trajectory, where Chinese actors endogenously build up technological leadership in strong competition to international actors.
2012	Binz et. al.	Explains that a sizable OST industry developed in Beijing is explained based on the specific anchoring process of the

		four key resources in the Transitions in Urban early development stage of the industry
2013	Mvurliwenande et. al.	mislead nature of measuring knowledge and capacity development using technical performance. Technical performance and competence development are analyzed together in order to provide the level of Knowledge and capacity development (K C D).
2013	lili et. al.	Discuss that Diffusing on-site wastewater treatment in urban China faces barrier related to by mismatched regulation, city planning and policy interventions. And the includes reformed decision-making and operational procedures, role transition of relevant stakeholders, and improved financing mechanisms.
2016	Fuenfschilling and Truffer	Socio-technical approach to emphasized the co-determination of institutions, actor and technologies can shape the innovation trajectory towards sustainable paths
2016	Poustie et. al..	Uses a transitional scenario analysis to discuss potential leapfrogging to a sustainable urban water future in urban water.
2016	Kiparsky et. al.	Identifies that barriers to innovation in urban wastewater utilities in California is related to cost and financing; risk and risk aversion; and regulatory compliance.
2016	Bichai et. al.	Shows that barriers in the water-recycling innovation system is related to the fragmented institutions that regulate water recycling and major barriers occur earlier in the system, leaving mainly the water recycling technologies in the early stages of the system, where policy-induced path dependency block most selection mechanisms
2016	Binz et. al.	Addresses the early technology legitimation phase that combines recent insights from innovation studies and institutional sociology, using portable water reuse in California.
2017	Bikfalvi et. al.	Shows that organization innovations in the water infrastructure sector describe partnership between academia and companies to train labour force to meet market needs.
2017	Duijin	Discuss the impact of individual and collective reflection on how to improve the work of public managers in the water infrastructure in Netherlands.
2017	Grotenbreg and Van Buuren.	highlights the relevance of an integrated approach among regulatory capacity, financial resources capacity to increase

		information and effective interplay among all of need are require to promote successful innovation within the scope of water-energy nexus in Netherlands.
2017	When and Montalvo.	Used behavioural approach to innovation to analyze the increase of capacity and capabilities of water utilities via the water operator partnership.
2017	Garrone et.al.	Indicates that regulations per se are not enough to promote environmentally-friendly wastewater treatment technologies in northern Italy. The paper indicates the important role of community and inter-firm characteristics such as technological and organizational capabilities to promote these type of technology.
2017	Tutuasus et. al.	Concludes that the drivers for technological development in water service sector is ambiguous and differs according to the location and also change over time.
2017	Tanner et. al.	Conclude the regulatory drivers are important for technological advance in the wastewater infrastructure in Uk that is lead by mainly big private companies and water utilities.
2017	Bichai et. al.	Discuss the adoption of decentralized wastewater treatment plants barriers. They conclude the path dependency related to the centralized wastewater treatment plants play a major issue and to overcome this barrier is necessary to have long term coordination and planning with a collective vision and complete economic assessment.
2017	Annala	Frames water innovation within the concept of frugal innovation and discuss that the role of citizens that adopts low cost household filters as a niche market to this new technologies even the co-production of these technologies might impact the resource-constrained environments.
2017	Sousa-zomer and Cauchick miguel	Highlights that despite the ongoing technological development of the water sector the lack of new business models in the sector presents a barrier for the adoption of green technologies in the water sector.
2017	Gabrielsson et. al.	Discuss the importance of incubators on the process of technological development.
2018	Moro et. al.	Analyze the industrial dynamics of water innovations, discussing who are the innovative leaders in Europe and China.

9 Papers

I. M.A. Moro, U.S. McKnight, M. Yang, B.F. Smets, M.M. Andersen, 2018. The industrial dynamics of water innovations. An analysis for Europe and China. International Journal of Innovation Studies. Accepted, in Press. (44 pages)

II. M.A. Moro, B.F. Smets, M.M. Andersen, U.S. McKnight. Analyzing the national innovative capacity in the water sector for China and Europe. (Submitted manuscript) (61 pages)

III. M.A. Moro, U.S. McKnight, B.F. Smets, M.M. Andersen Green catching-up and Economic Development - An Evolutionary Analysis of Water Innovation for China and Europe. (Manuscript in preparation) (45 pages)

IV. M.A. Moro, U.S. McKnight, B.F. Smets, M.M. Andersen. What aggregate data does not tell. Surveys and interviews with water innovators in the Chinese context. Report (28 pages).

In this online version of the thesis, **paper I-IV** are not included but can be obtained from electronic article databases e.g. via www.orbit.dtu.dk or on request from.

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The department dates back to 1865, when Ludvig August Colding, the founder of the department, gave the first lecture on sanitary engineering as response to the cholera epidemics in Copenhagen in the late

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