The Paths of Clean Technology: From Innovation to Commercialization

by

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ABSTRACT

My dissertation aims to contribute to multi-level studies of institutions, as well as the social construction of technologies. It consists of three papers. In Paper 1, I demonstrate the evolution of three renewable technologies (solar, wind, and biofuel) from their creation to the present day. Combining institutional theory and innovation process literature, I show how the institutionalization of renewable technologies has partially failed, despite their benefits for the natural environment. While there have been many inventions in the renewable field, they were often challenged during the development and implementation processes. The challenges moved from technical barriers in the earlier periods to political barriers in recent time.

In Paper 2, I demonstrate how the tension between two societal-level logics, neo-liberalism and environmentalism, influences the rate, diversity, and direction of political and technological innovations in the renewable field. I argue that the tension reduces the rate of innovation, but increases its diversity because it creates more discussions among actors. I test my arguments on 93 nations over a 33-year period, from 1980 to 2012.

In Paper 3, I argue how an organization's green identity and image influence the attraction of financial capital among the clean technology firms. I build a multi-level identity construct and test my arguments between different industry cultures (renewables versus non-renewables) and with different audience (green investors versus non-green investors). I argue that a firm's green identity has a positive effect on the acquisition of resources at a decreasing rate, while a firm's green image has a negative effect on the acquisition of resources because firms are penalized for greenwashing the public. I test my arguments on a random global sample of 120 clean technology firms.

ACKNOWLEDGMENTS

I would like to thank my friend, Erdal Yiğit, who I have not seen for the past eight months to finish this thesis, for his emotional support. I want to thank my parents and brothers, who have patiently waited to see me after five years, for their unconditional love. I am very grateful for the prayers of my mother and my brothers when I needed help. I am very thankful of my father who did not ask me to visit him when he was in hospital because he knew it would be difficult for me to go back to Iran in the middle of my PhD.

I would like to thank my supervisor, Professor Dev Jennings, who has advised and supported me much of my PhD program. I want to thank my committee members, Professor Jennifer Jennings, Professor Michael Lounsbury, and Professor Joel Gehman for their support and encouragement.

I want to thank my friends and classmates who supported me mentally and emotionally during the long winters in Edmonton. I am especially thankful to my friend and old colleague, Gwyneth Edwards, who has always been there for me when I needed, and who has shown me there is something very beautiful above the competition and self-interest in Academia. I want to thank my friends Raheleh, Behnam, Evelyn, Mia, and Amir for their care and support.

I dedicate my thesis to all the students who have financial difficulties, but are bold enough to finish what they have started. Nobody told me that writing the acknowledgement is such a difficult task, making your eyes so full of tears.

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INTRODUCTION

Clean technology has emerged in the last ten years as one of the most vibrant and innovative sectors to solve climate change and natural environmental problems (IPCC, 2012). As such, it exemplifies technology commercialization processes and problems: the emergence of varied and often competing technologies, the simultaneous need for basic science coupled with commercialization, and the search for scalable business models to meet local and global demands (Pernick & Wilder, 2007). In this thesis, I combine institutional and identity theories with the innovation literature to explain innovation and commercialization in clean technology. Consistent with this combined perspective, I address, theorize, and empirically examine three issues: 1) what are the obstacles to the institutionalization of clean technologies, 2) how does the tension between two societal logics at the nation-state level, neo-liberalism and environmentalism, influence the political and technological innovations in the clean technology field, 3) what entrepreneurial features of clean technology firm start-ups attract investment capital? In both the innovation and commercialization analyses, I control for standard economic features of industry and country in order to focus on how culture, policies, and firm identities enable clean technology development around the world.

In this overview section, I discuss my overarching theory, and then turn to the nature of clean technology and how I will use this sector to examine my theory. I finish with a preview of my contributions, which are developed in each chapter and examined in more detail in the concluding chapter.

OVERARCHING THEORY

I make two theoretical contributions. The first contribution is related to institutional approaches to organizations; the second contribution is to innovation and sustainability. Where institutional theory is concerned, I add to the theorization of cross-level institutional processes (Thornton, Ocasio, & Lounsbury, 2012; Seo & Creed, 2002). In the case of innovation and sustainability, I combine both knowledge and social construction approaches to clean technology development. I discuss both contributions in detail below.

Cross-Level Studies

Institutions function across different levels (Thornton et al., 2012; Friedland & Alford, 1991). Global institutions shape the structure and behavior of nation-states, organizations, and individuals around the world (Schofer et al., 2012). Yet, studies on institutions often focus either on the micro (organization or individual) or the macro (societal or field) levels (Zilber, Lounsbury, & Meyer, 2013). My thesis addresses the gap by looking at institutions from a combination of various macro and micro levels. Palmer, Biggart, and Dick (2008) argue that one of the weaknesses of new institutionalism theory is that it focuses on environmental level of analysis, whereas an organization theory should operate at individual, organizational, and environmental levels of analysis, draw on a wide array of disciplines in the social sciences, and capture full range of behavior inside and outside the organization. They argue that our understanding of institutional influence on the individuals inside an organization and on the organization itself is very limited. For instance, we do not know how institutions influence organizational decision making, implementation of organizational strategies, and learning processes (Palmer et al., 2008). Friedland and Alford (1991) also criticize organization and neo-institutional theories for underexploring actors in the social context in which they are embedded.

Most organizational studies demote one level to the background. It is assumed to exist, but never explored (Zilber et al., 2013), while a constant tension exists between micro and macro levels of institutions. In fact, the macro and micro levels of institutions are interrelated, influencing each other. At the macro-level, global institutions and world culture shape the identities, structure, and behavior of nation-states, organizations, and individuals (Schofer et al., 2012; Friedland & Alford, 1991). At the micro-level, individuals and organizations attempt to engage in agentic behavior that is ironically defined by the institutional context in which they are embedded (Greenwood et al., 2008).

My thesis contributes to multi-level studies of organizations in a number of ways. In Paper 1, on the history of renewables, I demonstrate that inventions in and across the countries are enabled and constrained by the institutional environment and the resource environment in which they are embedded. In Paper 2, on policy and patenting in the renewable energy field, I show the effects of institutional logics on country-level environmental policies and patents. In Paper 3, I combine the pro-environmental country-level construct with investor and firm identity considerations to understand how clean technology firms attract financial resources.

Knowledge and Social Construction Approaches

Knowledge-based and social processes simultaneously govern clean technology, like most advanced technologies (Benner & Tripsas, 2012; Hargadon & Douglas, 2001; Orlikowski, 1992). Any innovation draws on prior innovations and their applications. Prior innovations provide opportunity spaces for new innovations, and new innovation can recombine or form categories that allow for various options. The opportunity spaces are strongly conditioned by macro institutional factors that set up the industry structures (Stuart & Sorenson, 2003). For instance, the solar industry has not died, despite the strong natural gas players, because major players like China continue to invest heavily in solar. China's actions force other, more economically driven countries, like the U.S., to continue investing in some segments of solar industry that appear to have a reasonable mix of core knowledge yield and future economic potential, such as micro solar cells[1]. A firm's or investor's own knowledge bases and social relationships with others in the industry also shape the specific innovation paths or choices. Below, I describe briefly how each paper in the thesis contributes to knowledge and social construction approaches.

In Paper 1, I demonstrate that the development of renewable technologies is enabled and constrained by technological, social, and political forces. In this paper, I show that having a good technology and infrastructure is not enough, and certain regulatory and cultural forces should be in place at the right time to enable the development of a new technology. Furthermore, I demonstrate that actors, who are involved in the development, need to theorize politically about the success of the new technology. In Paper 2, I demonstrate how institutional logics influence the innovation, controlling for economic and physical resources. In Paper 3, I control for technological and economic conditions of firms to demonstrate that the identity and image, the country context, and the industry culture matter to acquire financial resources. Before launching into these papers, however, it is important to discuss the nature of clean technology, my domain of study, and why this domain is a particularly useful sector for my analyses.

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[1] Micro solar cells are the next generation of solar cells that are 20 times thinner and much cheaper than the solar cells of today, which are estimated to be in market by 2020 (http://cleantechnica.com, 2013).

The Nature of Clean Technology

The definition of clean technology is in flux and evolving. Some experts define it more strictly than others do. For instance, Jacobson and Delucchi (2009, p.1) believe that clean technologies include only those technologies that have "near-zero emissions of greenhouse gases and air pollutants over their entire life cycle, including construction, operation and decommissioning." They add that these technologies should not present "significant waste disposal or terrorism risks." According to this definition, a technology such as nuclear is not a clean technology, because it creates carbon emissions 25 times greater than wind when the energies for reactor construction, uranium refinement, and transportation are considered (Jacobson & Delucchi, 2009).

At the 2011 Academy of Management (AOM) Conference, management scholars defined clean technology in broader terms: "[it] is an umbrella term that has been used for industries that focus on different technologies offering products and services with minimal to no damage to the environment" (Cleantech Symposium, 2011). This definition is similar to that of Clean Edge, one of the leading research and advisory firms dedicated to the clean technology sector. Clean Edge (Clean Edge website, accessed December 2011) defines clean technologies as "a diverse range of products, services, and processes that harness renewable materials and energy sources, dramatically reduce the use of natural resources, and cut or eliminate emissions and wastes."

While all of these definitions share some similarities in terms of minimizing harm to the natural environment, as my starting point, I follow the Cleantech group definition because it is more precise, allowing me to easily identify clean technology firms. The Cleantech group defines clean technologies as a diverse range of products, services, and processes that 1) "provide superior performance at lower costs," 2) "greatly reduce or eliminate negative ecological impact," and 3) support "the productive and responsible use of natural resources" (Cleantech Group website, accessed December 2009) [2].

Types of Clean Technology. Clean technologies can be categorized into 13 areas: agriculture, air & environment, biofuels & biomaterials, energy efficiency, energy storage, materials, recycling & waste, smart grid, solar, transportation, water & wastewater, wind, and other (renewable energy providers, hydro/marine, geothermal, on-site systems, hydrogen production, and combined heat/power) (Cleantech Group website, accessed December 2011). Please see Appendix 1.1 for detailed description of each sector.

According to statistics, at the end of 2011, 14,975 firms in the clean technology field received funding to invest in clean technologies. Figure 1.1 displays the distribution of companies by sector (Cleantech Group website, December 2011). Note that the total number of companies in Figure 1.1 is less than 14,975 because some companies do not belong to a specific category. As shown in Figure 1.1, energy efficiency, solar, and water and wastewater companies have attracted the highest amount of capital.

The Evolution of Clean Technology. The amount of investment in clean technologies has changed dramatically in the past decade. According to the latest report published by Clean Edge, the world's first research and advisory firm dedicated to the cleantech sector, the percentage of total venture capital investment in clean technology has increased from less than 1% in 2000 to more than 23% in 2010 in the United States. In addition, the value of global market for Solar Photovoltaics (PV) and wind energy has increased from US$ 6.5 billion in 2000 to US$ 131.6 billion in 2010 (Pernick et al., 2011).

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[2] Cleantech group experts emphasize that clean technologies should not be confused with environmental technologies (envirotech) or green technologies (green tech) that were popularized in the 1970s and 1980s. Those were "end-of-pipe" technologies (e.g., smokestack scrubbers) that represented limited opportunities for attractive returns and were regulatory-driven (http://stats.oecd.org/, accessed May 2012).

The total number of clean technology investment deals at the end of 2011 was 6,380, equaling US$ 115.5 billion raised in this sector. Figures 1.2 and 1.3 show the number of investment deals and the monetary volume of investments (in millions US dollars) for each year respectively for 1997-2011. As the figures show, the investment trend, both in terms of the number of deals and the monetary volume of investment, has grown each year. Interestingly, while the number of deals has increased 10 percent from 956 in 2010 to 1,060 in 2011 (Figure 1.2), the monetary volume of those deals has more than doubled over that same time (Figure 1.3) (Cleantech Group website, accessed December 2011).

Another leading research company in the clean technology sector, Bloomberg new energy finance, states that global investments in clean energy, in general, have increased from US$ 52 billion in 2004 to US$ 243 billion in 2010 (Green investing 2011, 2011). Bloomberg experts add that investment in clean energy is not only a means to respond to the climate change concerns, but also a way of addressing the price volatility of traditional energy sources and increasing concern about the use of nuclear energy as an alternative energy source (Green investing 2011, 2011).

According to another research report issued by the Bloomberg group, if we want global warming to be limited to 2ºC without compromising economic growth, global investment in clean energy needs to grow to US$ 500 billion dollars per year by 2020 (Green Investing 2009, 2009). As of April 2011, investment in the clean energy sector is approximately US$ 250 billion per annum. In 2009-2010, governments around the world spent about US$ 194 billion to support the clean energy sector. The United States, as a global leader, has directly invested US$ 65 billion, and China, the second global leader, has directly invested US$ 46 billion in the clean energy sector (Green investing 2011, 2011).

It is worth mentioning that clean technologies have existed long before being labeled as clean technologies. Using ScienceDirect, Factiva, and Google to research the term "clean technology", I found that the term appeared in scientific, business, and economic journals as early as the 1980s (Factiva.com, ScienceDirect.com, & Google.com, accessed December 2011). Figure 1.4 shows the relative number of documents that include the term "clean technology" (Google.com, accessed December 2011).

Clean technologies, specifically those that work with renewable energy, have radically diffused in the past ten years. For instance, worldwide statistics show that the number of hybrid electric vehicle models available globally has increased from 2 types in 2000 to 30 types in 2010; and, while there were only 3 Leed-Certified commercial green buildings in the world in 2000, that number jumped to 8,138 in 2010. Looking at U.S. statistics also reveals that the number of hybrid electric vehicles on the road in the U.S. was less than 10,000 in 2000, but more than 1.4 million in 2010 (Pernick et al., 2011).

The Rationale and Design for Using the Clean Technology Sector

To me, clean technology represents an exemplary or "peak" case of innovation and commercialization, and, as such, allows me to examine the three research questions about the evolution and institutionalization of a technology. On one hand, I can examine how new global sectors that are based on innovation emerge, which is a central issue for innovation process theories (e.g., Cleantech Symposium, 2011; Journal of Business Venturing special issue on cleantech, 2010). On the other hand, I can also observe the real time growth and solidification of the field, which is vital to institutionalization. Indeed, several scholars at top universities have started to expand organizational theories using clean technology context. These studies include:

research on clean technology and investment at the University of Minnesota (e.g., Marcus, Malen, & Ellis, 2013; Malen, 2011); research on clean technology patenting by Michael Lenox and colleagues at the University of Virginia in collaboration with colleagues from Batten Institute (Bierenbaum et al, 2012); and research on U.S. renewable patents at the Harvard Business School and the University of Colorado by Lee Fleming and Kenneth Younge, who collaborate with the national renewable energy laboratory (NREL) (Perry et al., 2011).

Empirically, the scope of these other studies varies from global to local and from the entire clean technology industry to just the renewables. In my analysis, I focus on the global level and on multiple clean technology sectors, mainly renewable energies in the form of solar, wind, and biofuel. By focusing on the global level, I can study the evolution of the knowledge spaces in the sector more completely, given that it is a highly international system. Over the past three decades, 1,719,736 clean technology patents have been distributed in more than 100 countries (IP checkups website, accessed April 2013).

Clean technology is considered the “solution” to global environmental issues, such as climate change (IPCC, 2012). Response to environmental issues occurs at multiple levels, which creates a discourse that moves across levels. At the macro-level, world associations, such as the United Nations, set agreements like the Kyoto Protocol and the Copenhagen Accord, which are diffused and translated into nation-state environmental policies and influence the behavior of organizations. By studying clean technologies globally I examine a highly rational and technological practice (innovation) through the socio-cultural lens. Empirical testing of this link is not possible in other high-tech industries that do not possess such strong cultural and social components. Furthermore, one significant feature of clean technology is its “moral underpinning as a vehicle for the greater good" (Lane, 2011), which makes it a good research setting to explore how firms portray themselves in order to acquire financial resources.

Approaching this topic from a global level, I have chosen to constrain the number of clean technology sectors to three related segments. For most of my papers, I examined wind, solar, and biofuel sectors. I selected these three sectors because, while they are all renewables, previous research shows that each sector maintains different dynamics in terms of innovation activities (Perry et al., 2011). In Paper 3, I randomly selected 120 clean technology firms with an emphasis on the three sectors of solar, wind, and biofuel technologies.

Paper 1: Partially Failing Innovations in Institutional Systems: The History of Renewable Energies

In this paper, I draw on institutional and innovation process theories to theorize why renewable energies have yet to be fully legitimized as mainstream energy sources in spite of their benefit to the natural environment. In particular, I theorize on why renewables have remained "alternative" sources of energy throughout the history. To do that, I constructed a chronological narrative (Langley, 1999) of the evolution of three renewable technologies: solar, wind, and biofuel. I analyzed four time periods for each renewable technology: the pre-industrial revolution (period 1); the industrial revolution until the end of World War I (period 2); post World War I until the 1973 oil crisis (period 3); and 1974 until 2014 (period 4). Based on my Master's Degree training in innovation, I coded the key inventions in each period and identified the triggers and inhibitors of these inventions. In each of these periods, the shortage and the risks associated with other sources of energy, the technological advancements, and the government and social support facilitated the use of renewables, while the relative low price of conventional sources of energy, the lack of knowledge, and the political disruptions inhibited the development of renewables.

Therefore, I argue that the facilitators and the inhibitors of the development of renewable technologies have been circling throughout its history, but the facilitators were not able to break the circle.

Paper 2: Competing Logics and Innovation in Nation-States: Policy and Patenting in Renewable Energy, 1980-2012

In this paper I demonstrate how the tension between two societal logics, neo-liberalism and environmentalism, at the nation-state level, influences the rate, direction, and type of political and technological innovations in renewable energy field within countries. In spite of the evident and important operation of logics at the country-level of analysis (Djelic & Quack, 2008; Simmons, Dobbin, & Garrett, 2006), less institutional theory work has been done at this level of analysis to examine how the contestation of logics may influence the creation and adoption of alternative ideas and practices.

Building on the notion of dominant versus “alternative, minority” logic at an organization-level of analysis (Durand & Jourdan, 2012), I argue that neo-liberalism, a dominant and majority logic, and environmentalism, an alternative and minority logic, influence the renewable energy field at the nation-state level of analysis. My main question is what are the consequences of the tension between the dominant and alternative logics on the political and technological innovations in a nascent field (i.e. the renewable energy field)? To answer this research question, I explore the effect of the tension on the amount of innovation, the diversity of innovation, and the direction of innovation.

I argue that each logic stimulates innovation that is aligned with that logic, yet, the joint effect of the two logics creates tension in the renewable energy field. I suggest that the tension between the neo-liberalism and environmentalism logics decreases the rate of innovation, but increases its diversity because it creates more discussion. I collected county-level data on 93 nations over the 33-year period, from 1980 to 2012 and used longitudinal, negative binomial, and regression models to analyze the data. This paper is co-authored with Professor Dev Jennings and Youngbin Joo, a PhD student at the University of Alberta.

Paper 3: Being Green or Talking Green: The Effects of Identity and Image on Attracting Investment in Clean Technology

Micro-level studies of institutions often look at how institutions enable organizational identity construction (Lounsbury & Glynn, 2001). Identity is a construct that is central to institutional theorizing. Institutionalism can take identity study beyond the organizational level to locate the identity in the broader contexts (Glynn, 2008). In Paper 3, I build a multi-level (individual, organizational, and country-level) identity construct and explore its effect on garnering resources.

In this third paper, I demonstrate that identity is socially constructed within and across organizations. The paper responds to the criticism that most of the past research shows that entrepreneurial firms have unrestrained ability to manipulate the environment (Thornton et al., 2012). By incorporating industry culture, country, and audience elements into the identity construct, I show how these elements affect the way entrepreneurial firms manipulate their environment (Martens, Jennings, & Jennings, 2007; Lounsbury & Glynn, 2001). I Collected data on 120 randomly selected clean technology companies and used regression analysis to analyze the data.

Summary

In conclusion, I address three questions that are important to the intersection of institutional and innovation theories: 1) what are the obstacles to the institutionalization of clean technologies, 2) how does the tension between two societal logics at the nation-state level, neo-liberalism and environmentalism, influence the political and technological innovations in the clean technology field, 3) what entrepreneurial features of clean technology firm start-ups attract investment capital? The rationale for using clean technology as a domain of study is due to its nascent, rapidly evolving, complex character, with at least a moderate length history, multiple sectors, and adequate data on both the innovation and commercialization aspects of the industry. Each of the papers below addresses one of the three questions. In the concluding chapter, I summarize some of my overall findings, contributions to theory and research, and describe briefly my future research plan.

Figure 1.1: Clean Technology Sectors

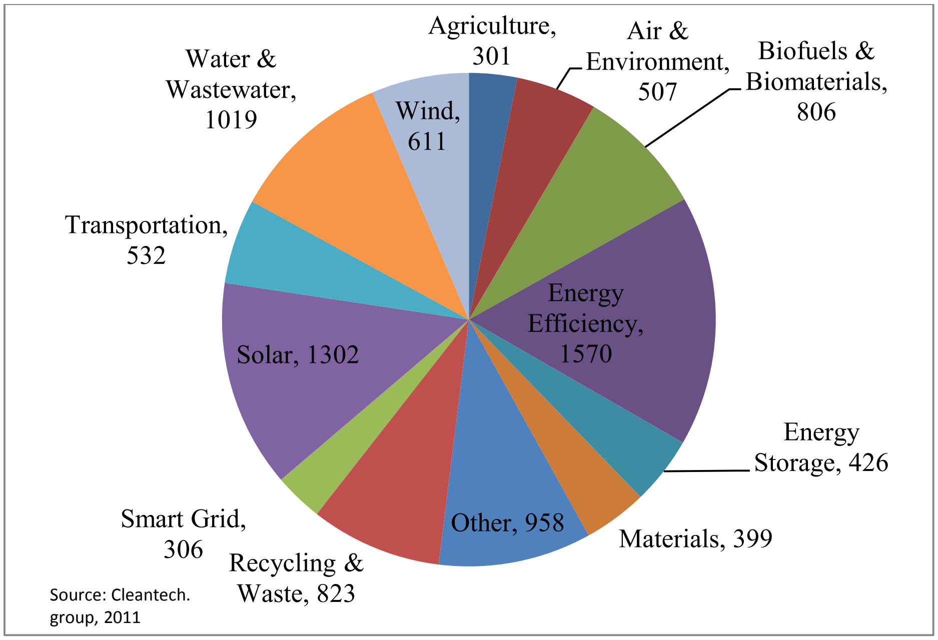
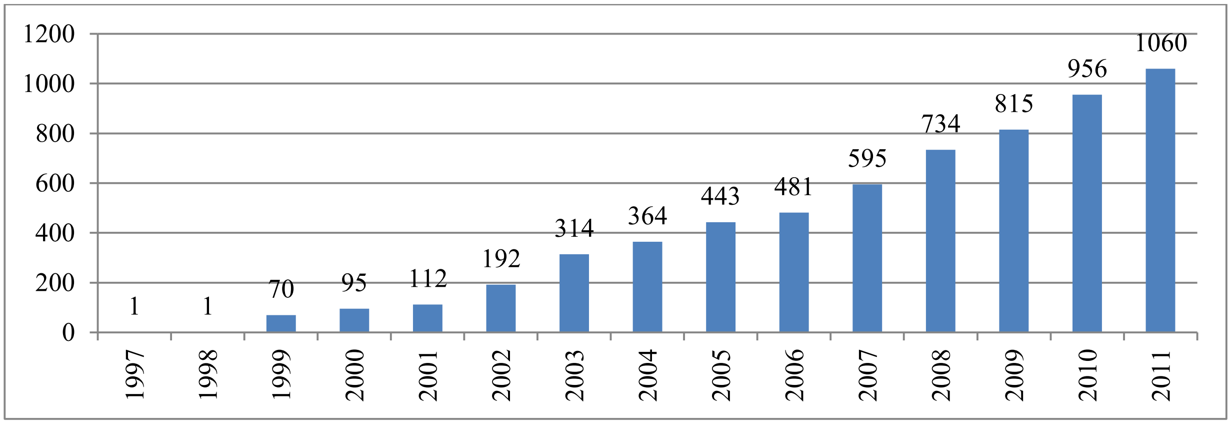
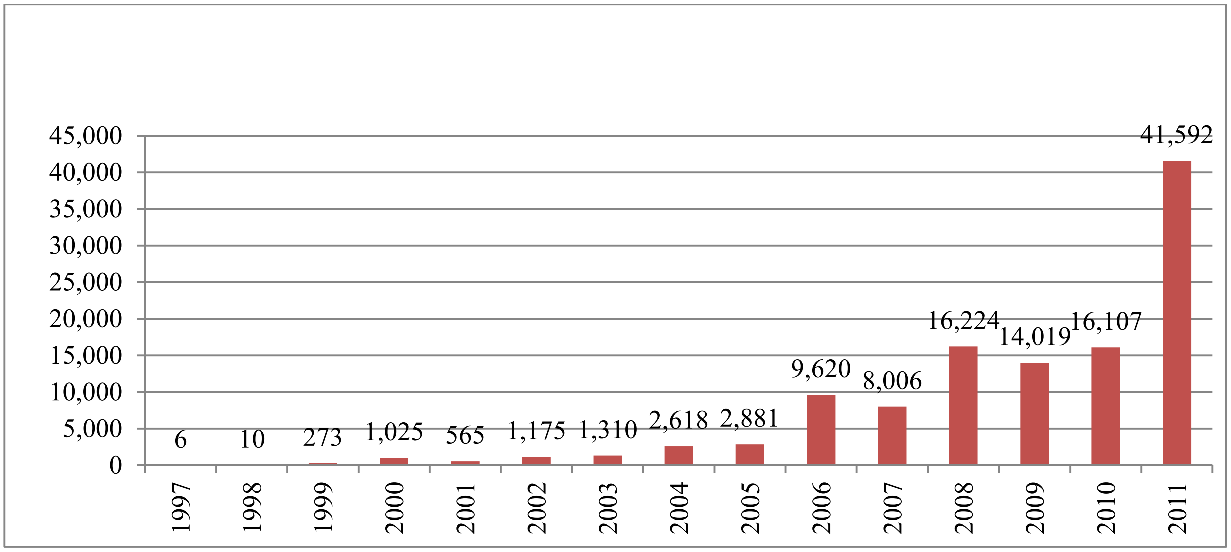


Figure 1.2: The Number of Deals per Year



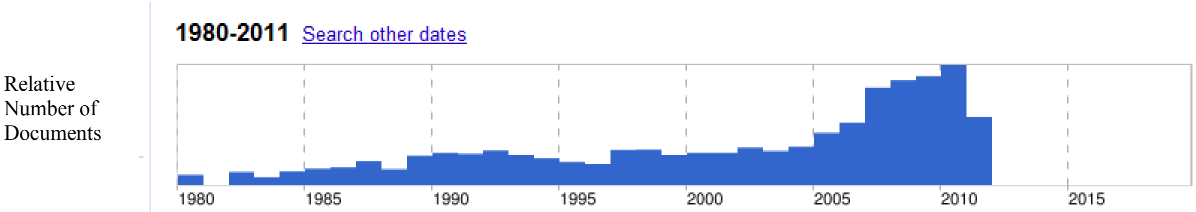
Source: Cleantech Group website, accessed December 2011

Figure 1.3: Amount of Investments (in Million Dollars) per Year



Source: Cleantech Group website, accessed December 2011

Figure 1.4: Mentions of Clean Technology



Source: Google.com, accessed December 2011

Appendix 1.1: Detailed Description of Each Sector

Materials	This sector includes polymers, metals, nanomaterials, chemicals, etc., all of which contribute to resource efficiency in some way.
Agriculture	This sector includes technologies, services, and related business models that contribute to more environmentally benign and sustainable agricultural practices and management of forests.
Air & Environment	This sector includes technologies, services, and related business models dedicated to removing active pollutants and greenhouse gases (GHG) from the air, after their release into the air.
Biofuels & Biomaterials	This sector includes technologies, services, and related business models dedicated to the production of liquid/solid fuels and chemicals from biomass and the production of electricity, heat from liquid/solid fuels.
Energy Efficiency	This sector includes technologies, services, and related business models designed to improve energy efficiency in buildings, data centers, built infrastructure, appliances, and consumer electronics.
Energy Storage	This sector includes technologies enabling the storage of energy, generally in mechanical, electrical, chemical, thermal, or potential (gravity) forms, over time for the later application to productive work.
Recycling & Waste	This sector includes technologies, services, and related business models contributing to the reduction, reuse, or recycling of waste streams.
Smart Grid	This sector includes technologies and services aimed at bringing a century-old electric grid into the information age; typically through the introduction of communications, monitoring, and control infrastructure to do things like increase system reliability and efficiency, enable active participation by utility customers, and integrate more diverse generation and energy storage assets with existing grid infrastructure.
Solar	This sector includes technologies, materials, services, and related business models enabling the harvest of solar energy for heating, lighting, or electric power production.
Transportation	This sector includes technologies, services, and related business models that enable the utilization of more sustainable transport options for people and goods.
Water & Wastewater	This sector includes technologies, services, and related business models that reduce the strains placed on the hydrologic cycle by expanding global population and industry while ensuring reliable access to clean water for domestic or industrial use.
Wind	This sector includes technologies, services, and related business models that enable the harvest of wind energy for electric power production.
Other	It includes renewable energy providers, hydro/marine, geothermal, on-site systems, hydrogen production, and combined heat/power. Hydro & Marine Power technologies are technologies used to harvest energy from water, either as kinetic energy from moving water, thermal energy from temperature gradients, or through osmosis capitalizing on salinity differentials; and convert that energy into electric power. Geothermal technologies are technologies that are dedicated to the harvest of geothermal energy for heating and electric power production.

Source: Cleantech Group website, accessed December 2013

PAPER 1: PARTIALLLY FAILING INNOVATIONS IN INSTITUTIONAL SYSTEMS: THE HISTORY OF RENEWABLE ENERGIES

INTRODUCTION

According to institutional theory, when new practices and ideas are legitimized, actors will adopt them - at the very least for symbolic reasons if not necessarily for the sake of efficiency (Greenwood et al., 2008; Scott, 2001). Renewable or "alternative" sources of energy have been around for hundreds of years, yet each time renewable energies have started to become legitimate, their institutionalization process has stalled. As a result, in 2015, we are still using conventional energy sources such as oil, natural gas, and coal, which, on average, are increasingly expensive to access and distribute and which damage the natural environment. In this first paper of my thesis, I explore the history of renewable energies to gain a better understanding of why institutionalization has stalled and whether there might be a hope for, at least, semi-institutionalization (Tolbert & Zucker, 1996) of some types of renewables in the near future. In other words, I try to understand what are the obstacles to the diffusion of renewable technologies?

To do so, I draw on both the institutional theory (Greenwood et al., 2008: 2011; Thornton et al., 2012; Scott, 2001) and the innovation process theory (Garud, Tuertscher, & Van de Ven, 2013; Van de Ven et al., 1999). Institutional theory is useful for several reasons: 1) it focuses on long periods; 2) it views institutionalization of innovations as a social and not just technological process; 3) it is well developed theoretically and empirically, which allows the mechanisms and stages of institutionalization to be identified. According to institutional theory (Greenwood, Suddaby, & Hinings, 2002; Hoffman & Ocasio, 2001; Hoffman & Jennings, 2011), innovations are trigged and then theorized by various actors, gradually objectified (e.g., through proto-types and accepted designs); then, if deemed legitimate, innovations begin to diffuse in an organizational field. Institutionalization is usually a matter of degrees - semi (partially) to fully, and more symbolically to substantively. Such has been the case with dozens of technical, social, and political inventions, such as the electric light (Hargadon & Douglas, 2001), the civil service reform (Tolbert & Zucker, 1983), the poison pill defenses (Davis, 1991), the mutual funds (Lounsbury, 2007), and the governance structures in professional service firms (Greenwood, Suddaby, & Hinings, 2002). Eventually, an innovation and their supporting infrastructure may become less acceptable and de-institutionalized (Hardy & Maguire, 2009).

However, perhaps because of my engineering background, I have always thought that the institutional theory has underplayed the importance of material resources, measurement of efficiencies, and failures, all of which are more commonly found in engineering. As a result, I have been drawn to innovation process theory, as summarized by Garud and colleagues (2013). This theory focuses on innovation and, although it has many parallels with institutional theory, it also injects some of these other more tangible elements into the institutionalization process. Like institutional theory, it has a stage process, which runs from invention, development, and to implementation. Unlike institutional theory, innovation process theory also starts with the role of prior failures, multiple inventions, and design principles. It also emphasizes the increasing role of resources and infrastructure (or supportive ecosystems), and the need for new platforms to be built around innovations. One of the drivers is legitimacy, especially in the Garud et al.'s (2013) version of innovation process, but the multiple experiments and the iterative shaping of the technology are equally important (Garud, Gehman, & Giuliani, 2014). Finally, the notion of failed or partially failed innovation is also very common in the technology and innovation process literature (Van de Ven et al., 1999). While not unexpected by institutional research, partial or complete failure is considered the more likely outcome for most innovation processes. This notion fits particularly well with renewable energy field, which is my phenomenon of study. Figure 2.1 summarizes these points on combining institutional and innovation process theory and guides my historical analyses.

--- Insert Figure 2.1 about here ---

To capture the various attempts at institutionalizing renewable energy, I examine the history of three distinct renewable energy technologies: solar, wind, and biofuel. The main rationale to use these three technologies is to provide context for Paper 2 and Paper 3. Furthermore, these three technologies are among renewables (i.e., are similar), but they have different paths of developments (i.e., show variation), which are explained in the historical analysis section. Several organizational scholars have examined history over a long period to study a problem or issue. For instance, Fligstein and McAdam (2012) studied human evolution to explain that humans have not only the capacity but also the need to engage in collective meaning making or what they refer to as "existential function of the social." Another example is Meyer and colleagues' (1997) study on the structuring of the world environmentalism regime.

Solar, wind, and biofuel technologies represent distinct types of renewable technology innovation (Cleantech group website, 2015; Pernick & Wilder, 2007), and each type of renewable innovation appears to have had its own historical rises and falls. Furthermore, each of these types has been known to have at least two "almost institutionalized" or "accepted moments", among some segments of society that used them. Solar was used very early in history, and it was revived in the late 1800s with the invention of solar engines. New inventions around solar arose then, but eventually failed. The same was true in the 1950-70 period for solar (and, again, perhaps in 2010-14). Wind power was partially legitimized on farms in the pre-industrial period but, instead of spreading, its use has stalled due to the success of the steam-powered engine. In the mid-1990s, Lowland and Scandinavian countries in Europe again started experimenting with wind power due to high electricity prices and their long history using windmills. Biofuel has long been used to generate heat but has been viewed as a more flexible, renewable source, only once the processing of biofuels was improved in the 1940s. At one point in the early 2000s, biofuels looked prepared to be widely accepted, but that has not happened.

As discussed below, I found that there were four periods of innovation and institutionalization for each type of renewable energy, and that some of these periods lined up closely with one another. As a result, I used four common periods for the three cases as the main narrative design for discussing my findings. Yin (2003) and Eisenhardt (1989) advocate starting with a strong case design, then modifying it based on what the qualitative analysis begins to reveal, and then telling the main story based on that modified framework.

To preview my findings, in each of the four historical periods, there was a shortage of energy and reduction in particular risks associated with alternative sources (partly due to technological advancements), government support, and local social mobilization. All of these factors facilitated the use of renewables. However, in each period, there also were massive price fluctuations in conventional sources of energy, a tremendous lack of knowledge about renewable energy, and political disruptions - all of which undermined the adoption and spread of renewable energy technologies. These cycles form an upwardly linked set of circles, a type of spiral towards greater acceptance and use. In each period the outcomes might appear disappointing, but across periods these outcomes have helped build up an infrastructure for renewables. The whole process continues to give us hope that alternative energies will be not just legitimized but widely adopted in this century. I also found that in the earlier periods, technical difficulties stalled the diffusion of the technologies; whereas, in the later periods, political barriers slowed down the diffusion.

My historical analyses contribute to institutional theory and innovation process literature, as well as to work on the natural environment. Most institutional theory studies look at how new ideas and practices have been institutionalized successfully (e.g., Maguire & Hardy, 2009; Greenwood & Suddaby, 2006; Tobert & Zucker, 1986). In this paper, I demonstrate how a practice that has existed for hundreds of years has yet to be fully institutionalized, and theorize on why this is so. In addition, I build on the institutional theory literature by offering a contextualized perspective through a cross-national study of innovation and institutionalization. Current studies on the development of the new ideas/practices have focused on a single region, mainly North America (e.g., Maguire & Hardy, 2009; Greenwood & Suddaby, 2006; Tobert & Zucker, 1986). Looking at the cross-national development of new ideas/practices enriches our understanding of cross-national institutionalization and the associated variables that either allow for or prevent such institutionalization. Finally, I highlight the importance of tangible resources as well as intangible resources in the institutional process, an area that has been understudied in the recent institutional theory studies (Jennings, 2010).

At the same time, I contribute to the innovation process literature by providing a macro, cross-national perspective, thereby complementing current studies that focus mainly on individual and organizational level within one country (e.g., Garud, Jain, & Kumaraswamy, 2002; Hargadon & Douglas, 2001; Garud & Rappa, 1994). My study demonstrates that macro-level innovation processes are temporal, global phenomena, where innovations may move and develop at different rates from one country to the next.

THEORY UNDERLYING MY HISTORICAL RESEARCH DESIGN AND ANALYSIS

As noted above, institutional theory is useful for examining the development and adoption of renewable energies, because the theory emphasizes both social and technical processes, covers a long time frame, is macro and micro, and considers various outcomes as possible, including partial institutionalization. At the same time, innovation process theory is useful because it underscores similar stages to institutional theory in the innovation and adoption process and considers the social construction of technology critical for the path it takes. By using innovation process theory, I focus more directly on innovation and design, to think about the role of material resources and critical moments, and pay as much attention to the failures as to the successes, because technologies often beget related technologies in future cycles.

As shown in Table 2.1, institutional and innovation process theory have interesting similarities and differences. To bring forth these similarities and differences, I line up the simple invention-development-implementation-outcome scheme with stages of institutional theory, as is depicted in Figure 2.1. I then compare and contrast the innovation and institutional factors in each column when assessing any historical case of innovation. Below I briefly review these elements in order to set up the key components to be examined in the historical case analysis.

Invention

According to the innovation process theory, both demand-pull and technology-push can trigger invention (Garud et al., 2013). According to the institutional theory, endogenous shock, which may be in the form of a problem, can trigger invention. For instance, institutional theorists have shown that a problem, such as the adverse performance of organizations (Greenwood &

Suddaby, 2006) or resource scarcity (Sherer & Lee, 2002), can trigger change, activate the innovation process, or lead to the development of new ideas/practices.

Exogenous shock, such as a social movement (Maguire & Hardy, 2009), technological disruption, or regulatory change, may trigger inventions as well (Greenwood et al., 2002). These social, technological, and regulatory changes destabilize the established practices (Oliver, 1992) and precipitate local inventions by new and existing actors. The actors invent independently to find solutions for the current problems in the field (Greenwood et al., 2002).

Regardless of the triggers of the invention, any invention is made through the collaboration of different actors, such as producers, evaluators, regulators, and users (Karnoe & Garud, 2012). How actors construct a technology and jointly create space to exploit its development influences their choice of paths (Garud & Rappa, 1994; Orlikowski, 2000). Invention requires knowledge and physical resources (e.g., material, labs, etc.), which is well documented in the innovation literature (for a review please see Tidd et al., 2005).

Development

Macro infrastructure is required for the development of an invention. It includes theorization (Greenwood et al., 2002), and physical, technological, political, and financial resources that support theorization (Garud et al., 2013). While the whole process of development can be influenced by external shocks (Greenwood et al., 2002), the critical element in development is theorization.

Theorization. A problem such as resource scarcity or social movement may trigger the innovation process, but actors who champion new ideas and practices need to theorize why the current ideas and practices are failing and what they can do to solve them. To be diffused, the invention should be theorized successfully, meaning that it should be justified as the solution for the general problem in the field (Greenwood et al., 2002). Tolbert and Zucker (1996) suggest that theorization has two major steps: specification of the problem and justification of the invention, which is the solution or treatment for the problem.

To understand theorization, one must ask several key questions: who theorizes; how do they theorize (Greenwood et al., 2002); and, when and where (i.e., in what context) do they theorize? Different types of agents can theorize (Greenwood, Jennings, & Hinings, Forthcoming) including professional associations (Greenwood et al., 2002), critics and journalists (Rao, Morin, & Durand, 2003), media (Sherer & Lee, 2002), and social movements (Maguire & Hardy, 2009). While different types of actors can theorize, they may not necessarily get the attention of the relevant audience. The agents need to have discursive legitimacy, which means they should have credibility to exercise their voice (Hardy & Phillips, 1998).

Theorization can be achieved through the use of discourse (Greenwood et al., Forthcoming). Discourse is the interrelated texts that are generated by actors. Texts give meanings to objects. Texts can be in the variety of forms such as written transcripts, verbal reports, pictures, and other artifacts (Phillips et al., 2004). Proponents and opponents of a new idea "rationalize" about their point of view through discourse. For instance, during the process of abandonment of DDT, the proponents and opponents advocated for their own perspective through discourse (Maguire & Hardy, 2009).

The context of theorization (when and where) refers to how the triggers and settings are used by various actors to theorize innovations. One of the best moments to theorize is when there is an exogenous/endogenous shock that opens up the discussion about the credibility of old practices and the advantages of new ideas/practices. For instance, the failure of two banks in

Alberta, Canada opened up the discussion about the suitability of public audit, and this led to the change in the accounting practices (Greenwood et al., 2002). In the case of the abandonment of DDT, the momentum of the theorization of opponents of DDT peaked when Rachel Carson's influential book, Silent Spring, which was highly critical of the use of DDT, was published in 1962 (Maguire & Hardy, 2009).

Resources. A successful theorization is not enough for the development of new ideas/practices. Favorable physical and technological, intellectual, financial, and political resources need to be present in the right time and the right place to develop the invention (Tidd et al., 2005).

Political resources are particularly important to keep the new ideas and practices alive, especially when the new ideas and practices do not seem to be economical. The importance of policies and regulations to support the new practices is well documented in both the institutional theory and innovation process literature. Policies can affect the direction and rate of innovation (Hascic et al., 2010). For instance, Maguire and Hardy (2009) show that after social movements contested the use of DDT, a federal law banned the use of DDT in the United States.

There are many studies in the innovation literature that show how policies act as supporting mechanisms in both shaping the new ideas and practices and diffusing the new practices (for a review, see Hascic et al., 2010). For instance, previous research shows that environmental policy stringency increased R&D expenditure among companies in the manufacturing industry in the U.S. (Jaffe & Palmer, 1997) and was positively correlated with firm's environmental patents in Japan, U.S., and Germany (Lanjouw & Mody, 1993).

Implementation

In this phase, if the innovation is developed (Garud et al., 2013) and theorized successfully, the innovation is diffused. As reviewed by Greenwood et al. (2008) and Thornton et al. (2012), implementation corresponds with increasing acceptance and diffusion of ideas and practices.

Legitimacy for Diffusion. Garnering various types of legitimacy and anchoring them to the new innovation is essential for diffusion. New ideas and practices need to have moral and pragmatic legitimacies (Suchman, 1995) to be diffused successfully (Greenwood et al., 2002). Moral legitimacy is obtained when the new ideas and practices are aligned with or nested in the broader norms; it is about “the right thing to do” (Suchman, 1995: 579). Pragmatic legitimacy is obtained if the new ideas and practices demonstrate “functional superiority” (Greenwood et al., 2002; Suchman, 1995). In the diffusion stage, objectification increases (Greenwood et al., 2002), meaning that a social consensus about the value of the new idea/practice increases among the actors (Tolbert & Zucker, 1996).

Platform Building. Acceptance and diffusion correspond somewhat to platform building as it is found in the technology and innovation literature (Garud et al., 2013). Political, technological, and physical infrastructure must be in place for the diffusion to occur. During diffusion, new subject positions arise among stakeholders that support the new practices, and a new body of knowledge emerges to normalize the new practices (Maguire & Hardy, 2009).

Standard setting is one way that leads to wider implementation of innovation (Garud et al., 2013). Another way that demonstrates the implementation of innovation is the generation of categories that are stabilized across different markets. Categories are generated and distributed through different venues such as exhibitions and trade shows (Garud et al., 2013). The emergence of other infrastructures, such as associations, critics, and consultants is another evidence of successful implementation (Greenwood et al., 2008).

At the end of the day, there should be an overall technological ecosystem that has involved and helps extend the new innovation (Adner & Kapoor, 2010). The ecosystem consists of actors who have social, economic, and intellectual interactions. The actors come from government, financial institutions, education system, and labor market, and they simultaneously compete and cooperate. Sometimes, there is a synergy between the elements of the ecosystem that helps the new innovation flourish (Tidd et al., 2005).

Outcomes

Semi or Full Institutionalization. In the semi-institutionalization stage, new ideas/practices somewhat diffuse and reach a level of normative acceptance. However, the practices are not permanent and may turn to fad and fashion (Tolbert & Zucker, 1996). Full institutionalization occurs when new ideas/practices reach cognitive legitimacy (Greenwood et al., 2002). Cognitive legitimacy is obtained when the new ideas and practices are comprehended and/or taken for granted. To achieve cognitive legitimacy, a new idea and practice must "mesh" well with the broader belief system and with the perceived reality of the audience (Suchman, 1995; DiMaggio & Powell, 1983). Taken-for-grantedness means that new ideas or practices are accepted by the audience without thinking (Suchman, 1995).

Innovation Successes and Failures. Innovation may lead to better, more efficient, and less costly technologies. A classic technological evolution diagram follows an s-curve, showing that as time passes the performance of the technology increases and then levels off. Not all innovations lead to better technologies. Some innovations may fail. Moreover, an innovation that is considered a failure at one point in time may be considered successful at a later point in time when complementary technologies and knowledge become available (Garud et al, 2013).

RESEARCH DESIGN

To understand why renewable energies were never fully institutionalized throughout history, I construct a “chronological narrative” (Langley, 1999) of the evolution of the three renewable technologies: solar, wind, and biofuel. Within the context of clean technology, these three are particularly fascinating cases. These cases are about renewable energy, but they have very different niches, adherents, and predictions about their likelihood of success, in spite of their gradual spread through patents and start-ups.

To assess each case, I have built a historical archive of documents on each technology. The primary sources for the solar technology are two books: “A Golden Threat” (Butti & Perlin, 1980) and “Let it Shine” (Perlin, 2013). The primary source for wind technology is the book “Power from Wind” (Hills, 1996), and the primary source for the biofuel technology is the work of Bill Kovarik (2013). I supplemented data extracted from these sources with other sources, including magazines, and online sources.

Next, I content analyzed more than 1000 pages of documents. Using my expertise in innovation from my Master’s Degree training, I coded the key countries, key types, triggers of inventions, key inventions for each type, key events, and the inhibitors. Results indicated that my cases mostly fit within the overall framework found in Figure 1.1. During the analysis the triggers, and enabling and inhibiting factors were often evident – especially the constraining and other negative forces behind the partial institutionalization of renewables and failures of many specific renewable technologies. Often these forces were discussed in terms of the nature of the technology, the patent, the players (champions and naysayers), and the ultimate demise of the effort. Thus, the finding tables are organized in a way that respects the invention-development-implementation logic, and, in each period, they highlight many of the factors theorized by the institutional and innovation process theories.

In addition, as mentioned in the opening, there was a need to compare the three cases temporally. On one hand, they are all clean technologies in an energy sector. As such, the cases are influenced by common factors like carbon fuel prices and innovation in one renewable versus another. On the other hand, each case is known to have a different history, both in its length and in terms of key events. To make comparison possible, for each case I bracketed the same time periods. Four overall time periods were used: the pre-industrial revolution (period 1); the industrial revolution until the end of World War I (period 2); post World War I until the 1973 oil crisis (period 3); and, 1974 until 2014 (period 4).

FINDINGS FROM HISTORICAL ANALYSIS

Solar

The solar technology's overall evolution is displayed in Table 2.2. In the following sections, I cover the highlights of that history. Most of this section is based on the work of Butti and Perlin (1980) and Perlin (2013).

--- Insert Table 2.2 about here ---

Pre-industrial Revolution. The origin of using the sun as a source of energy to heat homes dates back to 400 B.C. when Greeks and later Romans encountered wood shortages. Therefore, solar was included in the architecture of the Greek and Roman buildings. Other major inventions in this period included using bronze shields to concentrate sunlight to set fire by

Archimedes in 212 B.C, and using solar heat for horticulture in Europe during the 16th century. The main discovery in this period was the invention of the first solar collector by Horace de Saussure (a Swiss scientist) in 1767. The main trigger for the development of solar technology was shortage of fuel, and the main inhibitors were wars, dominance of church over science, and lack of complementary knowledge to commercialize solar energy (Perlin, 2013; Butti & Perlin, 1980).

Industrial Revolution (1800) Until the End of WWI (1919). In this period, the industrial revolution and the need for sources of energy other than coal, led to more solar technology inventions. There were several important inventions and discoveries in the nineteenth century: the invention of the first engine for Dish/Stirling system (1816), the discovery of the photovoltaic effect (1839) and the solar cell (1883), the invention of solar machines (1866-1919), and commercial solar water heaters (1891-1919). Most of the developments of solar technologies were in France and the United States. Due to the abundance of sun in the colonies, France and U.S. moved some of the solar technologies to French colonies and Egypt for experimental purposes. The main inhibitors of solar development were lack of knowledge to explain photovoltaic effect, inefficiency and high cost of solar energy compared to those of coal and gas, and wars (Perlin, 2013; Butti & Perlin, 1980).

Post WWI (1920)- Beginning of Oil Crisis (1973). In this period, most of the development in solar technology occurred in the U.S. The major inventions were: improvement in solar heaters in the U.S. (1920-1939), discovery of improved solar cells (1930-1960), solar architecture based on the glass, size, and orientation (1920-1950s), advancement of solar architecture based on solar collectors by MIT and Colorado Universities (1938-1960), and invention of solar heaters in Israel, Australia, South Africa, and Japan (1940s -1960s). The main triggers of the development of solar in this period were: transfer of solar technology knowledge from Europe to the U.S. through immigration and published documents, public support, advancement of complementary technologies such as the invention of double-pane glasses in 1935, university funded research, and the U.S. space program's support of solar cells. The main inhibitors of development of solar in the U.S. were: the scarcity of financial and material resources during WWII, Post-WWII changes in people's lifestyle, technical problems with solar devices partly because of lack of communication between engineering and solar community, lack of standards that deteriorated the reputation of solar architecture, high initial cost of solar devices, availability of cheap sources of electricity after WWII, increase in oil production and oil imports in the U.S. from 1953 to 1969, government support of nuclear energy, and lack of U.S. government support of solar cell research (Perlin, 2013; Butti & Perlin, 1980).

In Israel, Australia, Japan, and South Africa, knowledge created in the U.S. on solar heaters in the previous decades and fuel shortages in 1940s triggered solar heaters' invention and diffusion. Governments in Israel and Australia had a positive influence on the diffusion of solar heaters, whereas, the government impeded the diffusion of solar heaters in South Africa in 1961. The main inhibitor of the diffusion of solar heaters in Israel was access to large oil fields after Israel's war victory in 1967. In Japan, the main inhibitors were access to cheap fossil fuel from the Middle East starting in 1960, change of people's lifestyle after WWII, and rural electrification (Perlin, 2013; Butti & Perlin, 1980).

Oil Crisis 1974-2014. After the two oil shocks of 1973 and 1979, people around the world started to use and improve solar technologies invented in the past decades. Silicon solar cells developed by Bell Laboratory in 1954 were improved and their price dropped dramatically. In the U.S., solar pool heating made the American solar industry popular during 1970s. Passive solar architecture became popular in the late 1970s, too. In addition, people attempted to build solar cities during the 1970s. One of the first attempts was "village homes", built in Davis, California. Solar water heaters also grew from twenty thousand in 1978 to a million in 1983 because of U.S. tax credit and jump in oil prices in 1973 and 1979. However, because of the end of the tax credit in 1986 and the oil price drop, the sales of solar heaters dropped 90 percent in 1986. Solar water heaters were developed and used in other parts of the world including Japan, Australia, Israel, Cyprus, Greece, Barbados, Austria, Denmark, and China, after oil shocks of 1973 and 1979 (Perlin, 2013).

Another invention in this period was the use of photovoltaic panels/cells for individual homes (solar rooftop) in both developed and developing countries, such as in Tahiti (1978) and Kenya (1994). In developed nations, there was a debate over large-scale versus rooftop solar units in the mid-1970s and early 1980s. The United States was particularly in favor of large-scale units. In 1982, the U.S. Department of Energy (DOE) and an industry consortium began operating the "solar one" project, the first large-scale solar power plant, in Mojave Desert, California. In 1995, "solar one" was expanded to "solar two". Because "solar two" was successful, "solar tres" was built in Spain in 2011. In this period, the debate over centralized versus decentralized photovoltaic units encouraged Alpha Real, a Swiss engineer, to introduce his revolutionary "Project Megawatt", which initiated 333 solar rooftops that produced solar electricity. Extra electricity was sold by the residents to a utility company. The idea was named net metering and became popular in the U.S. later (Perlin, 2013).

Following 1980s, there have been many improvements that increased the efficiency of solar cells and reduced their cost through the collaboration of universities, governments, and private sector. Governments around the world have supported solar energy. For instance, in

1991, President Bush redesignated the U.S. Department of Energy's Solar Energy Research Institute as the National Renewable Energy Laboratory (Lindstrom, 2010). In 2011, as a result of the Fukushima nuclear disaster Germany left its nuclear program and invested more on renewables with the emphasis on Solar PV (www.energy.gov, accessed April 2015). Recently, president Obama announced his solar power commitments and executive actions (https://www.whitehouse.gov, accessed April 2015):

> "Today [2014], President Obama announced more than 300 private and public sector commitments to create jobs and cut carbon pollution by advancing solar deployment and energy efficiency. The commitments represent more than 850 megawatts of solar deployed – enough to power nearly 130,000 homes."

President Obama's plan is to train 50,000 workers to enter the solar industry by 2020 (http://alternativeenergy.procon.org, accessed June 2015). During the past decade, People around the world have tried to use solar energy for car racing and airplanes. Companies such as Arco and First Solar have made key improvements in the solar technologies. Solar technologies have been used in public places such as the Times Square in New York City, in space crafts, and space stations.

The main triggers of development of solar technologies have been the two oil shocks of 1973 and 1979, the government support in different parts of the world, the public awareness about environmental issues, and the increase of awareness of risk associated with nuclear energy. Some other triggers of solar technology development in other parts of the world have been: reducing unemployment in Barbados, the "no to nuclear movement" in Denmark, and a lack of the electricity grid access in rural areas in developing countries. The main inhibitors in this period were the Nixon administration's support for nuclear energy in 1973, lack of research funding allocated to solar cell research in the U.S. in the 1970s, fall of the oil prices in 1980s, Reagan anti-solar bias in the 1980s, and the discovery of shale gas more recently (Perlin, 2013).

Wind

The wind technology's overall evolution is displayed in Table 2.3. In the following sections, I cover the highlights of that history. Most of this section is based on the work of Hills (1996).

--- Insert Table 2.3 about here ---

Pre-industrial Revolution. The earliest windmills were horizontal and developed by Persians around 600 AD for grinding corn; these were imitated by China and Tibet in 1230. In Europe, the first windmills were vertical and appeared in France and England in the early 12th century. The oldest type of windmill in Europe was the Post Mill (a type of vertical mill). Later, other types of windmills dominated Europe, which were named Tower and Smock mills. The Industrial Windmill evolved around 1600 in the Netherlands and diffused to other parts of Europe, especially England. The Industrial Windmills were used for drainage purposes, sawing, crushing and pulping, paper making, mining, threshing, and pumping. In the 17th century, Europeans who immigrated to U.S. used their skills in their new country (Hills, 1996).

Windmills were initially built for grinding corn and drainage purposes, and as a substitute for watermills in areas that were short of water. Population increases and economic growth in Europe in this period also contributed to the growth of windmills. The main inhibitors for the diffusion of windmills were the advent of coal-driven steam engines in 1776. Wind-driven engines were less efficient and more expensive than coal-driven steam engines. In addition, windmills were large and unreliable because wind was not continuous. In the Netherlands, around 1750, Dutch prosperity declined, negatively influencing the development of windmills (Hills, 1996).

Industrial Revolution (1800) until the End of WWI (1919). From the Industrial Revolution to the end of WWI, the demise of traditional windmills in Europe, especially in England, occurred. In England, the use of windmills became uncompetitive mainly because the Watt steam engine patent's right expired in 1800, and their production cost decreased. Furthermore, several laws negatively affected the development of windmills in England: the elimination of tax on coal that was carried by Sea in 1831, the abolishment of Corn Laws in 1849, allowing grain to be brought to Britain tax free, and the introduction of free trade in 1875. Some other factors which negatively affected the development of windmills in England were improved railroad transportation, lack of power for extra machinery in windmills, and inability to guarantee delivery of products by windmill owners. In the Netherlands, the separation of the law countries in 1830 to Belgium and Netherlands negatively affected the Netherlands' economy and windmill development. In addition, windmills could not compete with steam engines in the Netherlands. Traditional windmills could still be seen across different parts of the northern Europe in the nineteenth century, but very few of them had profitable commercial purposes. The windmills were often hit by lightning strikes and there was no funding available for their maintenance (Hills, 1996).

Contrary to Europe, there was advancement in the development of windmills in the U.S. during this period. The first all-steel windmill was patented in 1872 in the U.S. However, the iron turbine mill did not reach the market until 1876. One of the main reasons that iron mill became popular in the U.S. was the work of Thomas O. Perry, an employee of the U.S. wind engine and pump company. In 1888, he developed an entirely new steel rotor and demonstrated that it was 87 percent more efficient than the earlier wooden one. The American windmill spread and a large market was developed all over the world. Another key achievement of the U.S. in this period was the development of windmills that produced electricity. During the late 1880s, Freely and McQuesiton, two American entrepreneurs, set up small-scale, wind-powered electricity generating plants to produce DC (direct current) electricity. Soon after, windmills that produced electricity were built in Denmark and Britain. Later in 1885, Sebastian Ferranti, an electrical engineer from England, recognized the potential of wind energy for generating alternating current (AC) in large power stations that could connect to a grid and be used for domestic purposes. In 1888 he built the Deptford power station, which is claimed to be the beginning of the present-day system of electric generation and distribution. However, in order to commercialize it, redesign of the windmills was necessary (Hills, 1996).

Post WWI(1920)- Beginning of Oil Crisis (1973). After the First World War, the interest to develop the traditional windmill increased. The performance of traditional windmills improved, but they were not suitable for further improvement, especially in the case of electricity generation. Using the aeronautical principles, the streamlined type of blades was developed in the Netherlands between 1935 and 1940, which proved to be valuable during WWII because of fuel shortages. The new design could develop about two and a half times as much power as the traditional Dutch sails. Although the war stopped further investigations on these types of mills, these sails created the direction for the future development of windmills. Many efforts were made to adapt Dutch mills to generate electricity, but they all came across the problem of inadequate strength in the gearing. To modernize these mills, the gearing had to be redesigned completely, and this was not possible at that time (Hills, 1996).

In the U.S. with the introduction of radios and small electric lighting plants for homes and farms after WWI, the interest to use wind power to produce (DC) electricity increased. The manufacturers switched to two- or three-bladed types instead of four-bladed type to increase the speed of rotation to drive generators. However, wind-powered generators still could not compete with steam-powered generators (Hills, 1996).

Windmills that developed AC electricity were improved during this period as well. While the work on aerodynamics done by Frederick Lanchester around 1900 was ignored by his contemporaries in Britain who designed windmills until after WWII, it stimulated research in other countries. At the end of WWI, scientists from Germany, France, and Russia became interested in the development of modern theory of wind power, based on the knowledge developed about airplanes and airplane aerodynamic propellers. These scientists laid the foundation of modern windmill theory. The improved windmills produced electricity for islands, where the alternative methods were more expensive (Hills, 1996).

Windmills that could connect to the grid were built in different parts of the world including the Netherlands, U.S., France, Russia, and Germany during 1920s up to WWII. However, WWII halted further work on wind turbines. After the WWII, Britain got interested in Wind turbines, but because of access to cheap oil prices, and the expectation of low-cost nuclear power, the nascent wind energy program was halted in the 1960s (Hills, 1996).

Oil Crisis 1974-2014. The oil shocks of 1973 and 1979 renewed interest in wind energy. Modern technologies in computer monitoring, and light materials such as fiberglass also increased the competitiveness of wind turbines. In addition, the Three Mile Island nuclear accident in 1979 in the U.S. and the Chernobyl accident in 1986 led the world to search for alternative sources of energy, especially renewables (Hills, 1996).

Regulations started to play an important role in the diffusion of the wind technology in the U.S. and other parts of the world in this period. In 1978, U.S. Congress passed the Public Utility Regulatory Policies Act of 1978, which mandated the companies to buy a certain amount of their electricity from renewable energy sources (Energy.gov, accessed April 2015). From 1974 to the mid-1980s, the U.S. government collaborated with the wind industry to improve the technology and to help the development of large commercial wind turbines. Large-scale research was conducted by a program under the supervision of the National Aeronautics and Space Administration to build a large-scale wind industry in the U.S. With the help of National Science Foundation (NSF) and the U.S. Department of Energy (DOE) four major wind turbines were designed and experimented in 13 wind turbines. Many multi-megawatt wind turbines that are used in the U.S. today are based on these experiments. The large wind turbines developed by the program set the world records for diameter and power output (Wind Energy Foundation, accessed May 2015).

In the 1980s and the early 1990s, low oil prices in the U.S. threatened to make wind power uneconomical. However, in the 1980s, due to the federal and state tax incentives for renewable energy, wind energy flourished in California. Wind energy's growth in the U.S. decreased dramatically after the tax incentive ended in the late 1980s (Wind Energy Foundation, accessed May 2015). However, in 1992, the energy policy act was passed by the U.S. Congress to re-establish the focus on renewable energy use. One of the incentives of the plan was a production tax credit of 1.5 cents per kilowatt hour (kWh) of wind-power-generated electricity, which led to increase of the number of wind turbines in the U.S. (Energy.gov, accessed April 2015). In addition to regulatory support, there was technological advancement in this period. In 1981, the National Aeronautics and Space Administration scientists Larry Viterna and Bob Corrigan developed "the Viterna Method", which has been the most popular method that has been used to predict the wind turbine performance. This method has helped to increase the efficiency of turbines output until today (Energy.gov, accessed April 2015).

In Europe, in 1978, the first multi-megawatt turbine was built in Denmark by the students and teachers of the Tvind School who had no professional training in wind power. The volunteers got help from German aeronautical engineers for the new wing construction. The turbines still work today and look similar to the modern mills with three blades (http://www.energybc.ca/, accessed May 2015). In addition, Danish government in 1979 introduced 30% subsidy for the installation of wind turbines, under the condition that the Danish test center, Risø, established in 1978, approved the design. The government action had an important influence on the development of quality wind turbines in Denmark. Overall, Denmark had a bottom-up market-driven approach, which was more successful than the U.S. top-down R&D oriented approach. Part of the success of Danish market was the tradition of building wind turbines that was started in the late 19th century (Vestergaard, Brandstrup & Goddard, 2004).

From 1981 to 1990, wind turbine installations increased in the northern Europe as a result of high cost of electricity, availability of wind sources (www.centreforenergy.com, accessed February 2014), and increase of concerns about climate change (Wind Energy Foundation, accessed May 2015). Europe has been the world leader for offshore wind power as well. The first offshore wind farm was installed in Denmark in 1991 (Environmental & Energy Study Institute, 2010). Up until the beginning of 2014, 69 offshore wind farms have been built in Europe. Until 2014, in terms of capacity, United Kingdom had the largest offshore wind capacity, followed by Denmark, Belgium, and Germany, respectively (The European Offshore Wind Industry, 2014).

In the past two decades, hundreds of policies and thousands of patents have made wind technology more viable. In 2012, wind became the number one sources of renewable electricity in the U.S. (Energy.gov, accessed April 2015). In 2008, the U.S. Department of Energy (DOE) published the "20% wind energy by 2030" report discussing the technical feasibility of using wind energy to generate 20% of the nation's electricity by 2030. The report examined the costs, impacts, and challenges related to producing 20% wind energy or 300GW by 2030 (Energy.gov, accessed April 2015). In 2013, Jose Zayas, Wind Program Director of DOE announced "wind vision", a new initiative to revisit the findings of the 2008 report. In 2015, the wind vision report was released showing that U.S. wind power can supply 10% of the electrical demand by 2020, 20% by 2030, and 35% by 2050 (Energy.gov, accessed April 2015).

Biofuel

The biofuel technology's overall evolution is displayed in Table 2.4. In the following sections, I cover the highlights of that history. Most of this section is based on the work of Kovarik (2013).

--- Insert Table 2.4 about here ---

Industrial Revolution (1800) until the End of WWI (1919). Biofuels in the form of oil extracted from plants and animals, sometimes blended with ethanol, have been used for illumination in the 19th and early 20th centuries in the U.S. and Europe. By 1860, many distillers produced alcohol for lighting in the U.S. and Europe. However, in 1862, the U.S. Congress imposed a tax of $2.08 per gallon on alcohol to create revenue for the U.S. Civil War. The tax made the biofuel less competitive (Kovarik, 2013).

In Europe, the first large scale biofuel program was built in Germany to support rural areas and nationalism in the late 1890s. German government supported the production of potato alcohol to support agrarians. France followed Germany and built the biofuel program around 1900, mainly to support agrarians. The rise in oil imports from Russia and the U.S., and the shortage of domestic oil reserves also contributed to the launch of a large-scale distillery building program in France (Kovarik, 2013).

Success of German and French Biofuel programs and people especially American farmers' unhappiness about the U.S. oil industry created an atmosphere, which led to the removal of tax on ethanol in 1906. However, because of the effect of the previous regulatory, market, and cultural barriers, the ethanol plan was not successful, and the changes in favor of ethanol stopped in the 1912-1913 in the U.S (Kovarik, 2013). In Britain, shortage of oil resources in the beginning of the 20th century and increase of petroleum price around 1906 were the major reasons for popularity of biofuel (Kovarik, 2013; Klass, 1998). In spite of the fact that British foreign policy mainly focused on securing supplies of petroleum from the Middle East, an Alcohol Motor Fuel Committee was founded in 1914. In 1921, the committee mentioned that the comparison of the cost of alcohol with petroleum shows that alcohol can be a potential fuel in places where sugar cane and other crops are abundant (Kovarik, 2013; London Times, 1921).

In this period, internal combustion engines were invented in 1826 and commercialized in 1864, which could be powered by conventional sources of energy and biofuel. Rudolph Diesel also designed the diesel engine in 1892, which could work with peanut, castor, and palm oil. American automotive engineers, including Henry Ford, supported alcohol for internal combustion. However, during 1920s, it was difficult for ethanol market to compete with gasoline in the U.S., which was the accepted fuel for automobiles. In addition, the pre-established gasoline industry of the 1920s blocked the use of ethanol as a solution for engine knock. Instead, the industry decided to use tetraethyl lead (Songstad et al., 2011; Dimitri & Effland, 2007).

Cellulosic biofuel was also discovered in this period. In 1819, Henri Braconnot, a French chemist, discovered how to convert straw, cotton, or wood to glucose using sulfuric acid treatment (Braconnot, 1819; cited in Rapier, 2009). In 1838 a French chemist named Anselme Payen isolated cellulose from plant and determined its chemical formula. During the 1870s and the 1880s, cellulose was used to produce a variety of products such as billiard balls, shirt collars, and camera film (Klemm et al., 2005; Kovarik, 2013).

Post WW I (1920)- Beginning of Oil Crisis (1973). After WWI, in France, a department was set up to encourage agricultural reconstruction. The department encouraged research about the production of alcohol fuels. In 1923, Article Six was passed, which required the importers of gasoline to buy alcohol from the State Alcohol Service (Kovarick, 2013; Egloff, 1939). In the U.S., during 1920s and 1930s, Chemurgy movement emerged to promote industrialization of agriculture through research. The movement became popular during the Great Depression. As the Great Depression increased and extra grains mounted in the Midwest, Chemurgy's focus became the power alcohol (bioethanol) movement. Henry Ford's ideas about alcohol fuel also inspired the movement. Several Midwestern states offered tax incentives to encourage the fuels that were a blend of alcohol and gasoline, which was named "agrol". However, in 1938, the enthusiasm for agrol declined mainly because those who were interested in petroleum lobbied against power alcohol and made sure that its price did not fall to the level of gasoline (Kovarick, 2013; Giebelhaus, 1980). With the approach of World War II, American's interest for bio-based raw material diminished (Finlay, 2003). Although the Chemurgy movement lost its activist character after the WW II, it played a significant role in supporting research among agricultural, industrial, academic, and governmental stakeholders. After the war, petroleum products increasingly displaced bio-based materials and the Chemurgic Council officially closed in 1972 (Finlay, 2003).

After WWI, demand for fuel increased, while the quality of gasoline declined because lower quality oil reserves were discovered (Kovarik, 2013). Researchers also predicted that there was only 20 to 30 years left to finish the oil reserves in the U.S. (Smith, 1920). During this period, there was a debate over whether the engine had to be redesigned to work with low-grade fuel versus whether the fuel had to be improved, raising compression. There were two solutions to improve the fuel: blending gasoline with ethanol, or adding tetraethyl lead, which was cheap. The U.S. auto industry chose the latter option.

Leaded gasoline dominated the world fuel markets in 1920s and 1930s. However, leaded gasoline caused health issues and after 90 years of fighting international public health agencies forced the market to stop adding tetraethyl lead to gasoline in 2011 (DePasquale, 2011). Discovery of tetraethyl lead as a fuel additive took the attention of researchers away from making ethanol more economical in the U.S. To the contrary, in Europe, people were more concerned about the health issues related to leaded gasoline; thus, blending gasoline with ethanol was more common in the late 1920s until 1950s when the use of ethanol-gasoline blends stopped because of the cheaper production of gasoline (Kovarik, 2013).

In this period, the biofuel laws and research in France, Germany, and Britain influenced the world. Engineers in Asia and Latin America who have studied in European universities were influenced by European ideas such as fuel improvement and agrarian support, which became the basis of the biofuel programs in their own countries between the 1930s and the 1970s (Kovarick, 2013; New York Times, 1931). Because of the high cost of importing gasoline, and available sugarcane processing equipment, developing nations including Brazil, Philippines, Cuba, and Panama actively developed biofuels program supported by their governments between the 1930s and the 1970s (Kovarik, 2013).

The oil shortage during the World War II encouraged gasogen innovation, which is gasification of wood or charcoal in generators. Most development in gasogen happened in Sweden and Germany. The war also forced innovation in China and India where the food was scarce. In these countries molasses from sugarcane that were not edible were converted to alcohol fuel; these acts were supported by the governments. In Brazil, ethanol production increased between 1937 and 1944 and the government enforced mandatory ethanol blending law. However, after the war, because cheap imported oil became available, alcohol blends became less popular and mostly used to counterbalance the sugar surplus until 1950s. By the 1950s, most of the alternative fuel programs were abandoned because of the increasing availability of cheap oil from the Middle East (Kovarik, 2013).

In this period, due to science advancement, concern about shortage of oil in the near future, and the insufficiency of crops to produce fuel, attention toward cellulosic biofuel increased in the U.S., and the American Chemical Society's cellulose division was formed in 1920. Research on cellulosic biofuels continued in the 1920s, the 1930s, and the 1940s in Britain, Germany, and the U.S. Different methods were used, such as hydrolyzing cellulose through acid-based processes and heating of carbohydrate (sugar) materials from plants under pressure, but none of them were successfully commercialized. During WWII, U.S. soldiers' uniforms turned to rags after a few weeks of staying in the tropical environment in the forests of southern Asia, which was because of the fungus named Trichoderma reesei that produced an enzyme which turned cellulose to glucose. Although research showed that the fungus could be useful to break down cellulose, because of the import of cheap oil in the 1950s from the Middle East, the research and economics of cellulose biofuel became less interesting (Kovarik, 2013).

Oil Crisis 1974-2014. During the 1970s, global oil consumption grew and the world became more dependent on the cheap oil from the Middle East. However, the 1973 and 1979 oil crises led to oil shortages and increase oil prices. The events urged a widespread search for alternative energy sources including biofuel. In Brazil, the ethanol program grew rapidly.

However, in the U.S., the ethanol program did not grow and was opposed by the U.S. oil industry. In Brazil, the program was seen as part of the economic development toward less dependency on oil imports and industrialization, and it had the full support of Brazil's automobile industry. However, in the U.S., the oil industry insisted that ethanol was a poor fuel that caused technical problems when blended with gasoline; the auto industry was more inclined to support the oil industry (Kovarik, 2013).

In June 1980, President Carter signed the Energy Security Act, which provided loans to small ethanol providers and set the first tariff on imported ethanol (Geri & McNabb, 2011). He also signed a bill to give a 54 cent per gallon tax incentive to ethanol. The Energy Security Act protected the U.S. ethanol industry up to the mid-1990s (Kovarik, 2013). However, the main reason that the corn-based ethanol program became successful in the United States was the removal, by law, of Tetra-ethyl lead (TEL), an octane additive, from gasoline in the late 1970s, due to public health concerns. From 1980 up to 2004, other methods were used to increase the fuel octane level, such as adding MTBE (methyl tertiary-butyl ether), but these methods were all harmful. The banning of MTBE in 2004 positively influenced the ethanol production from corn. Ethanol production increased from 2 billion gallons per year in 2002 to 13 billion gallons in 2013 (Renewable Fuel Association, 2014).

The oil embargo also encouraged research on cellulosic ethanol and third-generation biofuel. In 1974, during the congressional hearing in Washington D.C, a Scientist named Spano mentioned that cellulosic biomass could, by 1980, be operationalized on a large scale at a cost of 35 cent per gallon (Washington Post, 1974; cited in Kovarik, 2013). In spite of Spano's optimism, cellulosic biofuel became a complex research area in the biochemical engineering.

Researchers in many universities and government labs have spent decades to create an industry that is commercially viable (Kovarik, 2013).

The idea of using algae as a source of energy (third-generation biofuel) has been around since the 1950s. In the early 1950s, researchers proposed to produce methane gas from algae. Their suggestion received a lot of attention during the energy crisis in the 1970s, when different projects were introduced to produce gaseous fuels (hydrogen and methane) (allaboutalgae.com, accessed February 2014). From 1978 to 1996, the U.S. DOE's Office of Fuels Development funded a program named the Aquatic Species Program (ASP) in order to develop renewable transportation fuels from algae. In 1996, because of the anticipated high cost of algal biofuel production, and access to cheap oil, DOE decided to terminate the program. Ten years later, the volatility in the petroleum price, increase of interest in energy security and greenhouse gas emissions, and changes in the basic biotechnology tools led to the re-evaluation of the potential for algae-to-biofuel. As a result, the U.S. National Renewable Energy laboratory (NREL) restarted its algal biofuel program in 2006 (Biomassmagazine.com, accessed February 2014) and continues to operate. The initiative has developed partnerships with academia, national labs, and the biomass industry.

Most of the research in algae and in algae commercialization has been in the U.S. More than 100 start-ups and large companies, along with the U.S. government, have invested billions in the new industry. Today there is research on algae biofuel in both developed and developing nations, including Europe and Asia (allaboutalgae.com, accessed February 2014). However, according to the U.S. Environmental Protection Agency website, second and third generation biofuels are not commercially viable yet (Environmental Protection Agency webpage/ Biofuels and the Environment, accessed February 2014).

THEORETICAL IMPLICATIONS

Invention

In the renewable energy field, demand pull such as scarcity of resources in the four periods of history have mainly triggered the development of solar, wind, and biofuel technologies. However, in the later periods, technological push has been influential as well, especially technological advancements in other areas. For instance, in solar, theories of quantum mechanics and relativity in the early 20th century led to the rediscovery of selenium solar cells and photovoltaic effects in 1930s. In wind, aerodynamics theories and principles in the aircraft technology around 1900 led to the development of the modern windmill theory toward the end of WWI. In biofuel, advances in the basic biotechnology tools led to the re-evaluation of converting algae to biofuel in the recent years (2006-2014).

In addition to demand pull and technological push that are emphasized by the innovation literature as triggers of invention, I would like to highlight the importance of social push and the support of specific classes of actors (e.g., farmers) as triggers of innovation process, especially in the case of the development of biofuel technologies. I also found that almost all of the key inventions occurred through the collaboration of different actors. In particular, the collaboration between inventors and government has been crucial to the development of biofuel technologies globally.

Development

While there have been key inventions in solar, wind, and biofuel throughout the history, I argue that many inventions failed the theorization process, especially in the earlier periods. In this phase, innovation should reach moral and pragmatic legitimacy to be diffused successfully (Greenwood et al., 2002). Renewable technologies may have achieved moral legitimacy to some extent because they advocated for pollution reductions and, overall, a better planet. Yet, there have been some discussions in terms of the moral legitimacy of renewables. For instance, the debate about food versus fuel has had negative effects on the development of biofuel technologies, especially in developing countries like India and China (Kovarik, 2013). Issues with solar and wind technologies have been raised as well. For example, large-scale solar power stations increase the occurrence of death amongst birds because of the reflection of lights from mirrors (http://globalnews.ca/, accessed June 2015). In the wind sector, there are concerns over the noise generated by wind turbine (http://www.cbc.ca/, accessed June 2015) and the possibility of bird death traps, especially with offshore wind turbines (http://www.smithsonianmag.com/, accessed June 2015).

Renewable technologies have had serious issues to gain pragmatic legitimacy. Throughout the history, they often have been perceived as inefficient and costly. For instance, the development of solar cells in the late 1950s was abandoned in the U.S. (except for the U.S. space program) partly because of the availability of cheap oils. While I acknowledge that renewable technologies have had higher initial fixed costs compared to conventional sources, renewable technologies could have saved a lot of money and energy in operation. For instance, according to an article titled "Why not just build it right" written by Bliss, a physicist, if the passive solar architecture had dominated construction in 1976 through 1988, Americans would have saved more than three times the amount of oil drilled on Alaska's north Slope (Perlin, 2013). In the biofuel sector, there is evidence that, in 1938, the enthusiasm for agrol, a mix of alcohol and gasoline, declined in the U.S. mainly because those who were interested in petroleum lobbied against power alcohol and made sure that power alcohol's price would not fall to the level of gasoline (Giebelhaus, 1980).

Who Theorizes? Scientists and journalists have been the major agents that have advocated for the development of renewable technologies. In periods 3 and 4, governments and lay people have been involved as well. I argue, however, that one of the reasons that renewable energy development has partially failed the theorization process is because it has been challenged by opposing actors (e.g., oil industry) who have had discursive legitimacy. The finding confirms a previous study on climate change, which shows that scientists skeptical about climate change issues argued that the debate was manmade, and were successful (in part) because they had discursive legitimacy (Lefsrud & Meyer, 2012).

How to Theorize? Theorization is achieved through the use of discourse (Greenwood et al., Forthcoming). My findings show that public documents and exhibitions have had great influence in the development of renewable technologies, especially across countries. For instance, one of the influential documents that triggered the solar architecture in the U.S. during the 1930s was a study by the Royal Institute of British Architects (R.I.B.A) in 1931-1932. Americans built on this knowledge, which led to the emergence of solar architecture in the U.S. Another example is Hottel and his graduate student Woertz's publication (at MIT University in 1938) about solar collectors. Their publication was one of the main triggers of development of solar heaters in other parts of the world like Israel, Australia, Japan, and South Africa in 1950s and 1960s (Butti & Perlin, 1980).

Despite notable advancements, the historical development of renewables shows that renewable energy discourse was not fully supported by the broader energy discourse and has been contested by competing discourses (e.g., market discourse) that claim that renewable energies are neither economical nor efficient. My finding confirms Philips and colleagues' speculation that discourses that are not supported by broader discourses and are highly contested by competing discourses are less likely to be successful in the theorization process (Phillips et al., 2004).

***When to Theorize*?** Time is an important factor in the theorization process. The study of the historical development of renewable technologies shows that the timing of an endogenous or exogenous event has had a positive or negative effect on the development of technologies depending on whether the event has created or subtracted resources, respectively. For instance, because of the abundance of oil and gas in the U.S. during the three decades that followed WWII, and the attraction of nuclear energy by the U.S. and its allies, even though the improved efficiency of silicon solar cells attracted the attention of the world, there was no U.S. government funded research for solar cells during the period (Butti & Perlin, 1980).

Critical events that happen in certain point of times can change the field dynamics because of the change in the resources (Fligstein & McAdam, 2012). Looking at the historical development of renewable energy, I find that critical events in the form of wars, especially WWI and WWII, have negatively affected the development of solar and wind technologies. During WWII, research on solar collectors in MIT was halted because of the need to allocate university resources for military-related research. However, because biofuel technologies were less technology-driven, during WWII there were some advances in the development of biofuel technologies, especially in countries where fuel was scarce, such as Brazil, Philippines, India, and China (Kovarik, 2013).

There are also many examples of the critical events that positively influenced the development of renewable technologies. Fukushima and major oil spills opened up discussions amongst actors to allocate more resources to the development of renewable technologies. Germany shifted towards renewables after the Fukushima nuclear accidents. This finding is aligned with what Fligstein and McAdam (2012) refer to as "social appropriation," an important step to create change in the system. This finding also confirms Jennings and Zandbergen's (1995) proposition that crises encourage actors to promote alternative paradigms (e.g., Sustainability).

Where to Theorize? The place that the theorization occurs is crucial. Both tangible and intangible resources need to be present. The first solar engine was invented in France and was later transferred to French colonies during 1870s because of the abundance of sunshine and the extreme need for fuel in those areas. However, because of the lack of other resources, the development of solar engines did not continue within the French colonies during the twentieth century.

Field configuration events are also important places to theorize (Lampel & Meyer, 2008). There have been many exhibitions and conferences that helped the development of renewable technologies. For instance, the Association for Applied Solar energy research was formed in 1955 and the first World Symposium on Applied Solar Energy in Arizona was held by the association in the same year. People from all over the world including Israel, Australia, and Japan, attended and presented their research papers and solar devices. However, due to the lack of U.S. financial support, the association became bankrupt in 1963.

Interestingly, there are evidences in the earlier periods that exhibitions were also used to attract the attention of different stakeholders. In 1880, Pifre, assistant of Mouchot, the inventor of the first solar machines, tried to get financial support for the commercialization of solar power. He exhibited a solar generator in Paris that printed 500 copies of the Solar Journal. However, his effort eventually failed because of solar energy's inability to compete with coal (Butti & Perlin, 1980). In 1901, Eneas, one of the leaders of the solar movement in the U.S., exhibited a solar motor at the only ostrich farm in America, located in Pasadena. The ostrich farm was a national tourist attraction, the main reason that Eneas saw it as a perfect place to show his invention. Thousands of people saw the solar motor and more than a dozen popular and scientific publications sent reporters to cover the story. As a result of the publicity, Eneas founded the first solar motor company in California to commercialize the machine (Butti & Perlin, 1980).

Political Dimension of Theorization. The actors in the renewable field have not been successful to theorize the political chain of the cause and effect. In fact, their opponents (e.g., oil industry) defeat them to some extent by leveraging on their political capital. During the development of solar technologies, nuclear lobbyists in the U.S. impeded the development of solar cells in the 1950s. There is evidence that the Reagan administration had anti-solar biases and , in the 1980s, hid the research done by Deloitte consulting group on the importance of solar, which led to the budget reduction of solar research (Perlin, 2013). In the biofuel sector, there have been clashes in several points of time between American farmers who supported the ethanol programs and the oil and automobile industry, which supported oil and gas through varying tactics. For instance, in 1970s, in the U.S., the oil industry insisted that ethanol was a poor fuel that caused technical problems when blended with gasoline and the auto industry was more inclined to support the oil industry (Kovarik, 2013).

Implementation

Previous research shows that implementation of innovation would be smoother when new practices overlap and can be integrated into the old practices (Hargadon & Douglas, 2001). My findings imply that one of the reasons that the renewable technologies failed to fully institutionalize is because they have not been integrated into the conventional energy producing systems until recent years. This is partly because of their inability to compete economically with conventional sources of energy and partly because of the tension between supporters of the renewable energies and conventional sources of energy (Butti & Perlin, 1980; Kovarick, 2013; Hills, 1996). This confirms previous studies on innovation, which argue that when actors are competing, implementation of innovation is difficult (Van de Ven et al., 1999).

Lack of standards has been another reason for the failure. For instance, one of the reasons that solar architecture was abandoned in the U.S. in the mid-1940s was the misapplication of solar design. House builders started to use large windows in the solar design with improper orientation, in response to aesthetic demands. These houses were called “solar homes”, which deteriorated the reputation of solar houses. Another example is the lack of communication during the mid-1930s between the engineering and solar communities on how to prevent erosion in solar tanks, which was the main reason for the technical failure and abandonment of solar heaters in Miami. However, in the latter half of the twentieth century, governments began exercising monitoring mechanisms to increase the quality of renewable technologies. For instance, in 1979, the government of Denmark introduced a 30% subsidy for the installation of wind turbines, under the condition that the Danish test center, Risø, approved the design (Vestergaard et al., 2004).

Outcomes

Institutional theorists argue that full institutionalization occurs when new practices and ideas reach cognitive legitimacy (Greenwood et al., 2002). Renewables never reached cognitive legitimacy, given that they have all had difficulty meshing with the boarder energy environment due (in part) to resistance from the conventional energy providers. Renewables have not been, and may never be, taken for granted as long as there is access to conventional sources of energy. Some of the institutional theorists argue that if institutions are socially constructed then all institutions are fundamentally cognitive. The proponents of this view argue that institutions are "self-reinforcing" and external forces are not part of the institutional mechanisms (Phillips & Malhorta, 2008). According to this view, renewables have yet to be institutionalized.

It is important to note, however, that renewable technologies in each period of time have created an evolutionary platform for the next period. Overall, renewable technologies have improved in terms of cost, size, and efficiency. Some of the technologies were considered as failures, or useless at the time of the invention, but in the later periods, due to the advancement of knowledge, they improved and succeeded. For instance, in solar, in 1767, Horace de Saussure, a famous Swiss scientist, built the world's first solar collector (Jones, 2003). At the time he mentioned that "someday some usefulness might be drawn from this device…" (Butti & Perlin, 1980, p.59). The solar collector became the prototype for the solar collectors built in the late nineteenth and twentieth centuries. The collectors were used in different parts of the world to supply hot water and heat for homes and provide power for machines to operate (Butti & Perlin, 1980). Similarly, the economizer that was invented by Stirling in 1816 is used for the Stirling machines today. The selenium solar cells were rediscovered and the photovoltaic effect re-examined in the1930s, after they were abandoned in1890s, because classical physics in the late 19th century could not explain the photovoltaic effect. In the early 20th century, new theories of quantum mechanics and relativity revived research on solar cells. The new solar cell was very similar to the one that was developed by Fritts in 1883, with only minor design changes (Butti & Perlin, 1980).

In the wind sector, we see the cross-country and cross-continent temporal effect in the development of wind technologies. While the use of windmills in Europe declined during the industrial revolution until WWI (1800-1919), the Europeans who immigrated to the U.S. transferred the knowledge to North America, which led to several important inventions including the introduction of steel blades and electric windmills that produced direct current (DC). In the beginning of period 3 (1920-1973), the windmills were redesigned to produce AC electricity through the collaboration of French, German, and Russian scientists, based on the aerodynamics work done by Frederick Lanchester around 1900 in Britain. Surprisingly, his work was ignored by his contemporary windmill designers in Britain (Hills, 1996). In the biofuel sector, the biofuel technology knowledge that was developed in Europe since 1890 became the basis of biofuel programs in developing countries in Asia and Latin America between 1930s and 1970s (Kovarik, 2013).

Cultural Effects. Country culture influences the way innovation evolves in a country (Garud et al., 2013). For instance, in the U.S., there is an emphasis on large-scale type of innovation. In the solar sector, large-scale grid systems have been popular in the U.S. The “solar one” project, which consisted of 1818 large mirrors (40 m^2) to produce 10 MW of electricity was completed in 1981. In 1995, “solar one” was improved to “solar two” by adding 108 larger mirrors (95m^2), which created a legacy for large-scale solar panels. In contrast, Switzerland was the champion for small-scale solar panels. In 1987, Alpha Real introduced its revolutionary “Project Megawatt,” which asked 333 home owners to have solar rooftops and sell their extra electricity to the utility. In 1990 and 1991, Real presented the results of the “Project Megawatt” at the two most important international photovoltaic conferences and published the findings in the conference proceedings (Perlin, 2013).

In the wind sector during period 4 (1974-2014), emphasis in the U.S. has been on the large-scale wind-turbines and a top-down approach, due to the belief that economies of scale is required to reduce the price. In contrast, Denmark has had the bottom-up approach, starting with small and medium-sized wind turbines, which have evolved gradually. The comparison between these two countries shows that Denmark's bottom-up, decentralized approach has been more successful than the U.S. top-down, centralized approach (Vestergaard et al., 2004). Denmark's bottom-up approach is not limited to the development of wind technologies. In the solar sector, Denmark has the largest solar water heating plant in the world, located in Aero Island. Interest in solar water heaters started with the "no to nuclear" movement during 1970s by lay people, which was later supported by the Danish government (Perlin, 2013).

In the biofuel sector during the 1920s and 1930s in Europe, because there was less pressure from the oil industry and people were more concerned about the environment, biofuel programs were more popular and successful than biofuel programs in the U.S. during 1920s and 1930s. Cultural complexity may also lead to failure of innovation. For instance, when Americans tried to imitate the ethanol program developed in Germany and France during the 1890s and 1920s, it failed partly because of cultural barriers (Kovarik, 2013).

One of the limitations of this paper is that I did not elaborate on the role of power in the development of renewable technologies. The power is in the background of the paper when I discuss about the political dimensions of the theorization. According to Institutional theory there are power struggles among the actors who want the change and the incumbents who resist the change. I have discussed about the power struggles but I have not used the term in the paper. For instance, the power struggle between nuclear lobbyists and proponents of solar cell development inhibited the development of solar cells in 1950s. In the biofuel sector, lobbyists who supported petroleum in 1938 made sure the price of power alcohol would not fall to the level of gasoline (Kovarik, 2013).

CONCLUSION

The analysis of the historical development of renewables shows that renewables were never fully institutionalized. Historically, renewables were not well integrated within the broader energy field (except, to some extent, in recent times). Renewables have been challenged to reach pragmatic, cognitive and (to some extent) moral legitimacy.

Although in recent years some governments have pushed renewables through policies, many actors have been more interested in taking advantage of new opportunities rather than doing something good for the environment (Zietsma & Ruebottom, 2015). For instance, a study by Johnstone and his colleagues (2009) shows that more targeted policies are required to trigger innovation on more expensive renewable technologies, such as solar. This finding implies that when actors have the discretion to choose between different types of renewable energy innovations, they pick the less expensive type. In addition, the renewable field is filled with actors who have different motivations; the renewables field is filled with impurities. We see polluting incumbent companies (e.g., Exxon Mobil) with huge slack resources that control key knowledge assets in the renewable energy field.

This failure is partly due to the inability of actors in the renewable field to develop a sense of collective identity toward the natural environment and to legitimize themselves in relation to the broader energy field. This finding is aligned with Wry, Lounsbury, and Glynn's

(2011) speculation that a nascent collective identity is more likely to be perceived as legitimate by an external audience when the members situate themselves *within* an established field, in this case the broader energy field. In other words, actors who want to promote renewable energies have failed to frame their actions in a way that encourage cooperation of the actors in the broader energy environment (Fligstein & MacAdam, 2012). The failure to attract actors in the border context has moved to more aggressive behaviors by the environmentalists, who do not see middle-ground solutions to environmental issues.

The analysis of the historical development of renewable energies in the four periods shows that there have been major inventions in each period of time that acted as an infrastructure for the next period. I do not see a lot of successful developments among renewables in the pre-industrial phase except for wind technologies. In the later periods, the development phase has enriched and the theorization process has become more important as the technologies have evolved. Yet, there has been greater resistance to the developments as well. The inhibitors have moved from technical difficulties to obvious resistance of opposition, and hidden resistance (e.g., corporate front groups) in recent years (please see Figure 2.2). Finally, we see that the implementation phase has moved from a local implementation to a more global implementation, but renewables have never reached the full institutionalization phase, which is the key mechanism in the implementation stage (Garud et al., 2013).

In this paper, I identified several mechanisms that facilitated the development of renewable technologies. In the invention stage, demand-pull and technological push have been the main mechanisms. In the development stage, theorization has been the key mechanism. I find that the time and place of theorization are as important as who theorizes and how theorization occurs. Theorization itself consists of several sub-mechanisms, which are building pragmatic and moral legitimacy about the new products/ideas. In the development stage, the key mechanism is institutionalization. Institutionalization itself consists of several sub-mechanisms, which are increasing objectification and pragmatic legitimacy.

In the previous sections, I discussed about the main patterns of development of renewable technologies. While there are many similarities in the development of these technologies, I also observe a lot of heterogeneity comparing these three cases in terms of the initial development, the intensity of the technology, physical visibility, dominant countries, competition with the conventional sources, and political resistance.

Solar technology's initial development in the first two time periods was because of lack of other sources of energy such as woods and coal. Wind technology's initial development was for grinding corns. Later wind technology was used in places that were too dry to use watermills. Biofuel technology's initial development was to support farmers in Germany and France.

Solar technology has been more technology-driven than wind and biofuel technologies. In addition, solar technology has been mainly implemented in the collective form by market. For instance, by 1941 more than half the Miami's population had solar heaters. Wind technology has been built more individually in the past in the villages and windy places. Biofuel technology has not had the physical visibility of solar and wind technologies. However, the technology was supported in the collective form by the governments.

The countries that contributed a lot to the development of each technology differ. Solar technology's development in the past was based on the several breakthrough inventions in the U.S and France. Wind technology's development before the industrial revolutions was mainly in the Netherlands and Britain. However, after the industrial revolutions many breakthrough inventions occurred in the U.S. Biofuel technologies are less old than solar and wind technologies. Many development in the biofuel occurred in Germany, France, and Britain during the industrial revolution period, which was later imitated by the U.S. and developing countries such as Brazil, China, and India.

In terms of the competition with the conventional sources of energy, biofuel has been the most competitive one, yet, at the same time, the easier one to be integrated with the conventional sources. Many tensions occurred between auto and oil industry and biofuel technologies in the U.S. Solar technology's competition has been mainly with nuclear energy in terms of investment allocations in the past. Wind technology has been the least competitive one among all. In terms of the political resistance, biofuel development has been very political especially in the U.S. Solar development partially resisted by politics especially by the nuclear lobbyist in the U.S. and wind technology development has been less influenced by political resistance.

The paper also highlights the importance of history to understand the socio-cultural conditions around an issue in the current time. It confirms the historic recurrence theory, which argues that similar events are repeated throughout the history (Trompf, 1979). Many triggers and inhibitors of the development of renewable technologies have been repeated in each period of time. These technologies have been around for hundreds of years and yet, even with political push, these technologies are still considered secondary choices within society given the ongoing institutional resistance. This finding can be generalized to other contemporary social issues. It may help us explain why, in spite of government support, we face other ongoing social issues such as empowering aboriginals in Canada (http://www.socialjustice.org/, accessed April 2015).

To conclude, my findings indicate that we are still highly reliant on fossil fuels, as evidenced by the many countries that have found new extraction methods in the form of natural gas and shale (tight) oil. In addition, up until the Fukushima disaster, there was increasing discussion in the prior decade about the increasing use of nuclear power. Ultimately, then, the actual use of renewables would seem to depend on these macro forces. Without a demand for renewables, innovation in the area is likely to drop, being driven only by push, not pull, factors. Without the strong macroeconomic forces for renewable consumption, cultural and political factors will have to be the primary forces driving the development and use of renewables. It therefore remains to be seen whether climate change, GHGs, and carbon are culturally linked and if the political will to address temporary market failure in carbon emissions will be sufficiently strong to keep renewable technologies alive.

Figure 2.1: Combining Institutional and Innovation Approaches to Innovation

	Invention	**Development**	**Implementation**	**Outcomes**
Institutional Theory	Pre-institutionalization -Triggers -Independent innovation	Theorization - Who, how, where, when? - Politics	Objectification - Legitimacy - Diffusion	Institutionalization - Semi or full
Innovation Theory	Competing Inventions - Demand pull/Tech. push -Different design principles - Different products	Resources - Materials - Knowledge - Building infrastructure	Platform Building - Infrastructure - Standards - Systems	Improvements - Better technologies - Failed technologies

Figure 2.2: Inhibitors over Time

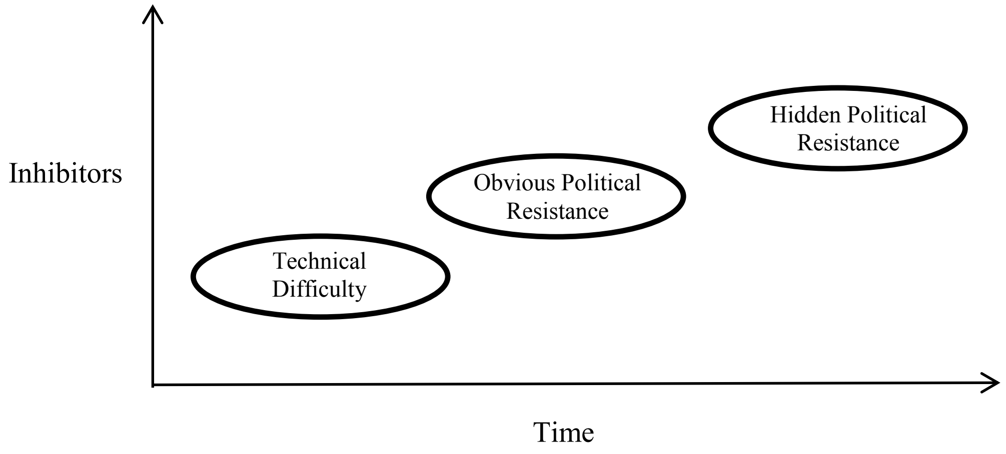


Table 2.1. Comparison of Institutional and Innovation Process Theory

	Similarities	Differences	
		Institutional Theory	Innovation Process Theory
Diffusion	• Both theories explain how a new idea/practice gets diffused	• Focus more on intangible resources such as values, beliefs, and political reasoning	• Focus more on tangible resources such as physical infrastructure, and networks among actors
Invention	• Both theories explain how invention happens • It is a collective effort • Invention is often a response to a problem	• An exogenous or endogenous shock can trigger the invention	• Demand pull or technological push triggers the invention
Development	• Both theories explain the development of new ideas/practices • Both theories argue that the key mechanism in this stage is transformation	• Focus more on theorization	• Focus more on building infrastructures and networks
Implementation	• Both theories argue that the key mechanism in this stage is institutionalization • Both theories highlight the importance of legitimacy in this stage	• Focus more on increased objectification (social consensus about pragmatic values of new ideas/practices)	• Focus more on physical infrastructures

Table 2.2: Historical Development of Solar Technologies

Period 1 (Pre-industrial Revolution)

Countries	Key Types	Triggers	Major Inventions/Events	Inhibitors	Key Patents	Key Companies	Development	Implementation
Roman Empire, Europe, America	-Solar architecture -Solar collector	-Shortage of fuel	- Greeks and Romans used solar architecture from 400 B.C. - Archimedes used bronze shields for solar concentration in 212 B.C. -Between 1200 & 1300 AD Anasazi built villages and intentionally used south-facing cliff dwellings to capture the winter sun. -1515: Leonardo da Vinci proposed a plan for the industrial applications of solar energy. -Solar horticulture in Europe in 16th century. -The invention of the first solar collector by Horace de Saussure in 1767.	-Wars, dominance of church over science, lack of complementary knowledge	-	-	-Local need-based development -No theorization	-Local platform building -No institutionalization

Period 2 (Industrial Revolution: 1800-End of WWI:1919)

Countries	Key Types	Triggers	Major Inventions/Events	Inhibitors	Key Patents	Key Companies	Development	Implementation
France, U.S., French colonies (e.g., Egypt)	-Dish/Stirling system -Solar cells -Solar machines -Low-temperature solar machines -Solar heaters	- Industrial Revolution & shortage of coal - Sunshine in French colonies -1902 coal strikes in the U.S. - Scarce & expensive wood & coal in 1890s in U.S. southwest -Sunny weather ,good price of the equipment, & high price of coal & artificial gas in California	-1816: the first engine for dish/stirling system invented (Scotland). -1839: discovery of the photovoltaic effect by Edmond Becquerel (France). -1883: invention of the first solar cell (made from selenium) by Charles Fritts (U.S.). -1866: invention of the first solar engine by Augustin Mouchot (France). -1870: invention of the first solar-powered steam engine by Ericsson (U.S.). -1892-1903: Aubrey Eneas improved solar machine design of Ericsson & Mauchot (U.S.). -1890: invention of first low-temperature solar machines by Charles Tellier (France). -1904: first solar plant founded by Willsie & Boyle (U.S.). -1910-1919: Suchman (U.S.) improved low-temperature solar machine and ran it in Egypt . -1891: first commercial solar water heater invented by Clarence Kemp named Climax (California). -1909: invention of 24-solar heater named Day and Night by William Bailey (U.S.). -1911: improved design of solar heater that was combined with conventional water heating system by Walker (U.S.).	-Inability of classical physics to explain the photovoltaics effect -Large size & inefficiency of solar motors; Napoleon war (1870), discovery of coal-mining techniques, improved railroad, coal price reduction, lack of continuous sunshine, & no storage system in France - High price & inefficiency of high temperature solar machines - Introduction of gas-producer engines in the U.S. southwest in 1910 - WWI - Discovery of natural gas in LA between 1920 & 1930	-1816: economizer -1861: first solar pump -1903: first low-temperature solar motor -1891: first commercial solar water heater -1898: improved solar heater -1909: Day and Night solar heater	-1892: first solar motor company founded in Boston -1910: first low-temperature solar machine company named the Sun Power Company founded in the east of U.S. -1911: Day and Night Solar Water Heater Company founded (U.S.)	-Cross-country technical development - Local theorization -Mainly scientists, local journalists theorize -Mix results on the success/failure of the time of theorization -Theorization based on the success of technologies. E.g.: “Sun power is now a fact, and is no longer in the "beautiful possibility” (Scientific American, 1914)	-Local platform building -From 1900 to 1911 a dozen of inventors filed patents for the improvement of solar heaters (but most of them were useless) -Eye brothers bought the right to sell Day & Night solar heaters in Arizona & New Mexico in 1913 - Solar heaters became familiar in Hawaii

Table 2.2 (continued): Historical Development of Solar Technologies

Period 3 (Post War I:1920-Beginning of Oil Crisis: 1973)								
Countries	**Key Types**	**Triggers**	**Major Inventions/Events**	**Inhibitors**	**Kay Patents**	**Kay Companies**	**Development**	**Implementation**
U.S., Israel, Australia, South Africa, Japan	-Solar water heaters -Solar architecture based on the glass, size, type, & orientation -Solar architecture based on solar collectors -Solar cells -Solar heaters in other parts of the world	-Post WWI population growth in Miami -Consumer's pressure to use solar heaters in Miami (1935) -People who immigrated from Europe brought solar architecture -Public support for solar architecture in 1940s -Housing boom after WWII -Research grant to MIT to study solar architecture -Scientists and engineers concern about fuel crisis in 1950s -Fuel scarcity in Israel in 1940 -High cost of shipping fuel to rural areas in South Africa -Depression years during 1930s in Japan	-Emergence of new market in Southern Florida in1920s -1931: Ewalds improved older solar heater design in Miami. -1935: companies entered the solar market with minor improvements in Miami. -1934 -1936: an American urban planner, Henry Wright, published many articles about solar architecture. - Son of Wright published about solar architecture in 1938 based on R.I.B.A report from U.K. -1930s: Fred Keck, a Chicago Architect, brought solar architecture to practice. - Keck built the first solar house in 1940. - First solar park was built in Chicago in 1941. -1938: MIT team with the leadership of Hottel started two decades of research on the use of solar collectors for house heating. -Mid-1940s: Colorado University started research on solar architecture based on using solar collectors -1947: MIT researchers resumed the research. -1946-1949: Dr. Telkes, a Metallurgy professor, used Galuber's salts to build the first fully-supported solar house. -1930s: rediscovery of selenium solar cells & photovoltaics effects. - 1954: accidental discovery of more efficient solar cells (silicon instead of selenium) in Bell Telephone Lab. -1950s: U.S. space programs. -First association for applied solar energy research founded in 1955. -1950: first solar heater was built in Israel. -First government program to bring solar heaters to Australia formed in 1952. -1954: first solar water heater was built in South Africa. -1947: first commercial solar water heater invented in Japan.	-High cost of solar heaters compared to electrical heaters after WWII -Change of people's life style after WWII -High initial cost of solar home - Increase of popularity of mechanical heating in late 1950s -Solar houses could not be kept warm in cloudy weeks -Access to cheap oil in late 1950s -U.S. government's lack of financial support of solar in 1950s -Increase of oil production & reliance on oil import in the U.S. from 1953 to 1969 -Access to cheap sources of energy in 1960s in Israel & Japan -Nuclear lobby in 1950s in the U.S. -No lobby for solar cell research in 1950s	- 1931: Duplex solar heater patented -1957: Bell lab scientists patented the solar cell -1953:Yassir patented the solar heater in Israel	-1923: Solar Water Company was founded in Miami - 1953: Yassir established Ner-Yah Company in Israel -1952: Solaharat & Beasley Industries emerged in Australia - 1954 Solar Water Heater Company was built in South Africa by Lewis Rome	-Cross-country knowledge transfer (e.g. transfer of solar heater's knowledge to Israel, South Africa & Australia) -Scientists and Journalists mainly theorize -Theorization through published books, solar international symposium, newspapers -Mix result on the success/failure of the time of theorization -E.g. New York Times: U.S. government "ought to transfer some of its interest in atomic power to solar" -Resistance begins (e.g. U.S. nuclear lobby, South Africa government)	-Local markets were created in U.S., Israel, Japan & Australia (e.g. from 1944 to 1946 up to one million solar homes were built in the U.S.) -Local institutions (e.g. consumers' pressure for solar heaters in Miami; public support of solar architecture) -Government's support of solar heaters in Israel & Australia

Table 2.2 (continued): Historical Development of Solar Technologies

Period 4 (Oil Crisis: 1974- 2014)								
Countries	**Key Types**	**Triggers**	**Major Inventions/Events**	**Inhibitors**	**Patents**	**Companies**	**Development**	**Implementation /Outcome**
Worldwide	-Solar pooling heating, -Solar passive architecture -Solar city -Solar water heating -Rooftop solar -Large-size solar panels -Solar airplanes, -Solar cars -Solar buildings -Solar-powered road panels -Solar grills -Solar-powered space crafts, etc.	-Oil embargo in 1973 & 1979 - Nuclear disasters - Rural areas' lack of access to electricity in developing countries -Governments' support (e.g. Israel government mandate in mid-1980s to use solar heaters) - Fight with unemployment -Social movements -Increase of awareness about environmental issues	-1976: the NASA Lewis Research Center started installing 83 photovoltaics power systems on every continent except Australia. -1976: David Carlson & Christopher Wronski, RCA Laboratories, fabricated first amorphous silicon photovoltaics cells. -30 million people celebrated Sun Day in 1978 designated by carter. A day devoted to solar power. -Solar pool heating made the solar industry attractive in 1970s in the U.S. -First solar conference in passive solar design was held in 1976. -First solar city named "Village homes" was constructed from 1970s to 1980 in California. -1983: in Austria the movement of "do-it-yourself" has made solar water heaters popular. - 1970s: In Denmark private Citizens established the Aero Energy Office. The office became the focal point for information on renewable energy sources. - 1987: Alpha real initiated the revolutionary project Megawatt to have 333 power-station owners. - 1980: ARCO Solar became first company to produce more than 1 megawatt of PV modules in one year. - 1980: First thin-film solar cell exceeded 10% efficiency using copper sulfide/cadmium sulfide at University of Delaware. - 1981: Paul MacCready built the first solar-powered aircraft named solar challenger. -1982-1986: first test of a large-scale thermal solar power tower plant, the solar one project, was made in the Mojave Desert. - 1991: Bush redesignated the U.S. DOE's Solar Energy Research Institute as the National Renewable Energy Laboratory. -1996: the most advanced solar-powered airplane, the Icare, flew over Germany. 1996: U.S. DOE along with the industry began the operation of "Solar two". - 1998: the remote-controlled solar-power aircraft, pathfinder set an altitude record of 80,000 feet. -2000: First Solar began production in Ohio at the world's largest photovoltaics manufacturing plant.	-1973: Nixon administration published a report that proposed 4 billion dollars for nuclear option, and only 36 million dollars for solar cells -Reagan administration and its anti-solar bias in 1980s - End of tax credit on solar water heating in 1986 - Oil price dropped in late 1980s - 1980s: discovery of gas, coal deposits to generate cheap electricity in Australia -1988: In Greece government lowered electrical rates, imposed high tax on solar heaters, & withdrew all incentives -Emergence of corporate front groups	70,390 patents have been filed in 123 countries	Around 1929 public and private companies around the world received funding	-In addition to scientists & journalists, other actors theorize as well (e.g. environmentalists, venture capitals) -Still there are problems with moral and pragmatic legitimacy -Resistance exists, but not obvious (e.g. corporate front groups, controlling knowledge assets by polluting companies)	-Cross-country markets are created -Partial institutionalization -Problems with cognitive legitimacy

Main Reference: Butti & Perlin (1980); Perlin (2013)

Table 2.3: Historical Development of Wind Technologies

Period 1(Pre-industrial Revolution)								
Countries	**Key Types**	**Triggers**	**Major Inventions/Events**	**Inhibitors**	**Key Patents**	**Key Companies**	**Development**	**Implementation**
Middle East, China, Europe especially Netherlands & Britain, America	-Horizontal windmills -Vertical windmills, -Post Mills (a type of vertical mills), - Polder Mills - Tower Mills (a type of vertical mills) - Smock Polder Mills (a type of vertical mills) -Post or Smock mills -Windmills for Sawing, Crushing and Pulping, Paper Making, Mining, Threshing -Windmill pumps	-Needed for grinding corns (600AD) - Needed for prayer wheels in Tibet and China (1230) -Shortage of water for operation of watermills in Europe (since 12th century) - Increase of population in Europe (since 12th century) -Economic growth in Europe (since late 13th century) -People who immigrated from Europe to U.S. (17th century)	600AD: Persians developed the oldest wind mills (horizontal). 1230: Persian horizontal windmills appeared in China & Tibet. Early 12th century: first windmills appeared in Northern France and Eastern England. 1105: first post mills were built in northern France (5 post mills). 1150: first post mills were built in northern England (Between 23 to 56 post mills). 1222: first post mills were built in Germany. 1259: first post mills were built in Denmark. 1274: first post mills were built in Netherlands. 1300: first post mills were built in Sweden. 1330: first post mills were built in Russia & Latvia. 1237: first post mills were built in Italy. 13th century: Polder mills appeared in Netherlands. The oldest polder mills were called Wipmolen. Late 13th century: first tower mills appeared in Europe. 1422: Origin of smock mills in Netherlands for drainage purposes. They were the origin of industrial mills. 1600: smock mills appeared in England. 1526: smock Polder mills were built with octagonal shape in Netherlands & were used for drainage. 1621: first windmills (post or smock) were built in Virginia. 1553: first wind-powered sawmills were invented by Cornelis Corneliszoon in Netherlands. 1663: first wind-driven saw mills were built in Britain. 16th century: windmills used for crushing and pulping in Netherlands. 1605: first paper mill was built in Netherlands. 17th century: windmills were used for mining in Britain. 1788: invention of threshing machine that could work with horsepower, wind, & water. 18th century: windmills for pumping water appeared in Britain & Scotland.	-Advent of coal-driven steam engines in 1776 that were more efficient -High price of windmills compared to steam engines -Large size of windmills -Dependency of windmills to weather -Ability of steam engines to work in different weather conditions - Around 1750 Dutch prosperity decreased because of the cattle plague, shipworms in 1730, & silting of river beds. These factors affected negatively the shipping & increased risk of floods; population declined by 40%	-1553: first wind-powered sawmill was patented by Cornelis Corneliszoon in Netherlands -1788: first threshing machine patented by Andrew Meikle that could work with wind power	-	-Local need-based development -No theorization	- Local platform building -No institutionalization

Table 2.3 (continued): Historical Development of Wind Technologies

Period 2 (Industrial Revolution:1800-End of WWI:1919)								
Countries	**Key Types**	**Triggers**	**Major Inventions/Events**	**Inhibitors**	**Key Patents**	**Key Companies**	**Development**	**Implementation**
Europe mainly England and Netherlands, U.S.	-Wind pumps -Windmills with steel blades -Electric windmills (DC) -Electric windmills (AC)	-Lack of water in the west of U.S. for water pumps in 1860s	-Development of wind pumps in the west of U.S. where there was not enough water in 1860s. -First all-steel windmill was patented by J.S. Risdon, Genoa, Illinois in 1872. -Thomas O. Perry & Noyes manufactured the first scientific designed windmill that was made of steel & named in Aeromotor in 1888. -Ernest Bolee patented a unique design of annular sail mill in 1868. -American windmills spread around the world in 1880. -A vital industry emerged in Britain in the 1870s. -1881: first person who proposed to use wind to generate electricity was William Thomson. -Alfred Wolff advocated the use of windmills to produce electricity in 1885. -Freely & McQuesiton, two American entrepreneurs, set up small-scale, wind-powered electricity generating plants to produce DC electricity. -Professor Poul La Cour started experimental windmill test station, which was set up by Danish government in 1891. -In Britain, first lighting plant powered by American windmills appeared in London in 1892. -Sebastian Ferranti was the first person who recognized the potential of using wind energy for generating AC in 1885	-Watt's steam engine patent's right expired in 1800 -Lighting strikes put windmills on fire in Europe -Less Money for the maintenance of windmills -Elimination of the tax on coal that was carried by Sea in 1831 -Opening of global market in the 19th century. - Improvement in transportations (railroad) during 19th century -The abolishment of Corn Laws in 1849 meant that grain could be brought freely to Britain -The introduction of free trade in 1875 -Better quality of the imported flour because of using of high milling systems -Lack of power in windmills for extra machines to clean the grains at the end of the 19th century -Inability of wind millers to guarantee deliveries at the end of the 19th century -Increase of demand of people for better quality flour especially after WWI -Separation of the law countries in 1830 to Belgium & Netherlands negatively affected the Netherlands economy -The design of windmills was not advanced enough & the capital cost was too high to connect to grid	-During 1850s, more than fifty windmill patents were submitted to the U.S. Patent Office -First all-steel windmill was patented by J.S. Risdon, Genoa, Illinois in 1872 -Ernest Bolee patented a unique design of annular sail mill in 1868	-Between 1850 & 1920 1075 new firms were founded in the U.S. -Aeromotor company was founded in 1888	-Cross-country technical development (e.g. people who immigrated to U.S. from Europe)	-Local implementation -E.g., J.Thomas & Son, Broad Street, Worcester produced 30,000 wind engines

Table 2.3 (continued): Historical Development of Wind Technologies

Period 3 (Post War I:1920-Beginning of Oil crisis: 1973)								
Countries	**Key Types**	**Triggers**	**Major Inventions/Events**	**Inhibitors**	**Key Patents**	**Key Companies**	**Development**	**Implementation**
Netherlands, U.S., France, Germany, Russia, Britain	-Streamlined windmills -Electric windmills (DC) -Electric windmills (AC)	- In Netherlands during WWII no diesel oil was available; electric power plants were in shortage of coal and other fuels -The introduction of radios and small electric lighting plants for homes and farms after WWI in the U.S. -Aerodynamics work done by Frederick Lanchester around 1900 -Alternative power was expensive in islands	-Albert G.von Baumhauer with the help of the Laboratory for Aeronautics at Amsterdam designed the first “curving streamlined foresail" in 1918. - Prinsenmolen Committee carried different tests to improve the performance of windmills in the Prinsenmolen between 1935 & 1940, which led to the emergence of new streamlined sails. -1920s manufacturers switched to two- or three-bladed types instead of four-bladed type to increase the rotation speed. -Scientists from Germany, France & Russia developed the modern windmill theory toward the end of WWI. -Using of electric windmills for grids in islands & villages in 1920s up to WWII (1939). -Using of electric windmills for grids in Netherlands, France, Germany, Russian, & U.S from 1920s up to WWII (1939). -Britain built wind turbines after WWII.	-Lack of interest of millwrights to build the steel blades -WWII -Wind-powered generators could not compete with steam-powered generators -Wind power was still costly -Availability of cheap oil & the expectation of low-cost nuclear power in 1960s halted the wind energy programs	New sails patented in 1922 by Albert G.von Baumhauer	-	-Cross-country knowledge transfer (e.g. the modern windmill theory emerged)	-Local markets were created (e.g. windmills that could be connected to the grid were built in Netherlands, U.S., France, Russia & Germany during 1920s up to WWII)

Table 2.3 (continued): Historical Development of Wind Technologies

Period 4 (Oil Crisis:1974- 2014)								
Countries	**Key Types**	**Triggers**	**Major Inventions/Events**	**Inhibitors**	**Patents**	**Companies**	**Development**	**Implementation /Outcome**
Worldwide	Electric windmills (AC)	-Oil crisis -Modern technology in computer and light-weight materials -The Electricity Act of 1989 for the privatisation of the electricity industry in Britain -The Three Mile Island's accident in 1979 in U.S. -The Public Utility Regulatory Policies Act of 1978 in the U.S. -Governments' support -High cost of electricity, availability of wind sources; concern about climate change -The energy policy act passed by the U.S. congress in 1992 -Pro-environmental laws in Europe especially Germany, Denmark, & Spain	-Wind turbines were built in 1980s by foreign manufacturers including Vestas in Britain. -1978 teachers and students in Tvind school in Denmark constructed the first multi-megawatt wind turbine. -Danish government in 1979 introduced 30% subsidy for the installation of wind turbines. -Three and four-bladed fiberglass wind turbines were built during the 1980s and 1990s in the U.S. & Denmark. -First offshore wind farm was installed in Denmark in 1991. -From 1974 to mid-1980s: U.S. government worked with industry: four major wind turbines were designed & experimented in 13 wind turbines. -1981: National Aeronautics & Space Administration scientists, Larry Viterna and Bob Corrigan, developed "The Viterna Method". -1981 to 1990: increase of wind turbine installations in northern Europe. -A production tax credit of 1.5 cents per kilowatt hour (kWh) of wind-power-generated electricity led to increase of wind turbines in the U.S. in 1990s. -2001: India added 300 megawatts wind power, increasing the national wind power capacity to 1500 megawatts. -2001: Wind power industry became a $7 billion industry. -2003: U.S. national wind power capacity reached to more than 6300 megawatts. -2003: Europe dominated the wind market with more than 28,000 megawatt wind generation (70% of world's wind capacity). -2003: Germany, the leader in terms of wind energy production (140,000 megawatts), employed 35,000 people, & produced 3.5 percent of country's electricity. -2003: Denmark was the leader in terms of proportion of electricity (20%). -2004: The total energy generation exceeded 39,000 megawatts. The cost of wind production dropped from 4 to 6 cents per kWh to 3-4 cents per kWh. -2007: Wind energy produced power to 2.5 million homes in the U.S. (5% of renewable energy). The number increased to 15 million in 2012.	-High capital investments -Low oil price in the 1980s & early 1990s -End of tax incentives for wind in the late 1980s in the U.S. -Emergence of corporate front groups	30,910 patents have been filed in 123 countries	Around 764 public and private companies received funding	-Knowledge advancement in other areas -New materials (fiberglass) -Social movement's support -Still there are problems with moral and pragmatic legitimacy -Resistance exists, but not obvious (e.g. corporate front groups, controlling knowledge assets by polluting companies)	-Cross-country markets are created -Partial institutionalization -Problems with cognitive legitimacy

			-2012: -wind becomes the number one source of renewable energy in the U.S. -2008: U.S. DOE published "20% wind energy by 2030 initiative". -2013: U.S. DOE announced "wind vision" a new initiative. -2015: The wind vision report was released showing that U.S. wind power can supply 10% of the electrical demand in 2020, 20% in 2030, and 35% in 2050.					

Main Reference: Hills (1996)

Table 2.4: Historical Development of Biofuel Technologies

Period 2 (Industrial Revolution: 1800-End of WWI:1919)								
Countries	**Key Types**	**Triggers**	**Major Inventions/Events**	**Inhibitors**	**Key Patents**	**Key Companies**	**Development**	**Implementation**
Germany, France, U.S., Britain	-Plant and animal oils -Ethanol (e.g. potato alcohol) -Internal combustion engines -Cellulosic biofuel	-Germany: supporting of agrarians, nationalism, tariff on imported oil & lack of domestic oil reserves -U.S: Success of Germany, 1896 congressional investigation about removal of tax from Alcohol market, people's unhappiness about U.S. oil industry -1906 U.S. revoked tax on biofuel -Scarcity of oil resources in the beginning of 20th century, increase of price of petroleum around 1906 in U.K -France: intention to support agrarians, support of the ministry of Agriculture, the increase in oil imports from Russia & the U.S, lack of domestic oil reserves -Concerns about long-term supply of energy in the U.S.	-Using oils for illumination in 1800 in Europe and the U.S. -Germany built the world's first large-scale industry (1890 -1916). -An international exhibit developed in Germany around 1900 dedicated to alcohol-powered automobiles, farm machinery & a wide variety of lamps, stoves, heaters, laundry irons, etc. -1906 U.S revoked tax on biofuel following Roosevelt support. -American farmers tried to follow German & French farmers from 1906 to 1912. -The motor union of Britain & Ireland formed the Alcohol Motor Fuel Committee in 1914. -Lunch of large-scale distillery building program in France from 1900 up to WWI. -Samuel Morey in 1826 developed the first internal combustion engine that used liquid fuel. -In 1860 Nicholas August Otto rediscovered the internal combustion engine & used ethyl alcohol engine (similar to Morey's invention). -Rudolph Diesel designed diesel engine in 1892, which could work with peanut, castor, and palm oil as well. -American automotive engineers favored use of biofuels around 1906. -Henry Ford mentioned that carburetors on his model T would be designed to use either gasoline or alcohol in 1906. -In 1819, Henri Braconnot, discovered how to covert straw, cotton, or wood to glucose using sulfuric acid treatment. -Inventions to use cellulose to build billiard balls, shirt collars, & camera film in 1870s & 1880s. -Around 1900, researchers discovered that cellulose can be broken down to glucose molecules & converted to different chemicals and fuels	-U.S. congress tax on alcohol to create revenue for Civil war in 1862 -Regulatory, market, & cultural barriers stopped the U.S. biofuel movement in 1912-1913 -In 1920s ethanol market could not compete with gasoline, which was the accepted fuel for automobiles	-Samuel Morey Patented the internal combustion engine in 1826 (US patent 4378) -1892 Rudolf Diesel obtained a patent (RP 67207)	-In 1864 Otto & Eugen Langen founded the first internal combustion engine production named company NA Otto & Cie	-Cross-country knowledge transfer -Social support in Germany, France, U.S. -Scientists, journalists & people theorize -Political actors both in favor and against biofuel program in the U.S (e.g. Roosevelt in favor of tax removal), oil's & some auto's lobbyist against biofuel in the U.S.) -First indication of competition between petroleum & ethanol industries was mentioned in an article ("Auto Club Aroused over Alcohol Bill") in 1906 in NY times	-Successful biofuel programs implemented in Germany -France & U.K with the support of governments implemented biofuel programs -U.S. was not successful because gasoline industry blocked the development

Table 2.4 (continued): Historical development of Biofuel Technologies

Period 3 (Post War I:1920-Beginning of Oil Crisis 1973)								
Countries	**Key Types**	**Triggers**	**Major Inventions/Events**	**Inhibitors:**	**Key Patents**	**Key Companies**	**Development**	**Implementation**
Many developed & developing countries (e.g. France, U.S., Germany, U.K., Brazil, Philippines, India, China)	-Ethanol -Fuel additives -Gasification - Ethanol from molasses - Cellulosic biofuel	-Government support to encourage agricultural reconstruction after WWI in France - Great Depression -Henry Ford's support in U.S. - Chemurgy movement - Worldwide demand to U.S. farm surplus as source of food -WWII - Increase of demand for fuel after WWI - Decline in the quality of gasoline -Researchers' concern about finishing of oil reserves -Engine knock problem -In Brazil: Agrarian movements in Germany, France, high cost of importing gasoline, availability of sugarcane	-A committee was set up in 1921 to investigate the power of alcohol fuel in France. -In 1923 Article six was passed that required gasoline exporters to buy alcohol for 10% blend in France. -During 1920s & 1930s Chemurgy movement emerged to promote industrializing agriculture through scientific research in U.S. -Chemurgy's focus became the power alcohol (bioethanol) movement because of extra grains in 1930s in the U.S. -In 1930s in U.S. several mid-western states approved tax incentives to blend ethanol with gasoline (agrol). -By 1938 the Chemical foundation in the U.S. spent about $600,000 to promote alcohol fuels and to build production facilities. -In 1946 the American petroleum industry established a committee to investigate agricultural raw materials, as a potential additive for motor oil. -Chemurgy movement lost its activists nature after WWII; the Chumrgy Council officially closed in 1972. -1919: debate over redesigning of engine to work with low-grade fuel versus improving the fuel and raising the compression. -Discovery of adding tetraethyl lead for engine knock in 1921 took the attention of researchers away from making the use of ethanol more economical. -In 1921 Ricardo patented racing fuels RD1 & RD2 (Ricardo Discol) that had methanol, ethanol & acetone. -RD1 & RD2 were broadly used for racing throughout Europe & the U.S. in the 1920s & 1930s. -1930s: Ricardo worked with National Distillers Company & Cleveland Oil Company on an alcohol fuel blend called “Discol” in U.K. -Brazil biofuel program started around 1919. By 1921, distilleries in the state produced about 2.2 million gallons of ethanol. -On October 23, 1922, the Brazilian Congress of Coal and other National Fuels lobbied for ethanol program. -Brazil envisioned having a national fuel program in 1930s.	-in 1938 Petroleum supporters lobbied against power alcohol in the U.S. - Bio-based materials were replaced with petroleum products after WWII -discovery of tetraethyl in 1921 to solve the problem of engine knock - In Panama, price war in the early 1930s inhibited distilleries to expand their markets; - the cheaper production of gasoline in 1950s -Cheap imported oil in Brazil and Philippines in 1950 - Cellulosic biofuel not ready for commercialization, research became less interesting because of cheap oil in 1950s	- In 1921, Ricardo, a British researcher, patented racing fuels RD1 and RD2	- In 1922, the Philippine Motor Alcohol Corporation was founded in Manila	-Cross-country knowledge transfer (e.g. transfer of knowledge from developed to developing countries) - Obvious form of resistance from petroleum industry in the U.S.	- Local markets were created (e.g. the number of Brazilian distilleries that were producing fuel-grade ethanol increased from one in 1933 to 31 by 1939, to 54 by 1945) - Local institutions (e.g. Chemurgy’s movement)

		processing equipment -Concern about health issue of leaded gasoline in Europe - Gasoline shortage during WWII -India: use of molasses' wastes; reducing the dependency on oil import; protection of the power alcohol industry -Science advancement to produce fuel from cellulose	-By 1931 a Brazilian law forced gasoline importers to buy alcohol in amount of 5% of their gasoline imports. -In Brazil first major alcohol fuel plant was built in Recife in June of 1927. -In Brazil in 1931 alcohol cost 5 cents per liter, while gasoline cost about more than twice per liter. -In 1933 Brazil's Institute do Assucar e do alcool was founded to keep track of research, promote the use of biofuels & give technical assistant. -In 1922 the Philippine Motor Alcohol Corporation was founded in Manila & several fuel types were tested in the company. -By 1931 Gasonol, a blend of 20% ethanol & 5% Kerosene, was commercialized in Philippines -In 1930s the Philippine policy was to use sugarcane ethanol as the pure fuel in automobiles, buses, trucks & locomotives. -By 1932 at least 30 nations including Cuba, Panama & Czech Republic had programs such as tax incentive and mandatory ethanol blending programs. -Cuba produced about 20 million liters of Espiritu in 1922, which was a blend of 80% gasoline and 20% alcohol. -In 1930s in Panama income tax on gasoline indirectly supported ethanol that was produced locally. -In Czech Republic, between 1926 and 1936, it was mandated by law to add 20% ethanol to gasoline. -In 1929 in Hungary, the law made the production of Moltaco, a blend of 20% ethanol mandatory for fuel producers. -Poland had a state alcohol monopoly during 1930s. -In Sweden 25% ethanol & 75% gasoline blend called "Lattbentyl" was common in 1930s. -In Sweden & Germany during WWII gasogens was innovated, which was the gasification of wood or charcoal in generators. -One of the provinces in India mandated the blending of ethanol to gasoline during WWII. -The usage of alcohol as a fuel in China was often the only available choice during WWII. -To protect the power alcohol industry in 1948 "the Indian Power Alcohol Act" mandated blending of ethanol with gasoline where possible. -American Chemical Society's cellulose division was formed in 1920. -In 1927 the British Fuel Research Board made some discovery to convert waste vegetables to alcohol to use in internal combustion engines. -In 1930 in Germany, Heinrich Scholler developed a process that used weak acid to percolate through wood chips in order to hydrolyze cellulose, which was more efficient. -Three Scholler plants (cellulosic) were established in the 1930s in Germany and one was built in Switzerland. -In 1930s the U.S. version of the new process to produce cellulosic biofuel was examined and modified in the U.S. Forest Product Laboratory in Madison, Wisconsin. - Professor Ernst Berl of the Carneige Institute of Technology made several important contributions to cellulosic biofuel research in 1940s. - In 1944 Berl claimed that it was possible to convert any material which has cellulose, starch & sugars into coal and petroleum. -During WWII U.S. soldiers' cotton uniforms disintegrated to rags after a few weeks of staying in the tropical environment in the forests of Southern Asia, which led to the discovery of a fungus named Trichoderma Reesei. - In the opening of the 1952 United Nations Conference on biofuels in India, Munshi, mentioned that because of the food scarcity in India, we cannot use crops and grains to produce power alcohol and the research on non-food biofuels should be encouraged.

Table 2.4 (continued): Historical Development of Biofuel Technologies

Period 4 (Oil Crisis: 1974- 2014)

Countries	Key Types	Triggers	Major Inventions/Events	Inhibitors	Patents	Companies	Development	Implementation
Worldwide	-Ethanol - Cellulosic biofuel - Third-generation biofuel	-Oil crisis of 1973 & 1979 -In Brazil: low price of sugar, less dependency on oil, economic development, industrialization, support of Brazil's automobile -In U.S.: support from agrarians to support farming & become less dependent on oil industry in 1970s -Removal of lead because of health issues in 1970s by law -Removal of BTX, which was cancer causing in 1980 -2006: the volatility in the petroleum price, increase of interest in energy security & GHG emissions & changes in the basic biotechnology tools, lack of access to high-quality feedstock encouraged research on third-generation biofuel	- In Brazil: the ProAlcool was founded in 1975, which mandated the blending of about 20 % ethanol with gasoline. -In 1975 several states in the American Midwest, mainly in Nebraska, started the research on getting ethanol from corn to blend with gasoline. - Joint research collaboration between the Brazilian Pro-Alcool program & the Nebraska in 1970s. -In June 1980 President Carter signed the Energy Security Act, which provided loans to small ethanol providers & set the first tariff in imported ethanol. -The Bush administration worked with congress to create 1990 clean air act & empowered EPA to give order to the oil industry to remove BTX from fuel and use octane boosting compounds like ethanol. -By 2004 19 states banned MTBE and it positively influenced the ethanol production from corn. -In 1974 a Scientist from Natick, named Leo Spano, in a committee hearing mentioned that cellulosic biomass could be operationalized on a large scale by 1980 at a cost of 35 cent per gallon. -From 1978 to 1996 the U.S. DOE Office of Fuels Development funded a program (Aquatic Species Program) in order to develop renewable transportation fuels from algae. -The Department of Energy (DOE) decided to terminate Aquatic Species Program in 1996. -U.S. NREL restartd the algae biofuel program in 2006. -Exxon Mobile after investing $600 million USD into research & development of algae concluded in 2013 that algae-based biofuel would not be available for at least 25 years. -Algenol claimed to have the first commercial facility in algae technology in 2015.	-Oil industry & Auto industry in the U.S. claimed that ethanol was a poor fuel and had technical problems to blend -MTBE (an oxygenate made from petroleum) was added to the list of fuel additive -No economical way to convert cellulose to fuel that can compete with oil price -Anticipated high cost of algae biofuel production & access to cheap oil - Disadvantage of algae: needs large amounts of water, nitrogen & phosphorous to grow	46,924 patents have been filed in 123 companies	Around 1382 public and private companies received funding	-Knowledge advancement in biotechnologies - Political support - Resistance exists, but not obvious (e.g. corporate front groups, controlling knowledge assets by polluting companies)	-Cross-country markets are created -Partial institutionalization -Problems with cognitive legitimacy

Main Reference: Kovarik (2013)

PAPER 2: COMPETING LOGICS AND INNOVATION IN NATION-STATES: POLICY AND PATENTING IN RENEWBALE ENERGY, 1980-2012

INTRODUCTION

Over the past three decades, a rich program of research has emerged among scholars interested in the role of institutional logics within fields and industries (Friedland & Alford, 1991; Scott, 2001; Thornton et al., 2012). In these contexts, studies have investigated how institutional logics shape organizational practices and market processes by providing overarching master scripts of society to constituent members in the field (for recent reviews, see Greenwood et al., 2011; Thornton et al., 2012). Yet, less institutional theory work has been done at the country-level of analysis to examine how logics influence the creation and adoption of alternative ideas and practice – i.e., innovations - in spite of the evident and important operation of logics at this analysis level (Djelic & Quack, 2008; Simmons et al., 2006).

One strand of institutional thought about innovation at the nation-state level has emphasized the ongoing rationalization in the world polity as the primary driver for the spread of new political and technological innovation, particularly as expressions of modernity (Meyer et al., 1997: 2010; Ramirez et al., 1997). The adoption of rationalized education, government, finance, and similar standards, via international organizations like WTO and UN, stimulate the adoption of other modern practices, such as universal health care and unemployment (Dobbin & Sutton, 1998), and even environmental organizations (Longhofer & Schofer, 2010). A second strand of institutional thought points to the contested nature of logics and that the degrees of overlap and incompatibility among logics may lead to quite different, vibrant ideas and practices within a nation-state (Djelic & Sahlin-Andersson, 2006; Pache & Santos, 2010). Emergent logics, even if they challenge current thought and practice in state, may even combine with incumbent ones, particularly when these new ideas and practices are endorsed by strong external actors and then adopted by competitors (Thornton et al., 2012).

An under-explored, current notion from research on contested logics in lower level field is that of dominant versus “alternative, minority” logics (Durand & Jourdan, 2012). As shown by these researchers, alternative logics through contestation can enrich the practice within an organizational field (Dunn & Jones, 2010). Yet at the nation-state level, having an alternative, minority logic seems insufficient to guarantee practice enrichment. At the global level, the web of relations is typically weaker among nations than within nations (Djelic & Quack, 2008). Furthermore, there is a variation within countries in the degree to which their ruling governments have mandates and capacity to create innovation. Indeed, there is evidence that in states where the mandate for the dominant logic is strong, as is institutional capacity to implement that logic, the innovation fostered by the alternative logic becomes successfully resisted by the retrenched dominant one (Zelner et al., 2009). Our research question, then, is what are some fundamental theoretical contingencies at the nation-state level that should enhance the positive effects of alternative, minority logics on alternative practice innovations?

To address this question, we examine how neo-liberalism and environmentalism as a dominant and alternative logic at the nation-state level influence the creation of new renewable energy policies and patents as alternative practices within countries. Consistent with the asymmetric logic notion, neo-liberalism and environmentalism can be viewed as both complementary and competing (Durand & Jourdan, 2012; Pache & Santos, 2010). Neo-liberalism is a belief in policies and practices that “reduce government constraints on political behavior, promote free political exchange, and establish the right to participate: i.e., to ‘democratization’” (Simmons et al., 2006: 783). The greater the neo-liberalism logic in a country, the more likely the state will rely on market-based systems of exchange and innovation. Environmentalism simply means valuing the natural environment. It runs from light green, which encourages engagement with markets and industry, to dark green, which advocates replacement of them with alternative practices (Hoffman & Bertels, 2010; Hulme, 2010). Thus, the way in which neo-liberalism and environmentalism are combined and under what conditions, will influence their impact on innovation.

Two institutional domains where the joint effects of neo-liberalism and environmentalism on innovation are likely to be observable are political policy formation (Hoffman & Ventresca, 2002; Jennings et al., 2011) and technology development (Zelner et al., 2009). Using a wide range of sources including the IPCheckUps, UNESCO, and World Bank, we collected data on the creation of market and regulatory policies for renewable energies and the patenting in biofuel, solar, and wind sectors in 93 nations over the 33 year period. The impact of logics and capacity on policies and patenting levels and diversity is estimated with longitudinal, negative binomial and regression models. Preliminary results confirm the more logics compete, the lower the rate of innovative policies and technologies - but the greater the diversity of new policies and technologies. As such, our study contributes to ongoing research in logics, policy, and innovation.

THEORY

Logics and Innovation among Nation-States

A logic refers to the underlying, coherent, enduring set of ideas and practices widely accepted by actors in a field (Friedland & Alford, 1991). While there are several generic logics (or “social orders”) operating in different domain of societies, such as market logic, religious logic, and family logic (Thornton et al., 2012), a logic tends to be specific to the fields in which it has evolved historically, even if it is indexed by these more general types. Hence, a logic like neo-liberalism has evolved in specific fields where government and corporate actors interact – i.e., at the national and international level - even though it also entails both market and state logics (Simmons et al., 2006; Weber et al., 2009).

Within a particular field, there is usually a multiplicity or plurality of logics, each one referencing different generic logics (Kraatz & Block, 2008). These logics as prescriptions of belief and action in a domain may complement or conflict with one another (Pache & Santos, 2010). In some cases, as noted many years ago by Weber (1930), a religious logic like Protestantism may reinforce a market logic, like the economic logic of capitalism; in other fields, logics may be at compete, as they do in U.S. banking where market versus community logics are promoted by national versus local banking (Marquis & Lounsbury, 2007). The reinforcing, complementary logics tend to stimulate further spread and specialization in the accepted ideas and practices in a field (Wry et al., 2014); whereas contested logics are associated with contested thought and behavior in the field and the substitution of one logic and its practices for another (Lawrence et al., 2001; Seo & Creed, 2002).

Recently, it has been pointed out that among multiple logics, some are typically more dominant and more minority-like (Durand & Jourdan, 2012). While for many years in institutional theory, the dominant logic was viewed as being the incumbent logic and the minority logic, the newer logic, this more recent perspective maintains that both instantiated and endured in a field, if unevenly (Greenwood et al., 2011). The different development and valences of these logics are recognized and can be used by field actors to increase (or decrease) the legitimacy of their own preferred logics, for instance in bargaining with the drug court system (McPherson & Sauder, 2013). In the case of asymmetry between two existing logics, researchers have been interested to see if the less dominant, “alternative” logic might enrich thought and practice in a field by offering an alternative institutional arrangement to which actors might conform. Certainly, where the logics of the arts and finance in the film industry (Durand & Jourdan, 2012) or in medical education (Dunn & Jones, 2010) are concerned, this process of enrichment is evident.

Asymmetric Logics in Nation-States. At the nation-state level, the plural logics and their effects may not be the same at lower levels of institutional analyses (Meyer et al., 1997). This is for two, related reasons. First, even though nation-states operate as a field and institutional domain, these actors are less organized and less governed by field-level consensus (Dobbin, 1994; Scott, 2001) than actors in lower level institutional fields like medical schools in medicine (Dunn & Jones, 2010), or American liberal arts colleges (Kraatz & Moore, 2002). Instead, at the global level, nation-states tend to be organized by relatively few coercive and learning mechanisms and far more mechanisms of competition and imitation (Simmons et al., 2006; Weber et al, 2009). Transnational organizations and trade relations typically act as “soft institutions” (Djelic & Quack, 2008) shaping ideas and practices across nation-states in the field.

Second, domestically (that is, within rather than across nations), the government, corporate, and NGO types actors tend to be much more concerned with the need to maintain legitimacy and their mandate than actors in lower level institutional fields (Olsen & March, 1989). Conversely, if legitimacy is granted that the state-level actor, particularly the ruling party, has the power to shape the belief and practice – the "rules of the game" – of other actors in the system (North, 1990), coercive and regulatory mechanism can then be used to enforce government's interests and to keep other alternative interests in check (Scott, 2001).

In the case of asymmetric logics, then, the degree to which the logics are promoted by global, soft institutions will help reinforce each logic. The trade treaties of countries (Weber et al., 2009), for instance, or reliance on imports (Zelner et al., 2009) have shown to influence the impact of new and/or alternative logics. But, a more important factor is the degree to which that logic resonates with actors in the nation state and whether actors in the state have the mandate and institutional capacity to instantiate that logic through innovations in idea and practice.

Innovations in Nation-States. Innovations refer to the perceived creation of some process or outcome that has not existed before as a recognized phenomenon, type, or category, and is attributed to some specific, identifiable, purportedly rational mechanism (Cliff et al., 2006; Wry et al., 2014). In nation states, there are different domains where innovation occurs. These domains are often formally designated by the level of government and by the different areas administered by government (e.g., health, education, and the military). Research and development and assistance to commercializing are recognized domains in modern states. Nations, then, will have innovations at higher levels in these domains in terms of policies - that is, "political innovations"- and also more try to foster innovation at the level of the market or organization, such as through patents, start-ups, and new industry development - that is, "technological innovations."

In any innovation system, the diversity of innovation or innovative practice matters (Dunn & Jones, 2010). Diversity refers to the number of different types, particularly referencing different logics. The diversity of political and technological alternative practice should, as a whole, allow creating a broader base for innovation in that domain. This base can be used directly to create new forms of innovative practice (Cliff et al., 2006), or may just provide the "cultural detritus" (Kroezen & Heugens, 2012) from which later innovation may be built.

The Impact of Asymmetric Logics on Varieties of Innovation

Based on our above theoretical discussion, we expect the effects of asymmetric logics to be evident in the rates and types of political and technological innovations. All logics are likely to stimulate consonant new idea and practice that extend those logics (Friedland & Alford, 1991; Thornton et al., 2012). Thus, a dominant logic is likely to stimulate some level of innovation, particularly in types of innovation aligned with it (Wry et al., 2014). Neo-liberalism as a dominant logic in the renewable field emphasizes on markets and on commercialization of new technologies to create and enlarge markets. It would likely lead to some degree of political innovation in pro-market policies and to the creation of near-market technologies. Environmentalism as the minority logic emphasizes on the regulatory approaches to manage the market externalities may lead to political innovation in pro-regulatory policies and the creation of far-market technologies.

Nevertheless, in the asymmetric logics view, alternative logics – even minority ones – are the real drivers of innovation in domains related to that logic. Some alternative logics may create conflict with current practice in the dominant logic, leading to hybrids (Battilana & Dorado, 2010); some may simply sit adjacent to current practices, allowing a separate set of legitimated practices (Dunn & Jones, 2010); and others may be a branch of current, mainstream practice, as in the French film industry (Durand & Jourdan, 2012). In other words, at the very least, these minority logics generate some alternative innovations, but the degree to which they do so depends on how contested or complementary the logic is to the dominant one in that field.

In the renewable field, at the nation-state level, we anticipate then that environmentalism as the alternative minority logic within a country will lead to greater levels of innovation when the neo-liberalism as the dominant logic is not as strongly held. It is because adherents to environmentalism logic will be more likely to be given voice in order for representatives of the neoliberalism logic to maintain power. If neoliberalism is much more strongly held than the environmentalism, state actors who represent it will have no need to placate environmentalism logic advocates. If both are strongly held, there will be contestation. This contestation may reduce the rate of innovation, because opponents are likely to counter and block each other (Pache & Santos, 2010), but the contestation should generate more diverse innovations (Dunn & Jones, 2010) because it creates more discussions about what should be the direction of political and technological innovations. Thus, we have a threefold set of logic-related expectations:

> ***Hypothesis 1A:*** *The stronger the dominant logic (neoliberalism) in a nation-state, the higher the rate of political and technological innovations, particularly the types of political and technological innovations aligned with that logic.*
>
> ***Hypothesis 1B:*** *The stronger the alternative, minority logic (environmentalism) in a nation-state, the higher the rate of political and technological innovations, particularly the types of political and technological innovations aligned with that logic.*

Hypothesis 1C: *The stronger the dominant and the alternative logic in a nation-state, the lower the rate of political and technological innovations - but the greater the diversity.*

As suggested by the discussion of external and internal forces affecting logics in the nation-state, controlling for the relatively weaker exogenous forces, the impact of asymmetric logics within a country on political and technological innovations will be moderated by nation-state's institutional capacity. Institutional capacity refers to the set of actors, networks, activities, and institutional mechanisms that comprise an institution (Greenwood et al., 2011). In the case of the nation-state, the essential infrastructure components are the government organizations and legal apparatus (Olsen & March, 1989; Scott, 2001). If a nation state has a large number of ministries and courts, a sizeable budget, and is relatively free of corruption, then its institutional capacity should be able to generate more policies as a form of political innovation, and foster more technological development.

The state with greater institutional capacity will also do a better job of translating logics into policies and practices. In the case of the neo-liberalism logic, the translation effect of the capacity should lead to an increase in that logic's effect on congruent political and technological innovation, but what about the case of environmentalism logic? One might argue that the capacity of the state would be used to resist the effects of environmentalism logic and thus capacity would reduce innovation rates, especially in alternatives. However, consistent with the plural logics perspective, we think that the contestation between the two logics may occur simultaneously (Greenwood et al., 2011; Kraatz & Block, 2008). Thus, the degree to which neoliberalism and environmentalism logics compete need to be considered jointly with institutional capacity. If the logics compete a great deal, then the state's institutional capacity will magnify that effect. If the logics are not competing, due to lack of environmentalism logic or weakness of both, then we would imagine that the state would still enhance what joint effect the two logics were having in the domains of policy and technology development. In other words:

> ***Hypothesis 2A:*** *The greater the nation-state's institutional capacity, the higher the rates of political and technological innovations, particularly the types of political and technological innovations aligned with the state.*
>
> ***Hypothesis 2B:*** *The greater the nation-state's institutional capacity, the stronger its impact on the joint effect of asymmetric logics on innovation.*

METHODS

Our empirical setting to examine the impact of dominant and alternative logics and institutional capacity on political and technological innovations is the renewable energy field. We argue that in the case of renewable technologies as a field, two logics are particularly applicable: neo-liberalism and environmentalism (Frank et al., 2000; Simmons et al., 2006; Zelner et al., 2009). These two logics, being derived from different arenas of social life and having different emphases for human versus natural activity, may clash on issues like the priority of human needs versus the need to preserve the environment for its own sake (Hulme, 2010). Neo-liberalism is dominant and fosters innovation more generally, and environmentalism is the minority logic and fosters innovation in renewables in particular. The former is more pervasive, yet the latter has diffused rapidly in the recent years. For instance, renewable technologies that are not evidently applicable to the core of the market economy, such as wind mills, may be under-valued in countries adhering more to neo-liberalism than environmentalism (Sine & Lee, 2009). These contradictions, depending on how they are worked out, may undermine innovation in the renewable energy field.

We use environmental policy foundation as a proxy to measure political innovation, and patenting in solar, wind, and biofuel as a proxy to measure technological innovation (de Rassenfosse & de la Potterie, 2009; Johnstone et al., 2010; Johnstone & Hascic, 2008). We use a strongly balanced cross-national panel dataset. The unit of our analysis is the country-year, and our dataset covers 93 countries between 1980, following the second oil crisis that occurred in 1979 because of Iranian Revolution, and 2012 (the most recent year for which we have completed data). Most renewable patents have been filed worldwide during these years plus the time frame is long enough to capture the impact of logics and institutional capacity.

To identify worldwide patenting activities, we relied on the IPcheckups database (2014). The IPcheckups database maintains patents for multiple domains, including clean technologies. The clean technology patents were identified by a group of experts in the clean technology field and they are based on the application of the patents. Our sample consists of total number of patents that were filed in USPTO (United States Patent and Trademark Office), EPO (European Patent Office), and WIPO (World Intellectual Property Organization). They were 46,924 biofuel patents, 70,390 solar patents, and 30,910 wind patents filed in 123 countries in our sample period. The first author of the paper (Sharifian) manually collected about 1000 patent’s locations that were missing in the IPcheckups database. 30 countries were dropped from our sample either because they were too small and there were no publicly available institutional variables or the countries have been dissolved over time. As a result, most analyses contain data on 93 countries for 33 years.

In the political innovation domain, two main types that concern us are: market-oriented policies vs. regulatory policies. The first type is oriented toward bringing renewable technologies and products to market, such as taxes, tax relief, grants or subsidies. As such, it is most congruent with neo-liberalism's emphasis on markets, freedom and property. The second type is comprised of standard setting, mandatory energy audits, and monitoring. The regulatory policies are more aligned with environmentalism, especially versions that see current methods of production as evidence of market failure. These policies are consistent with more autocratic rule, less organizational flexibility, and lower priority for individual property rights.

In the technological domain, we categorize the innovation in terms of how close they are to the current energy market. We define biofuel technologies as near-market technologies because biofuel can work with the traditional sources of energy. For instance, ethanol can be added to the gasoline or both fuels can be used in hybrid cars (Kovarik, 2013). Aligned with the notion of neo-liberalism that emphasizes on the importance of market, this logic may stimulate more the near-market technological innovation. We define solar and wind technologies as far-market technologies because they do not easily blend with the traditional sources of energy. Far-market technologies require new platforms and are less directly adaptable to the current energy market (IEA, 2013). Wind power is one example. Given its limited scalability due to land use and the size of the wind turbines, wind power does not easily hook into most electrical grids (Young & Dhanda, 2012). In many parts of the world, this requires direct easement of bylaws and other laws to level the playing field enough to make wind power marketable (Anderson & Drejer, 2008). Therefore, we suggest that environmentalism logic may stimulate more the far-market technologies.

Dependent Variables

Total Policies. To code renewable policies for each country, we used data on the International Energy Agency (IEA). The first author counted the number of renewable policies that were introduced each year per country. For instance, in 2008, Chile introduced the non-conventional renewable energy law, which required electricity providing companies to demonstrate that a certain percentage of the total energy they were committed to inject to the system was from non-conventional energy sources. So, the count of policies for 2008 for Chile would be increased by one.

Policy Diversity. Policy diversity refers to the number of different kinds of policies. To construct the diversity measure of policy, we first created a three-year moving average for each policy target type (i.e., biofuel, solar, and wind) in each country to capture inter-temporal nature of policy activity. Additionally, to address potential concerns about the abundance of non-innovative activities in our dependent variables, we created the moving average construct instead of simply entering the raw variables (we used the same approach for patent diversity). Adopting the standard approach for calculating the concentration, we then used the Herfindahl index to create the concentration index in each country-year. Because our variable of interest is diversity, we subtracted the concentration index from 1. Thus, the maximum of diversity measure is 1 and the minimum is 0.

Policy Ratio (Regulatory Policy/Market Policy). A neo-liberal logic is more aligned with market than regulatory policies; the opposite is true of environmentalism. IEA has categorized renewables into several groups**:** information and education, economic instruments (market), policy development and reform, research, development &deployment (RD&D), regulatory instruments, and voluntary approaches. The first author created “regulatory/market” policy ratio by dividing the total number of regulatory policies to the total number of market policies that was introduced to the country for each year.

Total Patents. For each country, the first author identified biofuel, solar, and wind patents separately for each year from the IPcheckups database and then summed them to create the total patents. They are the number of patents that were filed in USPTO, EPO, and WIPO (de Rassenfosse & de la Potterie, 2009; Johnstone & Hascic, 2008; Johnstone et al., 2010). The first author used the residence of the first inventor to identify the origin country of the patent (Fu & Yang, 2009; Bierenbaum et al., 2012). Biofuel patents comprised of patents for algae, biodiesel, biogas, biomass, ethanol, and microbes. Solar patents consisted of patents for concentrators, solar cells, panels, and systems, and thin films. Wind patents comprised of patents for wind farms, measurement and forecasting, and turbines and components.

Patent Diversity. As we constructed our measure for policy diversity, we measured the patent diversity using a three-year moving average for each patent (i.e., biofuel, solar, and wind). We then used Herfindahl index to create the concentration index. Because we were interested in diversity the number was subtracted from 1.

Patent Ratio (Far-market Patents/Near-market Patents). We used two “far-market /near-market” patents ratios in our analysis, one is named “solar/biofuel”, and the other is “wind/biofuel”. The first one was created by dividing the total number of solar patents to the total number of biofuel patents per country per year. The same method was used to create “wind/biofuel” construct. We defined biofuel patents as near-market patents because biofuel can work with the traditional sources of energy. For instance, ethanol can be added to the gasoline or both fuels can be used in hybrid cars. We defined solar and wind patents as far-market patents because they do not easily blend with the traditional sources of energy.

Independent Variables

Neoliberalism. This construct is captured by the first author using "polity 2" from the POLITY IV database. This database is widely used in political science research. The project was founded by a political scientist, Ted Robert Gurr, in 1960s and it contains annual data from 1800 to 2013 on the level of democracy for each country that has greater than 500,000 populations. Polity 2 is computed by subtracting the autocracy score from the democracy score. We think this measure is a good proxy for neoliberalism because it demonstrates the degree of government intervention and its autocratic power. It ranges from +10 (democratic) to -10 (autocratic) (Marshall, Jaggers, & Gurr, 2011). To test the validity of our measure we calculated the correlation between Polity 2, and measures of Economic Freedom from the Heritage Foundation. The Index of Economic Freedom from the Heritage Foundation (Miller et al., 2012) is only available from 1995. The correlations are moderate to high: 0.49, 0.46, 0.54, and 0.54 for property rights, trade freedom, investment freedom, and financial freedom, respectively. It indicates the validity of our measure.

Environmentalism. Capturing environmentalism over this long period and so many countries is difficult. To capture strong versus weak (or non-existent) environmentalism, we created a scale based on two variables: Kyoto membership (0/1), and green party formation (0/1). Membership in Kyoto was double-weighted and added to green party formation for all years from point of formation. In other words, all values by country year started at zero. The year in which there was the formation of a registered national green party, a one was added. The year in which a country ratified Kyoto, a two was added. Data for Kyoto ratification was obtained by the first author from UNFCCC (United Nations Framework Convention on Climate Change) website. She used Global Greens dataset to identify the date the green party was formed in each country and supplemented that data with searching the words “country name” and “green party” in the internet.

Institutional Capacity. Institutional capacity demonstrates the amount of resources governments have and how efficient they use these resources. We multiplied three variables to create this construct, which are government expenditure as a percentage of GDP, low corruption, and GDP (logged) for each country. The first author obtained data on the percentage of government expenditure of GDP and GDP for each country from World Bank dataset. However, to cope with substantial missing data, she used the annual average of government expenditure in each country for our sample period. She measured low corruption using corruption perception index (CPI) over time per country. Each year Transparency International Organization scores countries in terms of how corrupt their public sector is perceived to be. The index draws on corruption-related data that are collected by several reputable institutions. CPI reflects the views of experts living and working in the countries and it ranges from 0 (most corrupted country) to 10 (least corrupted country). This measure is highly correlated to freedom from corruption (0.90) from heritage foundation’s index of economic freedom. The combination of three variables maintained the face validity of institutional capacity as we combined total government expenditure with effective implementation by government, which is the corruption measure.

Control Variables

We controlled for world-level media attention to “renewables” issues, trade-related factors, and resource endowments to capture the effect of other social, political, and resource capitals. More specifically:

World-level Media Attention to "Renewables" Issues. To measure the media attention to renewables, the first author used Factiva database and counted the number of articles that used the term "renewable*" in their article in five major international magazines, which are The New York Times, The Economist, Financial Times, The Economic Times (India), and The Wall Street Journal Asia over time. This number was normalized in the equations.

Trade-related Factors. We controlled for energy import and oil price. The first author obtained net energy import data (% of energy use) from World Bank dataset. Net energy imports are estimated as energy use minus production; both are measured in oil equivalents. Annual average global oil prices ($/barrel) are also included to control yearly variations in policy and patenting as a result of responses to changes in oil prices in the globe. She obtained this data from BP Statistical Review of World Energy 2013.

Resource Endowments. Three control variables were collected: natural resources rents, total biocapacity, and population. Controlling for natural resources rents helps us to control for the effect of access of country to capital. In economic terms, rent is the surplus value after the deduction of costs and normal returns. Natural resources rents are the sum of oil rents, natural gas rents, coal rents, minerals and forest rents. Total biocapacity is hectares per capita of croplands, grazing land, forest, fishing ground, and built land that is available to a nation. This data is obtained from global footprint network by the first author. It is time invariant and belongs to 2007. Controlling for population also helps us to control for the country size and access to human capital. Data for both natural resource rents and population were obtained from World Bank dataset by the first author. Data on population was logged.

Analytic Approach

We have three sets of dependent variables: the amount of innovation, the ratio of type of innovation, and the diversity of innovation. For the amount of innovation, we address the discrete nature of both policy and patent variables by employing a negative binomial model. We do not use a Poisson model because a likelihood ratio test for over-dispersion rejected the null, which meant the mean and variance of the event count were not proportional (Cameron & Trivedi, 1986).[3] Our more nuanced dependent variables are the ratio and diversity measures of renewable energy policies and patents. Given that the ratio and renewable measures are bounded from zero to one by our research design, we test our hypotheses on the ratio and diversity of renewable energy policies and patents using generalized least square (GLS) estimation.

Since our sample traces multiple countries over a long period of time, our findings might be biased due to unobservable heterogeneity related to global or country-specific characteristics. First, year fixed-effects are included to control for global trends such as economic boom and bust that are likely to affect overall policy and patenting. Second, addressing country effects is a common research practice in the cross-country analysis using longitudinal dataset. The random-effects specification assumes that the observed country variables and the unobserved country-specific effects are uncorrelated. The choice between random-effects and fixed-effects may depend upon sample and statistical characteristics as well as theoretical preferences. Because some of our independent variables are time-invariant and Hausman exogeneity test did not reject the null across our models, we adopt a random-effect model.

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[3] Additionally, to address potential concerns about the abundance of non-innovative activities in our dependent variables, we conducted a Vuong test, which compares the zero-inflated negative binomial model with the negative binomial model. Because we did not reject the null, we present the negative binomial regression results throughout our paper.

In general, the innovation literature assumes a one-year lag between explanatory variables and total patent applications ultimately granted.[4] However, due to the paucity of prior research on the impact of cross-national variations in institutional sources on patenting in both developed and developing countries, we take a cautious approach and employ two-year lagged explanatory variables for our analysis of patenting activities (Lanjouw & Mody, 1996).

RESULTS

Table 3.1 contains summary statistics and correlations for the variables used in our analysis. As one would expect, the main dependent variables, total patents and policies in renewable sectors, are highly dispersed. The skewed distribution of these variables enhances the face validity of our sample. While some correlations for the interaction terms are high, a variance inflation factor (VIF) analysis revealed that multicollinearity was not a concern, as all VIF scores were well below the recommended threshold of 10, the largest being 2.79.

--- Insert Table 3.1 about here ---

Table 3.2 summarizes the effect of each logics, neo-liberalism and environmentalism on policies and patents (Hypotheses 1A and 1B). We enter control variables across different dependent variables (models 1, 3, 5, 7, and 9) before analyzing the main effects of our variables of interest. The effects of control variables are relatively consistent across different dependent variables.

Hypothesis H1A maintains that neoliberalism in a nation positively impacts the number of renewable energy policies and patents, particularly the ratio of market policies over regulatory

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[4] That is, we investigate the association between last year's value of variables of our interest and this year's patenting levels. In the case of the relationship of R&D and firm patenting in developed countries and high technology sectors, the use of a one-year lag is likely to be supported (Ahuja, 2000; Katila and Ahuja, 2002; Wadhwa and Kotha, 2006).

policies and near-market patents over the far-market patents in that country. As indicated in models 2 and 4, the effects of neoliberalism on renewable energy policies and patents are significant and positive. Interestingly, model 6 predicts that the effect of neoliberalism on the ratio of regulatory policies over market policies should be negative, but it is not supported. Model 8 predicts that the effect of neoliberalism on the far-market/near-market patent ratio should be negative, but the result presents positive and significant effect; similarly, the negative effect in model 10 is not evident. Thus, the primary predictions of Hypothesis 1A about the dominant logic's effects on innovation are fully supported, whereas the support for the more nuanced predictions is only partial.

H1B maintains that environmentalism in a nation should positively affect the number of renewable energy policies and patents, particularly of regulatory policies over market policies and far-market patents over near-market patents in that country. As indicated in model 2, the effect of environmentalism on renewable energy policies is significant and positive. Nevertheless, model 4 exhibits that the effect of environmentalism on renewable energy patents is positive, yet insignificant. Fortunately, more consistent with our theorizing, model 6 shows that the effect of environmentalism on the ratio of regulatory policies over market policies is positive and significant, and, as predicted, models 8 and 10 also show that the effect of environmentalism on far-market patents over near-market patents is positive and significant. Hypothesis 1B, therefore, is supported, including the many of the nuances about the minority logic's main effects.

--- Insert Table 3.2 about here ---

Table 3.3 examines the effect of having strong, if asymmetric logics – i.e., contestation - on policies and patents, as detailed in Hypotheses 1C. We maintain that the challenge to the dominant logic by an alternative logic in a country will negatively affect the rate of political and technological innovation but increase diversity. To capture logic contestation, we entered the interaction of neoliberalism and environmentalism. Models 1 and 2 present the effects of contestation of logics on renewable energy policies and patents. Consistent with our theorizing, contestation of logics negatively affects the creation of renewable energy policies and patents. Models 3 and 5 present the baseline model of control variables for diversity of policies and patents. Model 4 confirms that the effect of logics contestation on the diversity of renewable energy policies is positive and significant, even though model 6 does not support our claim. Overall, Hypothesis 1C is mostly support: contestation between asymmetric logics negatively affects the number of policies and patents, yet positively affects the diversity of policies (if not patents).

--- Insert Table 3.3 about here ---

Table 3.4 summarizes the results for Hypothesis 2A, which predicts that the institutional capacity of a nation positively effects the number of renewable energy policies and patents, particularly regulatory policies over market policies and far-market patents over near-market patents in that country. Models 1 through 5 present the effects of institutional capacity across different dependent variables. Models 1 and 2 present the effects of institutional capacity on renewable energy policies and patents. Consistent with our theorizing, institutional capacity is positively associated with the creation of renewable energy policies and patents. Model 3 confirms that the effect of institutional capacity on the ratio of regulatory policies over market-based policies is positive and significant. Consistent with our prediction, models 4 and 5 show that the effect of institutional capacity on far-market patents over near-market patents is positive and significant. Thus, Hypothesis 2A is overall strongly supported.

--- Insert Tables 3.4 about here ---

Table 3.5 summarizes the moderating effect of institutional capacity on the relationship between contestation of two logics, environmentalism and neoliberalism, on policies and patents (Hypotheses 2B). To examine the moderating effect, we entered interaction variables of the multiplicative term of neoliberalism and environmentalism and institutional capacity across different dependent variables. Model 1 presents the moderating effect of institutional capacity on the relationship between logics contestation and renewable energy policies. Consistent with our theorizing, institutional capacity confound the negative relationship between logics contestation and the creation of renewable energy policies. Likewise, model 2 shows that institutional capacity confounds the negative relationship between logics contestation on renewable energy patents. Models 3 and 5 present the baseline model of control variables for diversity of policies and patents. Consistent with our overarching argument, the results indicate that institutional capacity exerts a significantly positive direct effect on the diversity of policies and patents. Model 4 confirms that the moderating effect of institutional capacity on the positive relationship between logics contestation on the diversity of renewable energy policies is positive and significant. However, model 6 displays a significant negative effect of the interaction on patent diversity. We speculate that market-driven innovation's mechanisms might be different from those of political innovation in terms of diversity. Thus, there is moderate, if not strong support, of Hypothesis 2B.

--- Insert Table 3.5 about here ---

DISCUSSION

Given the surprising lack of research conducted on cross-national study on the impact of asymmetric logics at the nation-state level, particularly as a source of innovation, this study examined the fundamental theoretical contingencies at the nation-state level that should enhance the positive effects of alternative, minority logics on alternative practice innovations. We argue that the relationship between the rise of environmentalism and the response of the nation-state is not univariate, due to complex institutional mechanisms inherent in the contestation between institutional logics and institutional capacity within each country. To test the multiple dimensionality of cross-national innovations associated with these two institutional sources in renewable energy fields, we analyzed a strongly balanced cross-national panel dataset consisting of 93 countries over 33-year period.

Our analysis revealed that political and technological innovations in the renewable energy field were associated with both neo-liberalism as a dominant logic and environmentalism as a minority one. In particular, countries with strong neo-liberalism had more policies and patents for renewables, including far-market patents. Countries with strong environmentalism tended to have more policies, but not more renewable patents overall; instead ones in far market technologies (especially wind). The pervasive effects of neo-liberalism on innovation are in keeping with its effects on innovation in other domains, such as microfinance (Zhao & Wry, 2011), stock markets (Weber et al., 2009), and power projects (Zelner et al., 2009). This demonstrates the ability of neo-liberalism to accommodate and complement, to some degree, competing logics and their advocated policies (Simmons et al, 2006). Nevertheless, the environmental logic's effects were equally evident and in substantive terms (translated coefficient effects) larger than those of neo-liberalism, at least where policy was concerned.

Therefore, enduring alternative logics do appear to stimulate alternative practice at the nation state level, as documented in lower level fields (Durand & Jourdan, 2012).

As predicted by the arguments derived from contestation between dominant and alternative logics, our results indicate that the contestation of the two logics is likely to constrain the amount of political and technological innovations. That is, while each logic contributes to the amount of innovations positively, the contestation of logics is likely to put a cap on the amount of innovations. These findings corroborate with previous research on the dominant versus alternative logics (Marquis & Lounsbury, 2007; Zelner et al., 2009), yet, to the best of our knowledge, are the first to be reported for cross-national innovations in particular. Much more research is needed, however, on the underlying reasons for this negative relationship. Furthermore, consistent with our expectations drawn from asymmetric logic studies in lower level fields, contestation between these two logics generates more diversity in policy. It seems possible that there is either a move of opponents to form more distinct policies in more disparate domains, perhaps to avoid as much conflict or perhaps as a result of making deals that lead to trade-off in the passage of policies (Hoffman & Ventresca, 2002).

Finally, we argued that institutional capacity affected innovation in direct and confounding manners. As expected, institutional capacity affected positively across the dimensions of innovations and moderated the effects of logics contestation on innovations (Olsen & March, 1989; North, 1990). Unexpectedly we did not find the moderating effects of institutional capacity to be positively associated with patenting diversity. Instead, our results revealed that there was a negative effect of the interaction between institutional capacity and logics contestation on patenting activity. Thus, exploring which potential mechanisms suitably account for the relationship between institutional sources and innovations observed in our study represents an important direction for future work at the intersection of sustainability and institutional research.

Contributions

Our study offers three main contributions and associated implications. First, drawing from the socio-cultural approaches (Friedland & Alford, 1991; Thornton et al., 2012), we expand our knowledge of institutional sources of political and technological innovations, complementing the tradition of social-political approaches (Hamilton & Biggart, 1988; Dobbin, 1994; Fligstein, 1996). Therefore, we followed past calls for stronger theorization of such institutional sources in order to increase our understandings in innovations (Dobbin & Sutton, 1998; Hiatt et al., 2009; Sine & Lee, 2009). In particular, we explicated arguments derived from institutional logics and institutional pluralism (Thornton et al., 2012; Kraatz & Block, 2008) as theoretical drivers for the implementation of political and technological innovations. While the majority of extant institutional research on sustainability has invoked the external pressure as the primary-if not a sole driver for proactive environmental strategies, we complemented this approach with a simultaneous consideration of heterogeneous institutional pressures and institutional capacity as a confounding factor. The primary implication of our study is that future endeavors to understand innovations in renewable energy fields should take into account both cultural and political factors. We thus extend emergent applications of institutional logics within sustainability research (Hoffman et al., 1999; Hoffman & Jennings 2011; Gao & Bansal, 2013) as well as contribute to recent research on exploring moderators to the impacts of competing logics (Almandoz, 2014; Vasudeva et al., Forthcoming).

Second, we advance research on sustainability. By investigating the integrative approaches of institutional logics and institutional capacity for understanding cross-national innovations in renewable energy fields, we add to the body of literature examining the antecedents of proactive environmental strategies (Bansal and Hoffman, 2012). Despite the potential importance of social implications of innovations in renewable energy in the globe, almost all notable related research have departed from a single country level analysis (for similar comments see Schüssler, Rüling, & Wittneben, 2014). This relative neglect reflects upon both challenges in theorization in the cross-country setting and inherent empirical challenges in research on proactive environmental strategies drawing from large-scale macro-level data (Meyer, 2010). The dearth of such work is unfortunate, however, considering the prevalence and potential social and economic impact of renewable energy sector. Our research suggests that institutional sources are substantive elements of cross-national innovations in renewable energy fields and calls for future research in more detail.

A third contribution of our study is that it is one of very few attempts to investigate multiple dimensions of innovative activities. We endeavored to capture the heterogeneity of innovations in renewable energy fields by constructing multidimensional measures of both political and technological innovations. While our findings are consistent with previous institutional research, our observation of the amount, diversity, and direction of political and technological innovations is intriguing, providing preliminary evidence for the call for multidimensional institutional approaches.

Limitations

There are limitations of our study that could be fruitfully advanced in future research. First, we acknowledge that there are alternative institutional mechanisms that might explain cross-national political and technological innovations in the renewable energy field. In this paper, we tend to conceptualize macro-level institutional variables in a large sample of countries. Thus, some of our empirical measures are relatively coarse proxies for micro-level institutional mechanisms at practice. An in-depth comparative case study (Hamilton & Biggart, 1988; Dobbin, 1994; Guillen, 2001) or an intensive case study of a single country (Hoffman, 2001) may contribute to a more fine-grained understanding of detailed institutional aspects of innovations. There are inherently trade-offs. One of these is likely to be external validity. Although we incorporated several measures to capture nuanced aspects of innovation, we agree that we hinge upon generalizability over contextualization. Thus, we believe future insights could be gained from research in micro aspects of institutional sources of innovations in the renewable energy field.

Second, our innovation measures are drawn from policy and patent founding. In most cases the patenting and policies are empirically discernable and clear to quantify; however, our measures contain very conservative nature and are likely to underestimate innovative activities in informal economy. Future researchers might want to consider other variations in cross-country innovations in the renewable energy field, such as whether the relationships observed within our study differ for informal political and technological dimensions. Currently our measure of diversity is constructed among renewable sectors. Alternatively, this measure can be constructed through comparing renewable and non-renewable sectors.

Third, we acknowledge that it is difficult to discern the direct effect and indirect effect of institutional logics on innovations. There are several other potential mechanisms, which are likely to influence logics and then impact innovations. These could be social movements in countries, network based actions of NGOs (Hoffman & Bertels, 2010), and learning effects from prior innovation experiments (Greve, 2011). We hope that future research will continue unpacking this relationship between asymmetric logics and innovation among nation-states.

Fourth, there are concerns about how we measured neoliberalism and environmentalism logics. In this version of the paper, neo-liberalism is measured by an autocracy/democracy score. A better measure for neoliberalism is the Index of Economic Freedom from the Heritage Foundation. However, this data is only available from 1995. We calculated the correlation between autocracy/democracy measure and several key variables from the Index of Economic Freedom. All the correlations are above 0.46 indicating the validity of our measure.

Environmentalism is measured based on the Kyoto membership and green party formation. A better way to measure environmentalism is to look at the number of environmental organizations that were founded per country throughout our time period. Finally, there is a concern about endogeneity issue among the logic variables and our dependant variables, policy and patent. One might argue that the increase in our dependant variables, patents and policies, in a country would increase the neo-liberalism and environmentalism logics.

Table 3.1: Means, Standard Deviations, and Correlations

Variable	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 Total Policies	0.13	0.56																	
2 Total Patents	36.52	289	0.43																
3 Policy Diversity	0.06	0.17	0.56	0.27															
4 Patent Diversity	0.16	0.25	0.28	0.19	0.32														
5 Regulatory/Market Policies	0.04	0.28	0.49	0.20	0.34	0.18													
6 Solar/biofuel Patents	0.59	1.73	0.10	0.12	0.12	0.35	0.05												
7 Wind/Biofuel Patents	0.27	0.85	0.14	0.09	0.14	0.35	0.11	0.38											
8 Neoliberalism	3.33	7.20	0.16	0.12	0.22	0.45	0.11	0.23	0.15										
9 Environmentalism	0.91	1.13	0.32	0.10	0.40	0.43	0.25	0.19	0.28	0.30									
10 Neoliberalism x Environmentalism	2.37	9.53	0.27	0.14	0.33	0.42	0.18	0.19	0.20	0.58	0.52								
11 Institutional Capacity	3850	2697	0.20	0.12	0.22	0.55	0.09	0.21	0.18	0.45	0.21	0.39							
12 Neoliberalism x Environmentalism x Institutional Capacity	12652	28158	0.21	0.14	0.24	0.57	0.11	0.24	0.19	0.82	0.30	0.55	0.71						
13 Media (Normalized)	0	1	0.10	0.06	0.13	0.14	0.06	0.00	0.08	0.15	0.35	0.16	-0.03	0.09					
14 Energy Import	-29.25	190.74	0.04	0.05	0.09	0.13	0.03	0.09	0.04	0.34	0.09	0.16	0.11	0.27	0.04				
15 Natural resources rents (%GDP)	8.27	15.03	-0.09	-0.07	-0.10	-0.24	-0.06	-0.14	-0.07	-0.49	-0.10	-0.32	-0.28	-0.44	-0.02	-0.73			
16 Total Biocapacity	2.96	4.14	0.15	0.02	0.12	0.22	0.04	0.06	0.07	0.31	0.12	0.23	0.32	0.37	0.01	-0.01	-0.10		
17 Population (logged)	15.77	2.16	0.12	0.20	0.15	0.19	0.10	0.10	0.03	0.09	0.03	0.00	-0.18	0.02	0.00	0.09	-0.03	-0.12	
18 Global Oil price ($/barrel)	54.65	29.06	0.17	0.09	0.19	0.15	0.14	0.12	0.15	-0.03	0.39	0.13	0.03	-0.01	-0.25	-0.03	0.13	0.00	0.01

Table 3.2: Analysis of Hypothesis 1A and Hypothesis 1B

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Total Policies	Total Policies	Total Patents	Total Patents	Regulatory/ Market Policies	Regulatory/ Market Policies	Far market/ Near market Patents (1)	Far market/ Near market Patents (1)	Far market/ Near market Patents (2)	Far market/ Near market Patents (2)
Neoliberalism (H1A)		0.040*		0.137***		0.001		0.020**		0.001
		(0.021)		(0.010)		(0.001)		(0.008)		(0.004)
Environmentalism		0.339***		0.022		0.019**		0.115*		0.053†
(H1B)		(0.111)		(0.031)		(0.008)		(0.060)		(0.034)
Media (Normalized)	1.461**	1.018*	0.920***	0.791***	0.049***	0.024	0.299**	0.140	0.199***	0.136*
	(0.461)	(0.479)	(0.085)	(0.087)	(0.014)	(0.017)	(0.100)	(0.122)	(0.057)	(0.069)
Energy Import	0.121	0.116	0.973*	-0.424	-0.072†	-0.078*	0.431	0.394	-0.158	-0.146
	(1.039)	(1.028)	(0.486)	(0.399)	(0.039)	(0.038)	(0.337)	(0.338)	(0.185)	(0.186)
Natural resources	-0.049***	-0.036*	-0.024***	-0.009	-0.002***	-0.002**	-0.007†	-0.005	-0.006*	-0.005*
rents (%GDP)	(0.015)	(0.015)	(0.006)	(0.005)	(0.000)	(0.000)	(0.004)	(0.004)	(0.002)	(0.002)
Total Biocapacity	0.105***	0.088**	0.126***	0.065***	0.002	0.001	0.026	0.017	0.008	0.008
	(0.029)	(0.029)	(0.015)	(0.015)	(0.001)	(0.001)	(0.024)	(0.024)	(0.011)	(0.011)
Population (logged)	0.374***	0.400***	0.103**	0.249***	0.014***	0.013***	0.107	0.106	0.016	0.017
	(0.075)	(0.071)	(0.035)	(0.040)	(0.004)	(0.004)	(0.067)	(0.065)	(0.030)	(0.029)
Global Oil price	-0.013	-0.009	-0.046***	-0.046***	0.001	0.001	-0.003	-0.001	-0.006	-0.006
($/barrel)	(0.010)	(0.010)	(0.003)	(0.003)	(0.001)	(0.001)	(0.007)	(0.007)	(0.004)	(0.004)
Year dummies	Included	Included	Included	Included	Included	Included	Included	Included	Included	Included
N	2766	2754	2766	2754	2766	2754	2766	2754	2766	2754
Number of groups	93	93	93	93	93	93	93	93	93	93
$\chi2$	361***	369***	5732***	6464***	252***	259***	174***	184***	289***	289***
Log-likelihood	-884.01	-874.93	-5662.72	-5555.20						
R-squared overall					.09	.09	.07	.09	.09	0.1

† $p \leq .10$, * $p \leq .05$, ** $p \leq . 01$, *** $p \leq .001$ (two-tailed tests for controls; one-tailed tests for hypothesized effects)
Equations (1) – (4) use negative binomial analyses. Equations (5) – (10) use GLS analyses.

Table 3.3: Analysis of Hypothesis 1C

VARIABLES	(1) Total Policies	(2) Total Patents	(3) Policy Diversity	(4) Policy Diversity	(5) Patent Diversity	(6) Patent Diversity
Neoliberalism x	-0.038**	-0.018***		0.003***		0.001
Environmentalism (H1C)	(0.014)	(0.004)		(0.000)		(0.000)
Neoliberalism	0.112***	0.146***	0.001	-0.001	0.002*	0.002*
	(0.037)	(0.011)	(0.001)	(0.001)	(0.001)	(0.001)
Environmentalism	0.481***	0.104**	0.010*	0.001	0.020***	0.020***
	(0.126)	(0.037)	(0.006)	(0.006)	(0.006)	(0.006)
Media (Normalized)	1.049*	0.809***	0.093***	0.097***	0.040**	0.040**
	(0.480)	(0.086)	(0.012)	(0.012)	(0.013)	(0.013)
Energy Import	-0.298	-0.566	-0.045	-0.002	0.024	0.026
	(1.064)	(0.407)	(0.033)	(0.034)	(0.037)	(0.037)
Natural resources rents	-0.040**	-0.012*	-0.002***	-0.001†	-0.002***	-0.002***
(%GDP)	(0.015)	(0.005)	(0.000)	(0.000)	(0.000)	(0.000)
Total Biocapacity	0.087**	0.069***	0.004*	0.004*	0.009*	0.009*
	(0.029)	(0.015)	(0.002)	(0.002)	(0.004)	(0.004)
Population (logged)	0.400***	0.268***	0.017***	0.020***	0.029**	0.030**
	(0.072)	(0.042)	(0.005)	(0.005)	(0.010)	(0.010)
Global Oil price ($/barrel)	-0.009	-0.046***	-0.004***	-0.004***	-0.001†	-0.001†
	(0.010)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Year dummies	Included	Included	Included	Included	Included	Included
N	2754	2754	2754	2754	2754	2754
Number of groups	93	93	93	93	93	93
$\chi 2$	351***	6494***	840***	899***	923***	922***
Log-likelihood	-870.72	-5547.55				
R-squared overall			0.23	0.25	0.26	0.26

† $p \leq .10$, * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$ (two-tailed tests for controls; one-tailed tests for hypothesized effects)
Equations (1) – (2) use negative binomial analyses. Equations (3) – (6) use GLS analyses.

Table 3.4: Analysis of Hypothesis 2A

VARIABLES	(1)	(2)	(3)	(4)	(5)
	Total Policies	Total Patents	Regulatory/ Market Policies	Far market/ Near market Patents (1)	Far market/ Near market Patents (2)
Institutional Capacity (H2A)	0.228***	0.296***	0.008**	0.124***	0.075***
	(0.039)	(0.018)	(0.003)	(0.039)	(0.018)
Neoliberalism x	-0.050**	-0.010*	0.002**	0.001	0.006*
Environmentalism	(0.018)	(0.005)	(0.001)	(0.006)	(0.003)
Neoliberalism	0.114**	0.091***	-0.002†	0.017*	-0.006
	(0.049)	(0.012)	(0.001)	(0.009)	(0.005)
Environmentalism	0.417***	0.012	0.005	0.085	0.002
	(0.134)	(0.040)	(0.009)	(0.068)	(0.039)
Media (Normalized)	1.162*	0.766***	0.041*	0.191	0.235**
	(0.480)	(0.076)	(0.019)	(0.133)	(0.076)
Energy Import	0.190	-0.260	-0.056	0.755	0.004
	(0.959)	(0.439)	(0.057)	(0.570)	(0.305)
Natural resources rents	-0.024	-0.003	-0.001†	-0.001	0.000
(%GDP)	(0.016)	(0.006)	(0.001)	(0.007)	(0.004)
Total Biocapacity	0.075**	0.038*	0.001	-0.005	0.005
	(0.025)	(0.015)	(0.002)	(0.034)	(0.015)
Population (logged)	0.409***	0.581***	0.019***	0.134†	0.035
	(0.063)	(0.045)	(0.004)	(0.073)	(0.032)
Global Oil price ($/barrel)	-0.005	-0.047***	0.001	-0.004	-0.007
	(0.010)	(0.003)	(0.001)	(0.008)	(0.005)
Year dummies	Included	Included	Included	Included	Included
N	2482	2482	2482	2482	2482
Number of groups	83	83	83	83	83
χ2	384***	8288***	269***	175***	295***
Log-likelihood	-808.6	-5167.46			
R-squared overall			0.10	0.11	0.12

† *p* ≤ .10, * *p* ≤ .05, ** *p* ≤. 01, *** *p* ≤ .001 (two-tailed tests for controls; one-tailed tests for hypothesized effects)
Equations (1) – (2) use negative binomial analyses. Equations (3) – (5) use GLS analyses.

Table 3.5: Analysis of Hypothesis 2B

VARIABLES	(1) Total Policies	(2) Total Patents	(3) Policy Diversity	(4) Policy Diversity	(5) Patent Diversity	(6) Patent Diversity
Neoliberalism x Environmentalism x	-5.52†	-3.895***		1.252***		-1.015***
Institutional Capacity (H2B)	(3.748)	(0.786)		(0.208)		(0.213)
Institutional Capacity	0.302***	0.326***	0.016***	0.007*	0.038***	0.045***
	(0.063)	(0.019)	(0.003)	(0.003)	(0.004)	(0.005)
Neoliberalism x	-0.042*	-0.001	0.004***	0.003***	0.004	0.001
Environmentalism	(0.018)	(0.006)	(0.001)	(0.001)	(0.001)	(0.001)
Neoliberalism	0.088*	0.072***	-0.001†	0.002	0.002†	0.002
	(0.05)	(0.012)	(0.001)	(0.001)	(0.001)	(0.001)
Environmentalism	0.403***	0.012	-0.009†	-0.009†	0.015*	0.015*
	(0.132)	(0.04)	(0.007)	(0.007)	(0.007)	(0.007)
Media (Normalized)	1.235*	0.785***	0.104***	0.098***	0.047***	0.052***
	(0.484)	(0.075)	(0.013)	(0.013)	(0.014)	(0.014)
Energy Import	0.121	-0.171	0.097†	0.109*	0.066	0.054
	(0.937)	(0.447)	(0.051)	(0.051)	(0.06)	(0.06)
Natural resources rents	-0.025	-0.007	0.001	0.001	0.001	0.002
(%GDP)	(0.016)	(0.006)	(0.001)	(0.001)	(0.001)	(0.001)
Total Biocapacity	0.077**	0.045**	0.003	0.003	0.008*	0.008*
	(0.024)	(0.015)	(0.002)	(0.002)	(0.004)	(0.004)
Population (logged)	0.414***	0.616***	0.023***	0.022***	0.046***	0.045***
	(0.061)	(0.044)	(0.005)	(0.005)	(0.009)	(0.009)
Global Oil price ($/barrel)	-0.006	-0.047***	-0.004***	-0.004***	-0.001†	-0.001†
	(0.01)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Year dummies	Included	Included	Included	Included	Included	Included
N	2482	2482	2482	2482	2482	2482
Number of groups	83	83	83	83	83	83
$\chi 2$	384***	8329***	897***	946***	940***	968***
Log-likelihood	-807.47	-5155.17				
R-squared overall			0.29	0.29	0.49	0.49

† $p \leq .10$, * $p \leq .05$, ** $p \leq$. 01, *** $p \leq .001$ (two-tailed tests for controls; one-tailed tests for hypothesized effects)

Equations (1) – (2) use negative binomial analyses. Equations (3) – (6) use GLS analyses.

PAPER 3: BEING GREEN OR TALKING GREEN: THE EFFECTS OF IDENTITY AND IMAGE ON ATTRACTING INVESTMENT IN CLEAN TECHNOLOGY

INTRODUCTION

Clean technologies refer to technical products and services that reduce ecological impacts by, for example, lowering GHGs, improving water quality, or enhancing waste management efficiencies (Pernick & Wilder, 2007). These technologies are central to the mission of combatting climate change problems (IPCC, 2012), responding to water demand issues (United Nations, 2012), and competing in the global economy (The Economist, 2012). Yet many of these technologies are unproven and their economic yields are unclear. Therefore, a central issue for entrepreneurs working on clean technologies is how to raise and keep capital (Lane, 2011).

Previous research suggests that both the identity and image portrayed by entrepreneurial firms matter in resource acquisition (Martens, Jennings, & Jennings, 2007; Zott & Huy, 2007; O'Connor, 2004; Lounsbury & Glynn, 2001). More coherent identities make it easier for firms to be recognized and classified by investors, regulators, and potential employees (Rao, Monin, & Durad, 2003; Navis & Glynn, 2010). This classification then allows for a quicker assessment of the firm's potential. Firms that have ambiguous identity receive fewer resources (Ruef & Patterson, 2009; Zuckerman, 1999). Straddling categories (Wry & Lounsbury, 2013) or having ambiguous identities (Martens et al., 2007; Pontikes, 2012) makes it difficult for investors to assess risk and return, and thus they are less likely to commit capital. In contrast to identity as being more authentic, images are "fabricated, projected pictures" targeted towards different stakeholders (Gioia, Schultz, Corley, 2000; Bernstein, 1984), thus, are considered to be less authentic in the eyes of investors, and other constituencies.

When a firm is using both a new technology and working in a new industry category, it faces a double-burden: the firm must craft an identity for itself and help build an identity for its emerging industry. New research suggests that firms in such conditions rely on extant firms from close proximity niches or categories by building unique identities while drawing on these extant cultural materials (Wry & Lounsbury, 2013; Hsu & Hannan, 2005). In the case of clean technology, firms face a triple-burden: they must not only build individual and industry level (collective) identities, but also build identities that span two very different domains of operation: the technological and the ecological (Bansal & Roth, 2000; Jennings & Zandbergen, 1995).

I argue that under these conditions, firms may choose to manipulate their green identity as a means to build firm-specific and industry level identities to acquire resources.[5] In addition, clean technology companies that are faced with multiple challenges to build their identity may try to compensate this effect by creating a socially desirable image, that is, a green image. Therefore, in this paper, my main research question is *how do an organization's identity and image influence the acquisition of resources?*

To test my theorizing, I examined investments in 120 randomly selected clean technology firms with an emphasis on the three sectors of solar, wind, and biofuel technologies, which went public between 2000 and 2014. These investments included all committed market capital via initial public offering (IPO) and all listed post-IPO market investments. The names of the companies were drawn from the Cleantech group (www.cleantech.com/, accessed December 2011) and were supplemented with data from Zephyr, Orbis and company prospectus documents. To establish cleantech firm identities, I collected information on the founders, top management teams, and country context to capture the extensive nature of the firm's identity. These were

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[5] I distinguish between "clean" and "green" terms in this paper. "Clean" technology firms are those firms that deliver products and services to reduce negative environmental impacts. There are variations among these firms in terms of portrayal of being "green".

analyzed separately and combined into an overall green identity profile. To establish green image, I coded the green statements (accounts) from the summary section of the prospectus (for some examples please see Appendix 4.2). In the case of investors' evaluation, I examined the green identity of investors in the post-IPO investment. Finally, industry cultural context was defined by firms working in renewables versus non-renewables. All hypotheses about the effects of green identity, green image, investors, and industry cultural context were tested using panel regression models.

THEORY AND HYPOTHESES

Identity refers to the central, distinctive, continuous characteristics of an organization (Gioia et al, 2013; Albert & Whetten, 1985). As such, identity involves a firm's values and culture (Glynn, 2008). Yet, like all values and corporate cultures, identity is reflective of the wider environment. A firm's identity is typically reflective of a broader "collective identity" in an industry or field (Lounsbury & Glynn, 2001), which itself is a continuous set of a firm's profiles, roles, and interactions that define the industry's essential products and services. These collective identities have their own underlying structure and processes, being based on recognized logics (Thornton, Ocasio, & Lounsbury, 2012) and social codes that have evolved over time (Hannan, Polos, & Carroll, 2011). Collective identities become more complex as they involve more logics or elaborate social codes. For instance, identity in law firms draws upon the legal profession and the marketing logic (Greenwood, Suddaby, & Hinings, 2002) and in nanotechnology on science and corporate commercial logics (Wry et al., 2010). A coherent firm-level identity requires that it be anchored within the collective identity and successfully brokers the competing field-level logics and codes.

However, the way an organization forms its identity is not only influenced by the meanings and labels it borrows from the environment in which it is embedded (Glynn, 2008), but also by the identity of the organization's founders and key decision makers (e.g., top management team) (Gioia et al., 2013). In a study of the formation of an organization identity, Gioia and colleagues demonstrate that, in the first step, the founders articulate the initial identity claims, which creates a vision for the company (Gioia et al., 2010). Ashforth and colleagues (2011) conceptualize that, during the identity formation, the intra-subjective understanding ("I think") of the founders comes together at the inter-subjective level ("we think") to create a social reality about who they are as an organization, which creates a generic understanding ("it is") of the identity of the firm.

In addition, to have any noticeable impact, a firm's identity requires audience recognition and evaluation. At the same time, having an audience that observes identity automatically creates a split between a firm's actual identity and its perceived image (Dutton & Dukerich, 1994) or between identity and its evaluation (Rao, 1998; Zuckerman, 1999). Reducing - or at least not revealing - this gap is considered crucial for retaining organizational legitimacy (Meyer & Rowan, 1977). Less authentic firms are those that have a large and/or revealed gap. Firms that have unclear identities or a gap between image and identity have been shown to lose legitimacy (Elsbach, 1994) and to acquire fewer resources (Zuckerman, 1999).

The method of transmitting or displaying an identity has an impact on the evaluation of firm's authenticity. Hannan and colleagues (2011) argue that firm identity is based on social codes embedded within the firm at its founding. A firm's social codes may make the firm appear more or less authentic, based on the degree to which these codes fit evaluator categorizations (Hsu, Roberts, & Swaminathan, 2012); but firm's participants have less control over those evaluations. In the case of the organization's image, a firm may have more control on how it builds its image, but it creates greater debate among its constituencies about authenticity (Lefsrud, Graves, & Phillips, 2013).

Cultural theorists argue that portrayals and identities themselves are somewhat more malleable and consciously developed (Lounsbury & Glynn, 2001; Navis & Glynn, 2010). For instance, firms may develop stories or narratives (Martens et al., 2007) or use various types of speech acts (Cornelissen, Clarke, & Cienki, 2012) and visual displays (Jones et al., 2011) to garner resources. Firms may also use impression management techniques to portray themselves in acceptable ways (Zott & Huy, 2007).

Context has become equally important for understanding the image-identity gap that is evaluated by different parties. Context is frequently viewed as being based on fields underpinned by logics (Thornton et al., 2012) or cultural understandings (Lounsbury & Glynn, 2001). Different cultural contexts would seem to require different degrees and types of authenticity, because logics and values entail alignment of ideas and action. Logics and values also involve normative assessment of those ideas and actions by other members of collectives. In French cuisine, for instance, the authenticity of nouveau cuisine was a central issue for legitimacy (Rao et al., 2003). Similarly, in mutual funds, new types of funds had to be accepted by investors in order to diffuse (Lounsbury, 2007).

But identity researchers are still in the midst of grappling with the interaction between identity, image, and audience evaluation of authenticity across a variety of cultural contexts (Navis & Glynn, 2010). There is far more emphasis on the upside of identity and image than on the downside. An exception is the work of Navis and colleagues (2012) on the non-emergence of online groceries as a new market category, which they argue is due to the failure in the emergence of a core identity frame. Furthermore, no study, to my knowledge, has yet theorized and tested the effects of multiple sectors and countries as different cultural venues, where identities are evaluated in a way that influences legitimacy and resource provision. Clean technology is a venue that seems to allow me to explore these theoretical issues.

Clean Technology and Identity

Clean technology is perceived to be a sector that is technically and morally superior to conventional technologies (The 2013 Canadian Clean Technology Industry Report, 2012). Policy makers have pointed to clean technology as the wave of the future (The Economist, 2012; IPCC, 2012) and signaled that funds are available for viable clean technologies. Thus, firms that fit better with the expectations of the constituencies in the cleantech field may have greater access to resources and earning premiums over their counterparts that do not meet expectations

But identity and authenticity in clean technology, as noted in the introduction, are problematic. Clean technology is relatively new. Firms have a triple burden: they must craft identities at the firm level, craft collective identities, and balance highly competing logics. The logic of ecology, while based on the science, also involves elements of local community and spirituality (Gladwin, Kennelly, & Krause, 1995; Jennings & Zandbergen, 1995). The scientifically documented demands of ecosystems and the spiritual appeal of ecological domains can easily become at odds with market logics that drive on economic gains (Bansal & Clelland, 2004).

Furthermore, investors in clean technology appear to vary greatly in their motives (Cleantech group, 2012). Some investors are, themselves, clean technology providers; but many are not. There are large standard technology firms that see clean technology as a new opportunity or source of innovation. In addition, there are venture capital firms and banks that are primarily looking at high risk, high reward, and long term investments. Thus, the audience that evaluates the identities of clean technology firms is complex.

Research on audiences suggests that firms handle different audiences differently. A firm will handle analysts differently than banks and banks differently than ENGOs (Hart & Sharma, 2004). Ideally, there would be some prioritization of audiences and congruence among their interests allowing a firm to maximize its appeal (Ebbers & Wijnberg, 2010). In the case of investors in clean technology, segmentation or prioritization of audiences may not be possible. The market deals are not as large and as frequent, plus they tend to be bundled (Cleantech group, 2012). Therefore, in the case of resource acquisition, audiences need to be characterized as a whole. As a result, clean technology firms that craft green identities may end up suffering if they end up with investors who are much more concerned about market returns than clean tech claims or green missions.

Finally, in the case of cultural context, particularly of industries, clean technology has been acknowledged to contain very different industries (Cleantech group, 2015) and criticized for being a catch-all (The Economist, 2011). Yet researchers and policy makers continue to refer to clean technology as a sector (Pernick & Wilder, 2007). Within this sector there is a division between renewable and non-renewable technologies. Renewable technologies include solar, wind, biofuel and biomaterial, water power, and geothermal. Non-renewable technologies refer to technologies such as energy efficiency and energy storage (Cleantech group, 2012).

The technologies and traditions of these two subsectors and the specific industries within them tend to differ. For instance, solar has had its own path of development, one that was tied at first to the space race and more recently to Silicon Valley's development of wafer chips

(Bradford, 2006). The personnel and technologies from these related industries helped populate solar. The wind industry had also its beginnings in experiments with windmills and wind turbines; much of it is pioneered by Vestas in Denmark (Busby, 2012). The consortium of networked suppliers and buyers created a set of understandings about technologies, investments, and value, which helped propel the wind industry to success. In contrast to both industries, batteries and co-generation technologies have been tied much more closely to large extant manufacturers, such as General Motors, Samsung, General Electric and Siemens (Ofek & Wagonfeld, 2012). These ties strongly influence the flow of personnel and capital to the industries, and the degree to which start-ups in batteries and co-generation need or should appear to be green.

Hypotheses

To examine these issues about the authenticity of cleantech firm identity and image, which are coded in how cleantech firms portray their green identity and image, I first theorize about the ways in which cleantech identity and image are crafted and vary. I then examine their evaluation by investors and in different contexts.

Cleantech Identity. An important part of identity is history (Gioia et al., 2013), which explains why founders have important imprinting effects on a firm's identity. Identity scholars show that the founders' beliefs and value systems provide a valuable reference for the identity of the new organizations (Gioia et al., 2013; Gioia et al, 2010; Hannan, Baron, Hsu, & Kocak, 2006; Kroezen & Heugens, 2012).

In Hannan and colleagues' (2011) stream of research and also in the entrepreneurship literature, the founder's identity is considered an essential factor in the creation of a firm's identity (Kroezen & Heugens, 2012; Fauchart & Gruber, 2011; Hoang & Gimeno, 2010; Miller et al., 2011; Hannan, Baron, Hsu, and Kocak, 2006; Shane & Khurana, 2003; Shane & Stuart, 2002; Boeker, 1989). Fauchart and Gruber (2011) explain that the founder's identity shapes major decisions in the creation of new firms and argue that fundamental differences in firms are associated with the founder's identity. In another study, Hoang and Gimeno (2010) suggest that the founder's identity is linked to longer-term outcomes such as the success of the new venture. Shane and Khurana (2003), in their study on 134 firms founded to exploit a set of inventions patented by MIT during the 1980-1996, highlight the important role of founders. They emphasize that a firm's founding is not determined only by the characteristics of opportunities at hand and that founders have a significant role in the new venture due to their imprinting effect. In a similar study, Shane and Stuart (2002) demonstrate that the founder's social capital (direct and indirect ties with investors) can influence the resource acquisition and success of the new venture, highlighting the importance of the background of the founders.

Therefore, I argue that:

> ***Hypothesis 1:*** *Clean tech companies that are dominated by founders possessing a green background will attract more investment than clean tech firms that are not.*

Existing research on the formation of an organization identity shows that the beliefs and values of the leaders of an organization influence the firm's identity (Gioia et al., 2013). Gioia and Thomas' (1996) study of 611 executives from 372 colleges and universities in the U.S. shows how the top management team influences the process of identity change. Their study demonstrates that organizational identity has "strong and systematic" relationships with how the top management team interprets important issues in the organization. In another study, Humphreys and Brown (2002) demonstrate how a top management team attempts to change the identity of an educational institution from a traditional teaching-oriented identity to a modern research-oriented identity. In their study, the attempt of senior managers fails because they could not legitimize the identity change. The above literature suggests the following hypothesis:

> ***Hypothesis 2:*** *Clean tech companies that are dominated by a top management team with a green background will attract more investment than clean tech firms that are not*

National context has been examined much less for identity claims and market outcomes (Gioia et al., 2013). An exception is the work of Jack and Lorbiecki (2007) that finds that national identity can have an important influence on the formation of an organization identity. Glynn and Watkiss (2012) also argue that an organization is a social actor and its identity is greatly influenced by the broader societal culture in which the organization is embedded. They add that organization reflects the "cultural themes" and borrows the "cultural resources" from its environment. There are other studies that demonstrate how country conditions influence the behavior of organizations (e.g., Egri & Herman, 2000). Weber, Davis, and Lounsbury (2009) demonstrate how the country's context influences the likelihood of the stock exchange adoption,while Zhao and Wry (2011) show how the country-level economic conditions influence the behavior of micro-finance organizations. Therefore, I argue that:

> ***Hypothesis 3****: Cleantech firms that are located in greener countries will attract more investment.*

Authenticity is judged using cues (Navis & Glynn, 2011). If the cues are congruous with each other, authenticity is likely to be viewed as higher, compared to if they are incongruous. This is true whether examined from the point of view of signaling (Spence, 1973) or ethical reasoning. I would expect, then, for the cues of the founders, the top management team, and the country context to be compounded and thereby increase authenticity. However, there is likely to be a point of decreasing – and perhaps even negative – return for overly green identity portrayals. Overly green identities may be overly embedded in the ecological domain of clean technology, likely at the expense of the market and science domains. Thus, I hypothesize that:

> ***Hypothesis 4****: Cleantech companies with green founders, a green top management team, and based in greener countries will attract more investment at a decreasing rate.*

Based on the above hypothesis, green identity differs from the green leader and TMT because it is about the alignment of multiple identity cues, which are green leader, green TMT, and green country.

Cleantech Image. An organization image is how the company wants to be portrayed. Some identity scholars believe that the way an organization describes itself in public documents is not necessarily an expression of its identity, but the projected image that the organization hopes that other stakeholders will accept as legitimate (Gioia et al., 2013). Gioia and colleagues (2013) suggest that public documents, such as annual reports, are often fictions that may not be congruent with the actual identity of the organization.

Given that the pressure for companies to be responsible toward the natural environment has recently increased, it is not surprising that companies publicly portray themselves as being green regardless of their true identity. Previous research shows firms usually face tension between the demands of shareholders (to increase profit) and other stakeholders (to be environmentally responsible). Therefore, firms may be motivated to exaggerate their environmental accomplishments through their information disclosure strategies (Kim & Lyon, 2014). This phenomenon known as “greenwashing” is 119heir119ered prevalent in many industries (Delmas & Burbano, 2011).

Kim and Lyon (2014) explain that the literature on greenwashing focuses on a firm's decision to (1) exaggerate positive environmental performance, (2) disclose both the positive and negative aspects of environmental performance, or (3) remain silent (Delmas & Burbano, 2011; Lyon & Maxwell, 2011). The authors extend the theory of greenwashing and show that there is a fourth greenwashing option: firms may choose to "brownwash" the public by understating their environmental achievements. In this paper, I argue that in nascent fields, where firms are challenged to gain legitimacy, build their identity (Navis & Glynn, 2010), and acquire resources to survive (Martens et al., 2007), they create a favorable image about being environmentally friendly, to acquire resources. Yet, they may be penalized by the public for their greenwashing intentions. Therefore I argue that:

> ***Hypothesis 5****: Cleantech firms that portray a green image will attract less investment than clean tech firms that do not.*

Authenticity Evaluations. The success of identity portrayal depends on the audience as well. Companies portray their identity differently if they want to attract investors compared to if they want to sell their products/services to customers. Some work has moved in this direction. For instance, Pontikes (2012) finds that the authenticity of a software firm's identity depends on whether the evaluation is done by a consumer vs. venture capital audience (also see Kim & Jensen, 2011). In another study, Pollock and his colleagues (2008) show how investors and media allocate attention to newly public firms in the days following their IPOs and how it affects a firm's evaluation in the days that follow the IPO (also see Ebbers & Wijnberg, 2010). I argue that the degree to which authenticity influences funding depends on the overall coherence of the firm's *identity* on multiple dimensions: founder identity, top management team identity, and context. I hypothesize that if a cleantech firm has coherent and consistent claims across these three dimensions – i.e., "strong" green identities, then it is more likely to be deemed authentic. In contrast, due to the negative perception of greenwashing by the public, a cleantech firm with a strong green *image* deems to be less authentic. As a result:

> ***Hypothesis 6****: Green investors will fund cleantech firms with a) a stronger green identity but b) a weaker green image.*

Industry Cultural Contexts. The cultural context of founding and identity portrayals matters. Cultural claims, in particular, are strongly contingent on context (Thornton, 2004). For instance, the use of strong identity claims by radio stations was found to be successful (Navis & Glynn, 2010), but strong identity claims by online groceries was not (Navis et al. 2012). Some cleantech industries seem to have a stronger sense of collective "green" identity than others, putting a greater burden on firms and investors in these sectors to be authentic. The culture of industries in renewables and the foundation of particular industries like wind and water power, biomass and biofuels, has been based on individuals and groups with green missions (Pernick & Wilder, 2007). The ability of firms in such industries to attract investment would seem to be enhanced by having stronger green identities. Having green founders and top management team with experience in solar or wind, given the tightness of these communities, would seem to signal quite clearly that the firms are committed to their mission. Also, being from countries that are known to foster particular green industries, such as Denmark with wind power, the U.S. with solar, Germany with biodiesel and co-generation, is likely to increase the degree of authenticity of a firm's green identity within an industry culture. However, greenwashing is known to be a problem in renewable industries (Lyon & Montgomery, 2015). The above arguments suggest the following hypotheses:

> ***Hypothesis 7a****: In renewable industries the green identity of cleantech firms will attract more investment, particularly from green investors, than green identity in non-renewable industries.*

***Hypothesis** 7b: In renewable industries the green image of cleantech firms will attract less investment, particularly from green investors, than green image in non-renewable industries.*

RESEARCH DESIGN AND METHOD

Figure 4.1 demonstrates the summary of the hypotheses. To test the hypotheses, I collected investment data on 120 randomly selected clean technology firms worldwide with an emphasis on the three sectors of solar, wind, and biofuel technologies, which went public between 2000 and 2014. The level of analysis is firm-investment and I collected data on both IPO and post-IPO investments (n=539). I then used regression models of investment levels, controlling for panel variation, to test the hypotheses. The details of this design are provided below.

Sample

To identify clean tech firms and industries, I relied on the Cleantech group's definition of clean technology firms (http://research.cleantech.com/). This forum is the best known forum worldwide for cleantech investments and has recently been used by other organization and natural environment researchers (e.g., see Marcus, Malen, & Ellis, 2013, Malen, 2011). The industries range from those in energy efficiency and waste management – relatively standard domains tailored toward non-renewable sectors – to those in solar, wind power, and biofuels – renewables.

Dependent Variable

The dependent variable was the logged amount of money invested in a firm, in U.S. dollars. These investments included both IPO and post-IPO investments. Given the heterogeneous nature and varying size of these investments, I not only used the log of investments but also controlled for IPO vs. post-IPO periods.

Independent Variables

Green Founders. I identified the founders of the company through three sources: firm prospectus documents, company websites, and general internet searches. In the founders' backgrounds, I looked for evidence of experience in green industries. I then created a ratio, dividing the total number of green founders to the total number of founders in the company. For instance, in the prospectus document of Suntech Power Holdings, a Chinese company in the solar sector, it is written that "Zhengrong Shi is our founder…Dr. Shi is the inventor of 11 patents in PV [photovoltaics] technologies…" (Prospectus document, p.83). According to this document and the general search in the company website, and internet, the company has only one founder and the founder has experience in green industry, which means the score for this variable is: 1/1=1.

Green Management. I identified the top management team of the company via the prospectus document. In the top management team's backgrounds, I looked for evidence of experience in green industries. I then created a ratio by dividing the total number of green top managers to the total number of top management team members in the company. For instance, according to the prospectus document, Suntech Company, which went public in 2005, has 7 top managers. The CEO of the company, who is also the founder, is Zhengrong Shi. As mentioned above, he has experience in the green industry. According to the prospectus document, Dr. Stuart Wenham, who is the chief technical officer of the company, is a professor and the director for the center of excellence for advanced silicon photovoltaic, and photonics at the University of new South Wales in Australia (prospectus document, p. 84). Finally, Mr. Yichuan Wang, who is a manager of PV cell research and development, worked at Yunnan Semiconductor Company on the research, development, and manufacturing of PV products (from 1979 to 2001) (prospectus document, p. 85). Therefore, the green management score for this company is: 3/7= 0.43.

Green Country Score. To code the green country score, I used data on the International Energy Agency (IEA). I counted the number of environmental policies that were introduced each year per country and then created a density measure for each year. For instance, in 2008, Chile introduced the non-conventional renewable energy law, which required electricity-providing companies to demonstrate that a percentage of their total committed energy was from non-conventional energy sources. Based on this method, the count of policies for 2008 for Chile would increase by one onward.

Green Identity. To create the green identity construct to test hypothesis 4, I created a variable named "Green Lead Founder and TMT". I defined the lead founder based on the following criteria: was the founder active in the company at the time the prospectus was written and did s/he have the highest possible ranking in the governance system of the company (e.g., CEO)? If none of the founders were active at the time the prospectus was written, I chose the founder with the highest share value in the firm as the lead founder. Using the founder and TMT data, I created an ordinal variable, as follows: "2" represented firms having a green lead founder and at least one green TMT member; "1" represented firms having at least one green TMT member, but no green founder; and, "0" represented firms having neither a green founder nor a green TMT member. For instance, the score for Suntech Company is 2 because the lead founder and at least one member of the top management team have green backgrounds. I had no cases where the lead founder was green and at least one top management team member was not, so I did not include this category. I then standardized the country-level pro-environmental policies variable, and multiplied it by the "green lead founder and TMT" variable to create the green identity construct. I also squared the green identity construct in order to test for curvilinear effects. It should be noted that the reason I used "green lead founder and TMT" construct instead of the "green founders" and "green management" variables is that, in the prospectus document, companies are not required to report the information about the founders of the company, but they should report information about the top management team. Therefore, I had missing data for the founders of 35 companies.

Green Image. To code green image, I read the summary section of the prospectus documents, published by each company. I searched for words such as "clean*", "environment*", "emission", "renewable*", "sustain*", and "conserve*" in each paragraph. I then applied a coding protocol to understand whether the main theme of the paragraph was green or not. The protocol was comprised of 10 statements (please see Appendix 4.3). Two examples are: "the company talks about how its technology/product/process is green," and "the company talks about environmental awareness". If the bulk of the paragraph seemed to be about green issues, I coded it as green. I then added up all green paragraphs in the summary section of the prospectus to create a raw green story score. I calculated the percentage of the green statements (accounts) by dividing the raw score to the total number of paragraphs in the summary section and used the percentage in the models. Appendix 4.2 demonstrates some examples of green and non-green statements.

In my view, using green statements in the summary of the prospectus to measure the green image is appropriate. Previous research states that claims made in public documents such as annual reports are not the expression of an organization's identity. Instead they are "projected images" that the organization wants others accept to gain legitimacy (Gioia et al., 2013). Gioia and colleague add that "…these [claim] can be fictions that do not square with actual insider perceptions of identity" (Gioia et al., 2013, p. 170).

Green Investor. To code green investors, for each post-IPO deal, I created a dummy variable with "1" indicating that the deal had at least one green investor and "0" otherwise. I determined whether an investor was green using the individual and firm history of the investor. To code an individual investor's background, I looked at the person's or his/her firm's webpage. Being "green" was designated in the same way as with the founder and top management team: the person had worked in a green industry or green firm, or the main website of the person's current firm contained a green mission or green values. To code for greenness of the firm's investor, I looked at the portfolio investment of the firm to see if the company had a history of investment on green/environmental initiatives. For instance, Hannon Armstrong Sustainable Infrastructure Capital (HASI) and Sunpower made a deal in 2014 under which HASI provided $42 million in non-recourse debt to help finance Sunpower's residential solar lease program (Clean Technology Business Review, 2014). When looking at the "about us" section of HASI Company, it is written that "Hannon Armstrong provides debt and equity financing to the energy efficiency and renewable energy markets…" (HASI Website, accessed April 2015). Therefore (as an example), I coded this investor as a green investor.

Control Variables

I controlled for several firm-level variables, including firm age, number of board of directors, number of patents filed at the time of IPO, number of joint-ventures/alliances a firm made at the time of IPO. I also controlled for some financial variables to include total investments received by the firm before the time of IPO (logged), its net profit, and total assets a year prior to the IPO/investment (see Martens et al., 2007; Pollock et al., 2008).

Because the data was global, I used two global control variables. The first one was a dummy variable called “G7 countries”, which indicated whether a firm was among G7 countries. Such countries have very different economic conditions compared to those of non-G7 countries. According to the Credit Suisse Global Wealth Report October 2014, the G7 countries are the seven wealthiest developed countries comprised of Canada, France, Germany, Italy, Japan, United Kingdom, and United States that hold 64% of the net global wealth. The dummy coded “1” if the country was among G7 countries and “0” otherwise. I also controlled for the stock exchanges, creating three dummy variables: North American Stock Exchanges, European Stock Exchanges, and Asian Stock Exchanges.

I created a dummy for IPOs where I analyzed both IPOs and post-IPO investments together. Finally, I used standard industry and temporal controls for regression analysis. I created four industry dummies: biofuel and biomass production, solar, wind, and non-renewables. I also created a yearly dummy for the time of investments.

Methods of Analysis

I employed ordinary least square (OLS) regression to assess the impact of key decision makers, country context, green statements and investors net of controls. I applied OLS in four different samples: a pooled sample of all IPOs and post-IPO investments, a sample of post-IPO investments only, and split samples for all renewable vs. non-renewable industry investments. In the pooled analyses, the VIF for the main models were below 2.16, which indicated that multicollinearity was not an issue in the model. In the second set of analysis, the VIF for the main models were below 2.15. Table 4.1 also shows that there are no correlations among the main effects (but not interactions) and between the main effects and the control variables are above .54, again indicating collinearity is not an issue for testing the hypothesis. Notably, I created the "green lead founder and TMT" variable based on the "green founders" and "green management" variables to deal with the missing data on the "green founders" variable. Therefore, the correlation between these three variables is high, but I do not use them as independent variables at the same time in the models.

--- Insert Table 4.1 about here ---

RESULTS

Model 1 in Table 4.2 shows testing of hypothesis 1, which predicts that cleantech companies that are dominated by the green founders will attract more investment. I see strong support for hypothesis 1. In supplementary analyses of the post-IPO investments only, which reduces heterogeneity, I find that again having founders with green background attracts investments. These additional analyses are reported in Appendix 4.1.

Model 2 in Table 4.2 is used to test hypothesis 2, which is cleantech firms with larger number of green management will attract more investment. The result for the whole sample is significant, which means hypothesis 2 is supported. Model 3 in Table 4.2 tests hypothesis 3, predicting that cleantech firms that are located in greener countries will attract more investment.

I see strong support for the hypothesis 3 in the whole sample and post-IPO sample in Appendix 4.1.

Because I had some missing data for the founders of the companies, I created "green lead founder and TMT" variable. As it is shown in model 4 in Table 4.2, having green lead founder and TMT will increase the attraction of the investment. I use this variable to build the green identity measure. Models 5 and 6 in Table 4.2 test hypothesis 4, claiming that cleantech companies with green lead founders, green top management team and in greener countries will attract more investment, but at a decreasing rate. Although I do not see the green identity affects resource attraction in model 5, green identity's effect becomes significant in model 6 when I enter green identify square to test the curvilinear relationship, partially supporting hypothesis 4. The same result appears in the Appendix 4.1 for hypothesis 4. Model 7 in Table 4.2 tests hypothesis 5, claiming that cleantech firms with greener image attract less investment. The significant negative coefficient indicates that hypothesis 5 is supported.

--- Insert Table 4.2 about here ---

Cleantech Audiences

In hypothesis 6a, I argue that green investors will fund more cleantech firms with stronger green identity. Models 1 and 2 in Table 4.3 test this claim. I cannot find any evidence to support hypothesis 6a. In contrast, hypothesis 6b indicates that green investors will fund more cleantech firms with weaker green image. Models 3 and 4 in Table 4.3 test hypothesis 6b. According to model 4 in Table 4.3, green investors fund more in cleantech firms with weaker green image. The coefficient for the interaction is negative and significant, supporting hypothesis 6b.

--- Insert Table 4.3 about here ---

Cleantech Industry Cultures

In hypothesis 7, I argue that there are different industry cultures or a collective identity in clean technology sector segments and that these cultures may differentially affect the degree to which green identity attracts investment. I used sub-sample analysis to test hypotheses 7b and 7a. The results are shows in Tables 4.4 and 4.5. Table 4.4 explores hypothesis 7a, which claims that in renewable industries the green identity of cleantech firms will attract more investment, particularly from green investors, than green identity in non-renewable industries. In models 1-4, I see that green identity strongly matters for cleantech firms in renewable industries, but it has no effect for non-renewable industries. Interestingly, contrary to what I hypothesized, having a green lead founder or TMT strongly matters for non-renewable industry (please see models 5-8 in Table 4.4) and has no effect for the renewable industry. Thus, hypothesis 7a is partially supported.

--- Insert Table 4.4 about here ---

Table 4.5 tests hypothesis 7b, which claims that in renewable industries the green image of cleantech firms will attract less investment, particularly from green investors, than green image in non-renewable industries. Model 2 shows that having greener image negatively influences the resource attraction in the renewable industries; however, I find no effect of green image on resource attraction for non-renewable industries. As shown in model 3, cleantech firms in renewable industries are penalized more for their green image by the green investors than cleantech firms in non-renewable industries. Thus, hypothesis 7b is mostly supported.

--- Insert Table 4.5 about here ---

Extra Analyses

I did some extra analyses to see if the green image's effect changes for companies when the lead founder has a green background and at least one member of the TMT has a green background. The results are shown in Appendix 4.4. As you see in models 2 and 4, the interaction effects between "green image" and "green lead founder and TMT" as well as the interaction effect between "green image" and "green lead founder" are negative and significant. These findings imply that the negative relationship of green image on resource acquisition is stronger when the lead founder and at least one member of the top management team have green background. In other words, cleantech firms are penalized more when there are more discrepancies between the identity of the key decision makers in the organization and the organization's image.

DISCUSSION

This paper has examined whether green identity and image within the clean technology sector add any value to a new firm as a means of attracting investment. Being skeptical about the uniform value of having a green identity, particularly based on the triple-burden of identity creation in clean technology, and green image particularly because of greenwashing perception, I have explored the more specific question: "*how do an organization's identity and image influence the acquisition of resources?"*

I find that having green founders and management team, and being from a greener country have a positive effect on the acquisition of resources. In contrast, having a green image has a negative effect on the acquisition of external resources. I also find that having a high congruence among the elements of identity – overall green identity – has a positive effect on the acquiring of resources, but at a decreasing rate. An examination of industry cultural context shows that having an overall green identity matters more for renewable industries. Furthermore, having a greener image in renewable industries may be a greater liability for cleantech companies.

Potential Implications for Research and Theory

The primary area to which this research contributes is work on identity and image. Researchers are just beginning to grapple with how identity and image, investor evaluations, and industry cultures work jointly, especially across very diverse global and industry sectors. This work contributes to the multi-level studies of identity or what Ashforth and colleague refer as nested identities (Ashforth et al., 2011). Ashforth and colleagues (2011) suggest that we can learn a lot about identity via multiple-level studies. The study also responds to the call to study what identity influences rather than what it is (Pratt, 2012). In the recent Academy of Management Annals (2012), Gioia and colleagues suggest that one of the important directions of the identity work should be toward understanding identity's role in other organizational phenomena- in the case of this paper, the acquisition of external resources.

My work also contributes to entrepreneurship theory, particularly the process of resource acquisition. Scholars have theorized and demonstrated the importance of fitting categories and recipes, using stories, and also pitching investors for garnering resources. But work is just beginning on the combined effects of multiple appeals. A related issue is how entrepreneurial firms should reconcile their identity versus image to acquire resources. I think that this study can be generalized to other areas of entrepreneurship such as social entrepreneurship. I speculate that social entrepreneurial companies that have founders and top managers with the history of social work are more successful to acquire external resources than those companies that emphasize on their social missions in the public document. Future research may prove my speculation.

An equally important area to which this study contributes is natural environment and organization research. Scholars in that area have made consistent efforts to bring natural environment research directly into the domains of business and economics (Gladwin et al., 1995; Hoffman & Vantresca, 2002). I have examined investment in clean technology firms, a fundamental economic activity, and shown the ways in which green identity and image can help and hinder firms. In this way, I have avoided the pitfall of ideologically driven research that seeks to demonstrate that it always pays to be green (e.g., see Porter & Van der Linde, 1995).

I have also tried to theorize about and test green issues across multiple industries and countries, which are consistent with the move towards more international study of green issues (Bansal & Hoffman, 2011). Another contribution of this paper to the natural environment and organization research is to greenwashing literature. Previous research on greenwashing shows how companies use different mechanisms to deceive the external constituencies (for a review see Lyon & Montgomery, 2015). My paper adds to this stream of literature by showing that regardless of the intention of the organization, because greenwashing is a negative social norm, the companies may be penalized for greenwashing the public.

Limitations

The paper has several limitations due to its international context. First, company data in Europe and Asia is not as comprehensive as company data in North America; therefore, the sample is biased toward companies that went public in North America Stock Exchanges. However, I hand collected data and for each variable I tried multiple data sources to enrich the data. Second, because I was not able to read the news in other languages, I could not analyze the country media. Third, not all of the investor's deals are public and even if I used multiple sources to identify the post-IPO investments I could not cover all the investors as some deals' amount/name of the investors were not disclosed. Fourth, I used prospectus document to code the green leader and green TMT based on the biography of the people. One might argue that they can be fabricated as well. I believe this issue holds for any kind of research that includes coding of a written document. For the publication, another person needs to code a sub-sample of the prospectus document to check for the interrater reliability of my coding. Finally, there may be better ways to code the green image of a company such as interviewing critics in the field. This approach was not possible for my sample because of its international nature.

CONCLUSION

When all is said and done, if I were to offer a few small conclusions for researchers based on the theory and results in this study, they would be: actors (e.g., founders, managers) are deemed to be more important than acts (e.g., statements, claims) in crafting identity; national identity and industry culture matter; investors who have a similar identity (e.g., green) to one's company may be more sensitive to what one claims about its company. Translated into practitioner terms, these conclusions might be to choose key decision makers that their values are aligned with how one wants to portray the firm's identity, make sure that the company fits with the broader country and cultural context, and finally it may pay to be green, or have social mission but one should not overstate it.

Figure 4.1: The Summary of Hypotheses

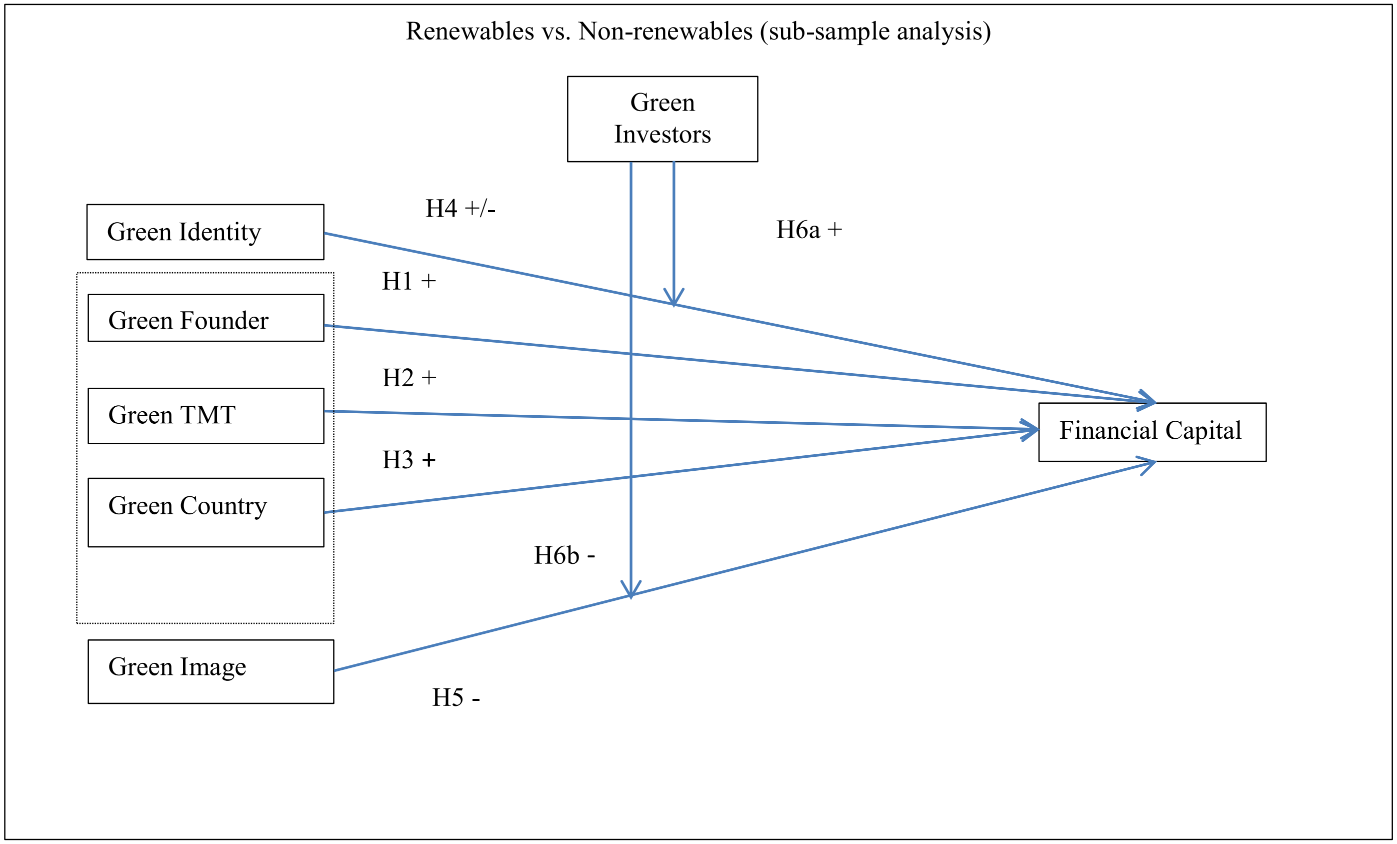

Table 4.1: Means, Standard Deviations, and Correlations

Variables	Mean	S.D.	1	2	3	4	5	6	7	8	9	10
1 Green Founders	.54	.47										
2 Green Management	.30	.28	0.54									
3 Green Country	22.94	14.3	0.48	0.06								
4 Green Lead Founder and TMT	1.14	.77	0.86	0.64	0.32							
5 Green Identity	.17	1.42	0.59	0.17	0.91	0.47						
6 Green Identity Square	2.04	2.79	0.65	0.21	0.67	0.59	0.82					
7 Green Image	.14	.16	-0.12	-0.33	0.10	-0.24	0.02	0.02				
8 Green Investor	.57	.50	0.09	-0.01	-0.04	0.13	-0.04	-0.01	-0.04			
9 Green Investor x Green Identity	.30	1.11	0.40	-0.01	0.68	0.32	0.75	0.57	0.13	0.34		
10 Green Investor x Green Image	.09	.16	0.06	-0.20	0.08	-0.00	0.12	0.16	0.70	0.44	0.31	
11 Firm Age	11.4	12.95	0.15	-0.20	0.11	0.15	0.19	0.30	0.11	-0.08	0.25	0.15
12 Number of Board Members	6.02	1.84	0.18	0.06	0.20	0.21	0.24	0.17	-0.10	0.01	0.31	-0.01
13 IPO Patents	11.18	42.6	0.24	-0.19	0.30	0.19	0.34	0.37	-0.07	0.11	0.37	0.00
14 JVs and Alliances	.51	1.23	0.04	0.02	0.15	0.12	0.19	0.21	0.07	-0.07	0.12	-0.00
15 Total Investment before IPO (logged)	9.62	8.60	0.06	0.19	0.11	0.10	0.04	-0.07	0.13	0.09	0.07	0.10
16 Net Profit (Thousand USD)	-286989.8	2053496	0.00	0.00	-0.02	-0.06	-0.00	0.12	0.13	0.01	-0.00	0.09
17 Total Assets (Thousand USD)	7993092	32300000	-0.12	-0.04	-0.09	0.00	-0.11	-0.25	-0.22	-0.14	-0.05	-0.21
18 G7 Countries	.53	.50	0.20	-0.03	0.54	-0.00	0.50	0.49	0.23	-0.03	0.36	0.20

Variables	11	12	13	14	15	16	17
11 Firm Age							
12 Number of Board Members	0.22						
13 IPO Patents	0.37	0.3622					
14 JVs and Alliances	0.13	0.23	0.11				
15 Total Investment before IPO	-0.27	0.38	-0.21	0.17			
16 Net Profit (Thousand USD)	0.02	-0.29	-0.03	0.02	-0.23		
17 Total Assets (Thousand USD)	0.08	0.40	0.02	-0.09	0.24	-0.61	
18 G7 Countries	0.03	-0.06	0.22	0.21	-0.09	0.32	-0.53

Table 4.2: OLS Analyses of the Impact of Green Identity and Green Image on Resource Acquisition (Amount USD)

	Green Identity						Green Image
VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Green Founders (H1)	0.648**						
	(0.234)						
Green Management (H2)		0.555*					
		(0.320)					
Green Country (H3)			0.035***		0.027*		
			(0.011)		(0.014)		
Green Lead Founder and TMT				0.275*	0.194		
				(0.121)	(0.125)		
Green Identity (H4)					0.052	0.320***	
					(0.118)	(0.098)	
Green Identity Square (H4)						-0.071*	
						(0.038)	
Green Image (H5)							-0.889*
							(0.536)
Firm Age	0.024***	0.022***	0.019***	0.021***	0.019***	0.021***	0.021***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Number of Board Members	0.296***	0.250***	0.249***	0.252***	0.252***	0.238***	0.258***
	(0.061)	(0.053)	(0.052)	(0.052)	(0.052)	(0.053)	(0.053)
IPO Patents	0.004*	0.003	0.002	0.003	0.002	0.002	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
JVs and Alliances	-0.065	0.029	0.029	0.013	0.014	0.050	0.037
	(0.099)	(0.075)	(0.074)	(0.075)	(0.075)	(0.075)	(0.075)
Total Investment before IPO (logged)	0.011	0.003	-0.003	0.002	-0.001	0.002	0.002
	(0.013)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Net Profit (Thousand USD)	0.000	0.000**	0.000*	0.000*	0.000*	0.000**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total Assets (Thousand USD)	0.000	0.000***	0.000***	0.000**	0.000***	0.000***	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

G7 Countries	-1.294***	-1.085***	-1.603***	-1.076***	-1.579***	-1.340***	-0.957***
	(0.242)	(0.228)	(0.287)	(0.226)	(0.287)	(0.253)	(0.229)
Dummy IPO	1.436***	1.844***	1.861***	1.851***	1.875***	1.860***	1.825***
	(0.240)	(0.209)	(0.208)	(0.209)	(0.208)	(0.208)	(0.209)
Constant	13.236***	13.590***	14.564***	13.525***	14.303***	15.192***	13.930***
	(1.793)	(1.860)	(1.844)	(1.854)	(1.880)	(1.873)	(1.848)
Exchange dummies	Included	Included	Included	Included	Included	Included	Included
Industry dummies	Included	Included	Included	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included	Included	Included	Included
Observations	352	539	539	539	539	539	539
R-squared	0.432	0.360	0.369	0.362	0.373	0.369	0.359
Adjusted R-squared	0.385	0.326	0.335	0.329	0.337	0.335	0.326
F	9.130***	10.64***	11.06***	10.76***	10.42***	10.67***	10.62***

Table values represent standardized coefficients (beta values)

† $p \leq .10$, * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$ (two-tailed tests for controls; one-tailed tests for hypothesized effects)

Table 4.3: OLS Analyses of the Moderating Effect of Green Audience on Green Identity and Green Image

VARIABLES	Model 1	Model 2	Model 3	Model 4
Green Lead founder and TMT	0.398†			
	(0.276)			
Green Country	0.066**			
	(0.028)			
Green Identity	-0.053	0.384*		
	(0.250)	(0.219)		
Green Investor	0.044	0.098	0.117	0.756*
	(0.291)	(0.307)	(0.298)	(0.388)
Green Investor x Green Identity (H6a)		0.088		
		(0.213)		
Green Image			-0.561	1.938†
			(0.876)	(1.315)
Green Investor x Green Image (H6b)				-4.168**
				(1.656)
Firm Age	0.013	0.014	0.017	0.027
	(0.016)	(0.016)	(0.017)	(0.017)
Number of Board Members	0.173*	0.189*	0.174	0.196*
	(0.104)	(0.106)	(0.107)	(0.106)
IPO Patents	-0.000	-0.001	0.001	-0.000
	(0.003)	(0.003)	(0.003)	(0.003)
JVs and Alliances	-0.166	-0.145	-0.104	-0.144
	(0.143)	(0.145)	(0.146)	(0.144)
Total Investment before IPO (logged)	0.003	0.008	0.016	0.017
	(0.019)	(0.019)	(0.020)	(0.019)
Net Profit (Thousand USD)	0.000	0.000	0.000**	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Total Assets (Thousand USD)	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
G7 Countries	-1.881***	-1.450***	-0.770*	-0.633
	(0.546)	(0.502)	(0.447)	(0.443)
Dummy IPO	0.481	0.224	0.353	0.379
	(1.145)	(1.164)	(1.179)	(1.160)
Constant	15.577***	16.738***	15.288***	14.673***
	(2.131)	(2.103)	(2.055)	(2.038)
Exchange dummies	Included	Included	Included	Included
Industry dummies	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included
Observations	192	192	192	192
R-squared	0.443	0.418	0.398	0.420
Adjusted R-squared	0.352	0.326	0.308	0.329
F	4.836***	4.555***	4.393***	4.604***

Table values represent standardized coefficients (beta values)

† $p \leq .10$, * $p \leq .05$, ** $p \leq. 01$, *** $p \leq .001$ (two-tailed tests for controls; one-tailed tests for hypothesized effects)

Table 4.4: OLS Analysis of the Impacts of Green Identity and Green Audience on Resource Acquisition (Amount USD) in Renewable vs. Non-renewable Industries

	Renewables				Non-renewables			
VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Green Lead founder and TMT	0.108				0.643**			
	(0.151)				(0.232)			
Green Country	0.035*				0.050*			
	(0.019)				(0.030)			
Green Identity	0.042	0.335**	0.258	0.216	-0.388	-0.368	-0.169	-0.330
	(0.142)	(0.113)	(0.206)	(0.250)	(0.296)	(0.381)	(1.005)	(1.104)
Green Identity Square		-0.082*				0.220		
		(0.042)				(0.156)		
Green Investor			0.149	0.111			0.643	0.618
			(0.330)	(0.353)			(0.502)	(0.516)
Green Investor x Green Identity				0.067				0.233
				(0.224)				(0.595)
Firm Age	0.024**	0.027**	0.023	0.023	0.008	0.010	0.186	0.193
	(0.012)	(0.012)	(0.018)	(0.019)	(0.022)	(0.023)	(0.117)	(0.120)
Number of Board Members	0.250***	0.213***	0.057	0.053	0.403***	0.519***	0.076	0.084
	(0.064)	(0.065)	(0.128)	(0.129)	(0.125)	(0.127)	(0.457)	(0.466)
IPO Patents	0.002	0.003	0.002	0.002	-0.012	-0.010	-0.033	-0.036
	(0.002)	(0.002)	(0.003)	(0.003)	(0.008)	(0.008)	(0.032)	(0.033)
JVs and Alliances	0.030	0.063	-0.327	-0.319	-0.141	-0.054	0.210	0.219
	(0.107)	(0.107)	(0.236)	(0.238)	(0.130)	(0.131)	(0.351)	(0.359)
Total Investment before IPO (logged)	0.003	0.013	0.029	0.028	0.002	-0.011	0.010	0.014
	(0.014)	(0.013)	(0.024)	(0.024)	(0.021)	(0.021)	(0.045)	(0.048)
Net Profit (Thousand USD)	0.000*	0.000**	0.000*	0.000*	0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total Assets (Thousand USD)	0.000**	0.000***	0.000	0.000	0.000	0.000	0.000**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
G7 Countries	-1.646***	-1.251***	-1.022*	-1.020*	-0.434	0.275	-0.872	-0.934

	(0.360)	(0.303)	(0.586)	(0.588)	(0.703)	(0.778)	(1.576)	(1.615)
Dummy IPO	1.821***	1.832***	-0.490	-0.487	1.326***	1.318***		
	(0.258)	(0.258)	(1.181)	(1.185)	(0.390)	(0.402)		
Constant	14.633***	15.317***	16.376***	16.457***	12.714***	12.187***	14.302***	14.202***
	(1.936)	(1.913)	(2.121)	(2.146)	(1.595)	(1.748)	(4.101)	(4.190)
Exchange dummies	Included	Included	Included	Included	Included	Included	Included	Included
Industry dummies	Included	Included	Included	Included	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included	Included	Included	Included	Included
Observations	402	402	151	151	137	137	41	41
R-squared	0.318	0.318	0.274	0.274	0.587	0.556	0.860	0.861
Adjusted R-squared	0.267	0.268	0.135	0.129	0.507	0.475	0.746	0.736
F	6.207***	6.451***	1.977***	1.888***	7.365***	6.864***	7.528***	6.865***

Table values represent standardized coefficients (beta values)

† $p \leq .10$, * $p \leq .05$, ** $p \leq$. 01, *** $p \leq .001$ (two-tailed tests for controls; one-tailed tests for hypothesized effects)

Table 4.5: OLS Analysis of the Impact of Green Image and Green Audience on Resource Acquisition (Amount USD) in Renewable vs. Non-renewable Industries

	Renewables			Non-renewables		
VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6)
Green Image	-0.742	-1.490†	1.637	-0.326	1.168	3.292
	(0.636)	(0.948)	(1.429)	(1.360)	(4.764)	(6.333)
Green Investor		0.132	0.815*		0.650	1.355
		(0.329)	(0.399)		(0.503)	(1.447)
Green Investor x Green Image			-5.029**			-2.576
			(1.757)			(4.946)
Firm Age	0.024**	0.029	0.037**	0.005	0.162	0.136
	(0.012)	(0.019)	(0.019)	(0.023)	(0.113)	(0.125)
Number of Board Members	0.233***	0.011	0.050	0.476***	0.090	0.201
	(0.064)	(0.129)	(0.126)	(0.125)	(0.454)	(0.508)
IPO Patents	0.003	0.002	0.001	-0.009	-0.032	-0.027
	(0.002)	(0.003)	(0.003)	(0.008)	(0.030)	(0.032)
JVs and Alliances	0.021	-0.308	-0.322	0.006	0.170	0.200
	(0.107)	(0.235)	(0.229)	(0.120)	(0.226)	(0.237)
Total Investment before IPO (logged)	0.012	0.042	0.041*	-0.014	0.001	-0.020
	(0.013)	(0.025)	(0.024)	(0.020)	(0.057)	(0.071)
Net Profit (Thousand USD)	0.000**	0.000**	0.000***	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total Assets (Thousand USD)	0.000*	0.000	0.000	0.000	0.000**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
G7 Countries	-0.861***	-0.394	-0.203	-0.313	-0.766	-0.283
	(0.265)	(0.478)	(0.470)	(0.652)	(1.674)	(1.938)
Dummy IPO	1.763***	-0.487	-0.309	1.336***		
	(0.259)	(1.175)	(1.144)	(0.404)		
Constant	14.035***	15.446***	14.821***	13.076***	14.050***	12.654**
	(1.883)	(2.025)	(1.982)	(1.614)	(4.182)	(5.026)
Exchange dummies	Included	Included	Included	Included	Included	Included
Industry dummies	Included	Included	Included	Included	Included	Included

Year dummies	Included	Included	Included	Included	Included	Included
Observations	402	151	151	137	41	41
R-squared	0.303	0.279	0.334	0.549	0.861	0.862
Adjusted R-squared	0.255	0.141	0.201	0.471	0.746	0.738
F	6.272***	2.028**	2.386**	7.047***	7.541***	6.922***

Table values represent standardized coefficients (beta values)

† $p \leq .10$, * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$ (two-tailed tests for controls; one-tailed tests for hypothesized effects)

Appendix 4.1: OLS Analyses of the Impact of Green Identity, Green Image, and Green Audiences on Resource Acquisition (Amount USD) for Post-IPO Investments Only

	Green Identity						Green Image
VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Green Founders (H1)	0.553*						
	(0.297)						
Green Management (H2)		0.424					
		(0.390)					
Green Country (H3)			0.042***		0.028		
			(0.013)		(0.018)		
Green Lead Founder and TMT				0.283*	0.147		
				(0.152)	(0.162)		
Green Identity (H4)					0.120	0.433***	
					(0.149)	(0.124)	
Green Identity Square (H4)						-0.087*	
						(0.050)	
Green Image (H5)							-0.515
							(0.665)
Firm Age	0.020**	0.023***	0.018**	0.022***	0.019**	0.022***	0.022***
	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Number of Board Members	0.369***	0.288***	0.291***	0.288***	0.294***	0.280***	0.297***
	(0.081)	(0.068)	(0.068)	(0.068)	(0.068)	(0.069)	(0.069)
IPO Patents	0.002	0.002	0.001	0.002	0.001	0.001	0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
JVs and Alliances	-0.102	-0.044	-0.046	-0.062	-0.059	-0.023	-0.039
	(0.122)	(0.095)	(0.094)	(0.096)	(0.095)	(0.095)	(0.095)
Total Investment before IPO (logged)	-0.002	0.001	-0.006	0.001	-0.004	0.001	0.000
	(0.017)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Net Profit (Thousand USD)	0.000	0.000*	0.000*	0.000*	0.000*	0.000*	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total Assets (Thousand USD)	0.000	0.000**	0.000***	0.000**	0.000***	0.000***	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

G7 Countries	-1.242***	-1.088***	-1.725***	-1.110***	-1.717***	-1.438***	-0.989***
	(0.312)	(0.286)	(0.352)	(0.284)	(0.352)	(0.317)	(0.289)
Constant	13.971***	14.911***	15.712***	14.788***	15.690***	16.269***	15.127***
	(1.902)	(1.962)	(1.933)	(1.953)	(1.977)	(1.949)	(1.950)
Exchange dummies	Included	Included	Included	Included	Included	Included	Included
Industry dummies	Included	Included	Included	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included	Included	Included	Included
Observations	262	419	419	419	419	419	419
R-squared	0.445	0.321	0.337	0.325	0.340	0.340	0.320
Adjusted R-squared	0.386	0.278	0.295	0.282	0.295	0.296	0.277
F	7.557	7.446	7.982	7.581	7.471	7.769	7.412

Table values represent standardized coefficients (beta values)

† *p* ≤ .10, * *p* ≤ .05, ** *p* ≤. 01, *** *p* ≤ .001 (two-tailed tests for controls; one-tailed tests for hypothesized effects)

Appendix 4.2: Examples of Green and Non-Green Statements

Company Name	**Country**	**Sector**	**Green Statement**	**Non-green Statement**
A123 systems	USA	Energy Storage	“We design, develop, manufacture and sell advanced, rechargeable lithium-ion batteries and energy storage systems. We believe that lithium-ion batteries will play an increasingly important role in facilitating **a shift toward cleaner forms of energy…”** (prospectus, p. 3)	“In our largest target market, the transportation industry, we are working with major global automotive manufacturers and tier 1 suppliers to develop batteries and battery systems for hybrid electric vehicles, or HEVs, plug-in hybrid electric vehicles, or PHEVs, and electric vehicles, or EVs…” (prospectus, p. 3)
Adecoagro SA	Argentina	Agriculture	**“…**We promote sustainable land use through our land transformation activities, which seek to **promote environmentally responsible agricultural production** and **a balance between production and ecosystem preservation**…” (Prospectus, p.5)	**“**As of September 30, 2010, we owned a total of 287,884 hectares, comprised of 21 farms in Argentina, 15 farms in Brazil and two farms in Uruguay. As of September 30, 2010, our land portfolio was valued at $784 million by Cushman & Wakefield…” (Prospectus, p.1)
Agcert International PLC	Ireland	Air	**“**AgCert was founded in 2002 to produce and sell **reductions in Greenhouse Gas emissions** (referred to as Offsets) from agricultural sources on an industrial scale. These Offsets are intended to satisfy **the requirements of the Kyoto Protocol** and as such will be capable of being traded on the newly established European cap and trade system, the European Union Emissions Trading Scheme (“EU-ETS”). (Prospectus, p. 13)	“In April 2005, the Company entered into an agreement providing for a (7.8 million investment by IFC, member of the World Bank Group. The Directors anticipate that IFC will play an important role in assisting the Group to expand into new markets in Asia.” (Prospectus, p.15)
China Biodiesel International Holding Co.	China	Biofuel	“Biodiesel, **a renewable, non-fossil alternative** to mineral diesel.is produced from a variety of waste oil, either animal or	“The principal raw material used by the group for the production of biodiesel is waste oil which is purchased from oil

			vegetable in origin. As a non-fossil fuel, it has become a valuable contributor to global initiatives attempting **to reduce greenhouse gas emissions**…” (Prospectus, p.9)	processors. These processors principally source their oil from waste palm oi, used cooking oil, or other waste oil sources.. (Prospectus, p.9)

Appendix 4.3: Additional Protocol Used to Code Green Image

- The company talks about how its technology/product/process is clean
- The company talks about how its technology/product/process helps to deal with the problem of climate change and global warming.
- The company talks about how its technology/product/process helps to reduce the carbon emission/ waste
- The company talks about the importance of saving/managing energy and how it saves/ manages energy
- The company talks about environmental standards and regulations
- The company talks about environmental awareness
- The company talks about general environmental issues that exist in the world /and how it is going to address them
- The company talks about general sources of energy that are environmentally-friendly
- The company talks about the management of energy
- The company talks about environmental funds (e.g. the Sustainable Development Technology Canada) that has received or is going to receive.

Appendix 4.4: Analysis of the Interaction Effects of Green Image and Green Founder and TMT on Resource Acquisition (Amount USD)

VARIABLES	Model 1	Model 2	Model 3	Model 4
Green Image	-.907*	1.11	-1.22*	.145
	(.533)	(.892)	(.597)	(.882)
Green Lead Founder and TMT	.277*	.559***		
	(.120)	(.155)		
Green Image x Green Lead Founder and TMT		-1.70**		
		(.602)		
Green Lead Founder			.359†	.700**
			(.226)	(.277)
Green Image x Green Lead Founder				-2.37*
				(1.13)
Firm Age	.021***	.024***	.025*	.030*
	(.006)	(.006)	(.012)	(.012)
Number of Board Members	.262***	.255***	.287***	.288***
	(.052)	(.052)	(.061)	(.061)
IPO Patents	.003	.003	.003†	.003†
	(.002)	(.002)	(.002)	(.002)
JVs and Alliances	.015	.010	-.078	-.080
	(.075)	(.074)	(.102)	(.101)
Total Investment before IPO (logged)	.003	.005	.018	.020
	(.010)	(.010)	(.013)	(.013)
Net Profit (Thousand USD)	.881*	.825†	.612	.558
	(.441)	(.438)	(.607)	(.604)
Total Assets (Thousand USD)	.658*	.565†	.441	.362
	(.289)	(.289)	(.309)	(.310)
G7 Countries	-1.00***	-1.01***	-1.16***	-1.14***
	(.229)	(.227)	(.245)	(.244)
Dummy IPO	1.84***	1.85***	1.39***	1.41***
	(.208)	(.207)	(.245)	(.244)
Constant	13.48***	13.09***	13.60***	13.23***
	(1.85)	(1.84)	(1.80)	(1.80)
Exchange dummies	Included	Included	Included	Included
Industry dummies	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included
Observations	539	539	348	348
R-squared	.366	.375	.416	.424
Adjusted R-squared	.331	.340	.365	.372
F	10.52***	10.57***	8.14***	8.10***

Table values represent standardized coefficients (beta values)

† $p \leq .10$, * $p \leq .05$, ** $p \leq$. 01, *** $p \leq .001$ (two-tailed tests for controls; one-tailed tests for hypothesized effects)

THESIS CONCLUSION

Innovation in clean technologies is considered by many to be a key method for combating climate change (IPCC, 2012). Clean technologies have lower greenhouse gases (GHGs) and can be utilized on a small and large scale, within many different locales (Pernick & Wilder, 2007). This makes clean technologies one of the “next technologies” to replace coal, oil, and natural gas. But innovation is needed to make these technologies more efficient and cost-effective (Malen, 2011; Markus et al., 2013), and to develop the infrastructure to support them (Economist, 2012).

Given the linkage to the global issue of climate change and the challenge of making clean technologies cost effective, development of clean technologies is normally considered to be a macro economic and political issue. From an economics standpoint, one common line of thought is that clean technologies, like all technologies, represent an opportunity for nations to invest early and leverage them for competitive advantage (Porter & Van der Linde, 1996). While there is evidence that strong positions in some types of clean technologies and their supporting infrastructure have yielded limited forms of competitive advantage (e.g., Lanjouw & Mody, 1996; Jaffe & Palmer, 1997; Brunnemeier & Cohen, 2003; Popp, 2003), even within these niches advantage has been slow to develop (King & Lenox, 2002; Markus et al., 2013). Not surprisingly, then, given the debatable economic nature of the entrance and development of clean technology, the issue of innovation in clean technologies might be better viewed as a political and social process. Some argue that the current market failure may continue in the long run, given the asymmetric way in which costs and benefits are born by industry members versus the general public (Vogel, 2012).

These arguments and approaches notwithstanding, GHGs continue to rise and our climate continues to warm. Clean technology development and adoption do not seem to be occurring at a rapid enough rates. One of the underlying problems is that the use of clean technologies, and the supporting policies required to stimulate use, depends on a different mindset; society must accept that the climate is warming and that fossil fuel stocks are likely to be inadequate in the short and medium--range (Gladwin et al., 1995; Hulme, 2010). In addition, policy makers must be willing to bet on replacement - even disruptive - technologies if society is to move away from conventional sources of energies (Pernick & Wilder, 2007). Rational, market-focused versions of economics and politics are less able than behavioral theories to address disruption and implementation of different methods (Hoffman & Jennings, 2012). Versions of behavioral theory that examine beliefs, mindsets, and change of practice, along with different frameworks for governance and policy, are better suited to help us understand how to stimulate the clean technologies. The behavioral approaches on which I relied upon within this thesis were the combination of institutional and identity theories, combined with the innovation literature, to explain innovation and commercialization in the clean technology field. I discuss my specific contributions in the following section.

INSTITUTIONAL AND IDENTITY THEORIES

Most of the institutional theory studies look at the successful institutionalization of new ideas and practices (Maguire & Hardy, 2009; Greenwood et al., 2006; Tobert & Zucker, 1986). In Paper 1, I demonstrate how the renewable energy practices that have existed for hundreds of years neither faded nor were fully institutionalized. This paper also contributes to the cross-national studies of institutionalization. Most of the studies on the development of the new ideas/practices are on a single region, mainly North America (e.g., Maguire & Hardy, 2009;

Greenwood et al., 2006; Tobert & Zucker, 1986), often ignoring the effect of global institutions. Finally, in Paper 1, I highlight the importance of tangible resources, which is understudied in the recent institutional theory research (Jennings, 2010).

In Paper 2, I build on knowledge of institutional sources of political and technological innovations. I demonstrate that an alternative, minority logic to the dominant logic ("asymmetric logics") in a nation state can enhance innovations in the political and technological domains in which the logics interact. These contingencies have only recently been explored in organizational fields at lower levels of analysis. At the nation-state level, the difference in diffusion mechanisms, variations in actor cohesion, and actor capacity, compared to other levels of analysis, suggests that responses to alternative logics may also differ. Strong competition with the dominant logic may decrease the level of innovation, but increase its diversity. A nation-state's capacity may enhance these effects. It confirms, as Pache and Santos (2010) and Greenwood et al., (2011) claim, that contradictions in logics within a field may generate institutional change, in this case via innovation in clean technologies.

Furthermore, Paper 2 contributes to the growing interest in policies within institutional fields (Hoffman & Vantresca, 2002; Simmons et al., 2006; Meyer, 2011), which is at the heart of current institutional theory research. Policies, even more than practices, are both mechanisms and outcomes, thus particularly useful for studying institutional change and its effects. Studies of stock markets (Lounsbury, 2007; Weber et al., 2009) and electric utilities (Zelner et al., 2009) are based on this premise. Still, most of these studies have been on the impact of specific policies or on transitions between contextualized logics of one generic type. Simmons et al. (2006) call for studies of multiple, competing policies as a way of linking very different institutional logics, like democratization and religious fundamentalism, to more complex within-field processes. Paper 2 is a step in that direction.

The study in Paper 2 also puts further pressure on mainstream institutional theory to not only acknowledge and partly incorporate the natural environment into institutional frameworks, but also treat it as its own logic and domain of operation (see Hoffman, 1997; Jennings & Zandbergen, 1995; Hulme, 2010). The natural environment is not just a thread that crosses logics and domains, but an area of life that has its own unique effect, such as the way in which science views climate change (Lefsrud & Meyer, 2012) and the way in which community boundaries of resource industries operate (Zietsma & Lawrence, 2010).

Finally, I see organizational identity and image as products of the institutional environment in which they are embedded. In Paper 3, I create a multi-level identity construct to understand how a firm's identity influences the acquisition of resources. In this paper, I also show that, due to skepticism that exits in the broader environment, clean technology firms might be penalized for their green image.

INNOVATION AND ENTREPRENEURSHIP THEORIES

Paper 1 contributes to the innovation process literature by providing a macro, cross-national perspective on innovation processes. It complements current studies that focus mainly on individual and organizational levels, within one country (e.g., Garud et al., 2002; Hargadon & Douglas, 2001; Garud & Rappa, 1994). Paper 1 demonstrates that the macro-level innovation process is a temporal, global phenomenon, where innovations may move and develop at different rates, from one country to the next.

In Paper 2, I claim that most of the innovation literature is based on the assumption of economic equilibrium generated by economic completion among nations (e.g., Jaffe & Palmer, 1997; Lanjouw & Mody, 1996; Brunnemeier & Cohen, 2003). This assumption implies some sort of zero-sum game among nations hoping to develop new technologies. However, seeing the development of such mitigation technologies from the lens of dual logics and policy re-introduces not just the political dimension into such arguments, but also the cultural one. The paper is also one of the first attempts to investigate the multiple dimensions of innovation activities. I tried to build multidimensional measures of political and technological innovations and examine the antecedents of the rate, diversity, and direction of innovation.

Paper 3 contributes to entrepreneurship theory, particularly the process of resource acquisition. Most of the entrepreneurship literature looks at the effect of individuals (e.g., founders) on the process of resource acquisition. In this paper, I combine the individual-level variables with country and cultural variables to demonstrate that both micro and macro factors matter in the process of resource acquisition.

Finally, my thesis has advanced research on sustainability. In Paper 1, I identify some of the major obstacles toward the full institutionalization of clean technologies. In paper 2, I add to the sustainability literature by demonstrating the macro-level factors that influence the creation of proactive environmental practices (clean technology policies and patenting). Finally, in paper 3, I have tried to avoid the ideological pitfall of demonstrating that it always pays to be green (e.g., see Porter & Van der Linde, 1995), while joining researchers interested in demonstrating cross-national differences in green innovation (Bansal &Hoffman, 2011).

PRACTICAL IMPLICATIONS

My thesis has several practical implications. At the macro-level, the findings help us understand how we can facilitate the diffusion of clean technology globally to fight climate change. Climate change is recognized as one of the greatest environmental and economic challenges facing the world today (United Nations, 2010). Nevertheless, accords such as Kyoto and Copenhagen have (so far) failed, in large measure because company incentives for pollution control have been insufficient (Hoffman et al., 2002) and cross-national differences have not been sufficiently built into international frameworks (Barovick et al., 2009). As a result, current emission strategies have increased the total amount of emissions in the world (Harvey, 2009; Leake, 2008). One high profile "solution" to this problem is the use of clean technology portfolios by organizations and communities (Sachs, 2008). Ambec and Lanoie (2008) show that selling pollution-control technologies motivates firms to address natural environmental issues. Many research groups in science are promoting clean technologies such as solar and wind, with economists costing out the details. Among them are technologies that use or produce renewable energy, store energy or make it more efficient (Jacobson & Delucchi, 2009). My thesis emphasizes the importance of behavioral approaches to address the climate change issue.

Paper 1 provides guidance on reducing obstacles so that full institutionalization of clean technologies can take place. For instance, proponents of natural environment can not only build a more coherent collective identity but also look for solutions to get involved the businesses. Paper 2 highlights the importance of societal logics on the diffusion of clean technologies. Policy makers need to include socio-cultural factors in addition to economic factors in their decision making processes, in order to combat the climate change issue. Finally, Paper 3 has practical implications for entrepreneurs in the clean technology industry. Based on the findings of Paper 3, I suggest that clean technology companies choose decision makers (e.g., top management team) whose values are aligned with the core identity of the clean technology firm.

EPILOGUE – A FEW FINAL THOUGHTS

After finishing the first year in the PhD program, I needed to find a new supervisor. Because of my interest in the natural environment, I asked Professor Dev Jennings to be my supervisor. He nicely agreed to adopt me as his student and I am very grateful for that. After working on several entrepreneurship projects with him and my teaching mentor, Professor Jennifer Jennings, I embarked on this thesis four years ago, hoping to understand the innovation and commercialization side of clean technologies. My original approach to the twin sides of this entrepreneurial process has drawn heavily on my engineering and strategy background. My intent was to understand the phenomenon of clean technology evolution, with a particular focus on why its evolution has been slower than its scientific benefits would have suggested. Through work on projects with Jennifer and Dev Jennings, I gained more appreciation of the behavioral side of organizations – especially the subtle ways in which social construction, politics, and culture can shape observable phenomenon, such as family business dynamics. In my proposal and post-proposal stage, I modified my project to account for more cultural processes in the clean technology domain, first by using institutional theory, then by using innovation process theory. As a result of "backing-in" to theory, I ended up writing the chapter on commercialization first, then that on logics, and finally the evolutionary history of the industry.

My future plan is to work with my committee members to publish these three papers in high-quality journals. For this thesis, I developed two different international panel datasets on country-level and organization-level. My aim is to write at least a couple of more papers from the data that I have not used in this thesis. Furthermore, I want to turn back to the paper that I developed during my candidacy on how knowledge imbalance and mutual knowledge dependence influence different collaborative strategies among clean technology firms. Because of time constraints, the committee nicely agreed to remove that paper from the thesis during the candidacy exam.

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