

Green Bonds for Global Investments in Sustainability

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Green Bonds for Global Investments in Sustainability

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Green Bonds for Global Investments in Sustainability

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By

Clarence Henry Tolliver III



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DEPARTMENT OF URBAN AND ENVIRONMENTAL ENGINEERING
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CERTIFICATE

The undersigned hereby certify that they have read and recommended to the Graduate School of Engineering for the acceptance of this thesis entitled, “***Green Bonds for Global Investments in Sustainability***” by **Clarence Henry Tolliver III** in partial fulfillment of the requirements for the degree of **Doctor of Engineering**.

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ABSTRACT

Sustainability is a concept that has roots in international policy discourse of the mid-20th century. As the 4th Industrial Revolution brings with it an unprecedented level of technological proliferation that will underpin precipitous economic growth in all corners of the globe, responsible resource management, eco-system preservation, and other environmental stewardship aspects are increasingly salient to climate and sustainable development agendas. In the context of rising global surface temperatures, polar ice melting, widespread wildfires, and other record-breaking phenomena, the international community is pressed to promote sustainable development in line with the economic growth – environmental stewardship dichotomy.

The Paris Agreement of the United Nations Framework Convention on Climate Change and the United Nations Sustainable Development Goals are among the prominent international policy agendas established to address each of these pursuits. The former calls to keep 21st century global temperature rises within 2° Celsius through low-carbon, climate-resilient global development. The latter calls to eradicate poverty and hunger, promote peace, justice, and human rights, and realize environmentally-friendly, sustainable economic growth and universal prosperity. Ambitious and far-reaching, both frameworks entail substantial costs that include over \$53 trillion in energy-related investments by 2035 for the Paris Agreement and \$5 to \$7 trillion in annual investments through 2030 for SDG investments. Accordingly, green bonds are growing in salience to the finance agendas of both frameworks due to their ability to bring the benefits of debt finance to the realm of socially responsible and institutional investments in sustainability. The objective of this Thesis, therefore, is to investigate the extent to which green bonds are effective investment vehicles for sustainable development outcomes as measured by environmental and other observable impacts of the assets they are employed to finance.

The discussion of green bonds for sustainability in this Thesis is divided into five main parts. Part I contains two chapters and will discuss sustainability and capital market concepts. Chapter 1 outlines global sustainability agendas and the potential for green bond finance to funnel capital into sustainability investments. Chapter 2 discusses the defining features (including merits and demerits compared with other market securities) of bonds as debt securities, capital market formation theory, empirical measurements of conventional market determinants, and a novel theoretical model for assessing green bond markets and sustainability.

The Part II contains Chapter 3. It provides an overview of green bond market growth, a geographical distribution of reported global green bond proceeds allocations, and a calculation of the main sustainability impacts of the infrastructures financed with green bonds. Part III consists of two chapters. Chapter 4 draws from the previous literature on bond market determinants discussed in Chapter 2 and the policy insights discussed in Chapter 3 to measure the conventional and unique drivers of green bond market growth and their impacts on sustainability. Chapter 5 builds upon the findings on green bond investments in renewable energy presented in Chapter 3 and green bond market drivers in Chapter 4 to investigate the policies influencing sustainable outcomes via support for green bond finance for renewable energy.

Part IV consists of Chapter 6. This chapter builds upon the sustainability discourse presented in Chapter 1 and the results of Chapter 3 to investigate how energy consumption bolsters sustainability. Finally, Part V consists of Chapter 7 which summarizes the main findings on green bonds for sustainability that were derived throughout the research activities of this Thesis.

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Chapter 1: Introduction

21st century civilization faces two potentially conflicting mandates. On the one hand, the Fourth Industrial Revolution of nanotechnology, artificial intelligence, and other wide-ranging scientific breakthroughs (Schwab, 2016) is poised to bolster technological “leapfrogging” among emerging economies while reshaping the infrastructure and institutions at the core of the developed world. Such far-reaching advancements will underpin substantial growth worldwide, with global gross domestic product and population levels expected to exceed \$135 trillion and 9 billion people by 2050 (Johnson & Jorgensen, 2006). In the face of these developments, climate change and sustainable development weigh heavily on the future welfare of humanity and the environment. Both challenges require targeted reforms of international conventions, from reducing dependence on emission-heavy fossil fuel technologies, to enforcing practices that ensure biodiversity, ecosystem preservation, and responsible resource use.

Accordingly, climate and sustainable development challenges have prompted global action for a transition to green, low-carbon economies. Leading up to the 2012 United Nations Conference on Sustainable Development in Rio de Janeiro, the United Nations Environment Programme (UNEP) published a report titled *Towards a Green Economy, Pathways to a Sustainable Development and Poverty Eradication* that urged the investment of 2% of global GDP into the greening of ten key sectors of the economy for greener, sustainable growth: (1) agriculture, (2) buildings, (3) energy supply, (4) fisheries, (5) forestry, (6) energy efficiency, (7) tourism, (8) transport, (9) waste management, and (10) water (Wooders et al., 2011).

Despite growing consensus on the priority to make a global shift towards a climate-change resilient sustainable economy, one critical question remains: how should this transition to be financed? Answers to this consideration lie at the heart of green or environmental finance.

Notably, “the fundamental goal of environmental finance is to deliver the greatest amount of environmental benefits to the largest number of people at the lowest possible cost. The way to achieve this goal is to drive down the cost of environmental projects. As such, the principle aim of environmental finance is to decrease the cost of environmental projects” (Curley, 2014).

Both traditional project finance mechanisms (e.g. issuing equity and debt securities) and free market mechanisms (e.g. cap-and-trade systems) play complimentary roles within environmental finance for climate and sustainability outcomes. Among the former set of mechanisms, the comparative advantages of debt instruments (i.e. loans and bonds) over subsidies and equity include their applicability to flexible payment schedules, various credit enhancement techniques, alignment with long-term project schedules, leverage options, and other benefits that ultimately drive down finance costs. This Thesis closely examines green bonds as investment vehicles for eco-friendly projects and assets conducive to sustainable development. In doing so, this work examines both the trends and determining factors behind green bond finance. This Thesis also creates a unique space in the research literature, connecting studies on conventional capital markets and climate, sustainability, and other environmental policy supports with global trends in green bond finance.

1.1. Global sustainable development agendas

The concept of sustainable development has roots in discourse that took place at the 1972 United Nations Conference on the Human Environment in Stockholm. There, delegates from throughout the international community agreed that both aims of the economic development-environmental stewardship dichotomy could be achieved in a mutually beneficial manner. It wasn't until the 1987 *Report of the World Commission on Environment and Development: Our*

Common Future (Brundtland, Khalid, Agnelli, Al-Athel, & Chidzero, 1987), more commonly known as *The Brundtland Report*, that the classic definition of sustainable development would be articulated via the United Nations (UN) as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs.” Inspired by such seminal works as *The Tragedy of the Commons* (Hardin, 1968) and *The Limits to Growth* (Meadows, Meadows, Randers, & Behrens III, 1972), the report laid the ground work for the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. There, over 100 state leaders and representatives from 178 nations recognized sustainable development not only as a global challenge, but as a critical process for coping with and preventing further environmental degradation around the world.

Later, in the 2002 World Summit on Sustainable Development in Johannesburg, 191 state governments joined UN bodies and multilateral finance institutions to derive the post-Rio Summit commitments to sustainable consumption and production, water and sanitation, and energy. Taking place shortly after the same 191 UN member states met at the Millennium Summit in 2000, these commitments complemented the 8 Millennium Development Goals (MDGs) outlined in the United Nations Millennium Declaration which aim to reduce poverty, hunger, and environmental degradation while bolstering universal human health.

Following the January 2013 UN General Assembly Open Working Group on Sustainable Development Goals and the 2012 to 2015-year Post-2015 Development Agenda process, the 17 Sustainable Development Goals (SDGs) within the UN *2030 Agenda for Sustainable Development* report were developed as the successors to the MDGs. Collectively, the SDGs formed a new paradigm through which to classify specific components of the modern, overarching concept of sustainability. With the goal of filling in the gaps and overcoming the

Table 1.1: Overview of UN Millennium Development Goals and UN Sustainable Development Goals

	UN Millennium Development Goals	UN Sustainable Development Goals
Publication: Declaration Venue Year	<i>United Nations Millennium Declaration</i> United Nations Millennium Summit 2000	<i>The 2030 Agenda For Sustainable Development</i> United Nations Sustainable Development Summit 2015
Number of signatories	189	193
Effective years	2000 – 2015	2016 – 2030
Targets	1. Eradicating extreme poverty and hunger; 2. Achieving universal primary education; 3. Promoting gender equality and empower women; 4. Reducing child mortality; 5. Improving maternal health; 6. Combating human immunodeficiency virus and acquired immune deficiency syndrome (HIV/AIDS), malaria, and other diseases; 7. Ensuring environmental sustainability; and 8. Developing a global partnership for development.	1. End poverty in all its forms everywhere; 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture; 3. Ensure healthy lives and promote well-being for all at all ages; 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all; 5. Achieve gender equality and empower all women and girls; 6. Ensure availability and sustainable management of water and sanitation for all; 7. Ensure access to affordable, reliable, sustainable and modern energy for all; 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all; 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation; 10. Reduce inequality within and among countries; 11. Make cities and human settlements inclusive, safe, resilient and sustainable; 12. Ensure sustainable consumption and production patterns; 13. Take urgent action to combat climate change and its impacts; 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development; 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss; 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels; and 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development.

Source: Created by author using information from the UN (2015) and UNDP (2015)

shortcomings of the MDGs, the SDGs aim to eradicate poverty and hunger, promote peace, justice, and human rights, and realize environmentally-friendly, sustainable economic growth and universal prosperity (UN, 2015). In this manner, the SDGs serve to clarify the modern definition of sustainability that is observed in this Thesis and prominent literature. Table 1.1 provides an overview of both MDG and SDG contextual details and specific targets.

That same year in December, parties to the United Nations Framework Convention on Climate Change (UNFCCC) presented the historical Paris Agreement at the Conference of Parties 21 (COP 21) in Paris. Echoing the calls to combat climate change and invest in sustainable, low-carbon development prominent throughout the SDGs, the Paris Agreement's central objective is to keep 21st century global temperature rises within 2° Celsius above pre-industrial levels (and within 1.5 ° Celsius if possible) and to finance low-carbon, climate-resilient global development (UNFCCC, 2015a). At the core of the agreement are Nationally Determined Contributions (NDCs), country-specific pledges to reduce greenhouse gas (GHG) emissions and adapt to climate change in a sustainable manner. Prominent NDC target actions include implementing renewable and efficiency-enhancing energy technologies, preserving natural ecosystems, improving agriculture, forestry, and land use practices, upgrading water supply and management systems, and adopting other sustainability enhancing infrastructures and processes.

SDGs related to clean water and sanitization (SDG 6), access to next-generation energy (SDG 7), infrastructure and industrialization (SDG 9), and other targets align with the climate-focused commitments prominent throughout Paris NDCs. Still, both frameworks entail substantial investments. For instance, the U.N. Commission on Trade and Development (UNCTAD) estimates that meeting the SDGs requires \$5 trillion to \$7 trillion in annual investments through 2030 (UNCTAD, 2014), while the International Energy Agency estimates

that maintaining the 2° Celsius temperature threshold of the Paris Agreement will require \$53 trillion in energy-related investments alone by 2035 (IEA, 2014). Additionally, NDCs could require \$97 to \$191 billion by 2030 (Hof et al., 2017). The international community is thereby pressed to mobilize large volumes of public and private capital in pursuit of these agendas.

There are a number of precedent-setting environmental finance instruments that are conducive to advancing SDG and NDC-related environmental targets. Established under the UNFCCC Kyoto Protocol as an avenue for developed countries to fulfill their greenhouse gas (GHG) emission reduction commitments via qualified projects in developing countries, the Clean Development Mechanism (CDM) was “seen by many as a trailblazer...the first global, environmental investment and credit scheme of its kind, providing standardized emissions offset instruments, CERs [certified emissions reduction credits]” (UNFCCC 2019a). Multiple studies have verified the contributions of the CDM to green outcomes. Ellis *et al.* (2007) observed that CDM portfolio developments resulted in greater carbon dioxide (CO₂) emissions credits, increased awareness of climate change mitigation options among potential investors, and more robust climate-related institutions. Schneider, Holzer, and Hoffmann (2008) combined empirical study assessments with expert testimonies to reveal that CDM perpetuates green technology transfer by increasing commercial viability, reducing barriers to information and capital, and improving institutional frameworks. Most recently, Seres, Haites, and Murphy (2009) assessed over 3,000 CDM projects and proposals to demonstrate that after a certain threshold number of projects in a given country, the transfer of emissions-reducing technologies that were previously unavailable in CDM host countries extends beyond the CDM projects themselves.

The Green Climate Fund (GCF) is another important environmental finance mechanism. It was similarly established under the UNFCCC in 2010, but as a more direct means of funneling

funds (predominately through grants and loans) into GHG emissions curbing and climate change adaptation in developing countries. Since its inception, 40 contributing countries have allocated \$4.6 billion to 93 green projects, with another \$1.8 billion available for implementation and an additional \$10.3 billion in subsequent pledges. Already supporting projects expected to reduce global CO₂ emissions by 1.4 billion tonnes (GCF 2018), the GCF will likely to play important role in financing Paris Agreement and other green policies throughout the developing world.

The CDM and the GCF both highlight the diversity of options among effective environmental financing schemes. In the related context of traditional project finance, the comparative advantages of debt instruments (i.e. loans and bonds) remain important considerations in financial decision-making. Such advantages include an applicability to flexible payment schedules, various credit enhancement techniques, long-term project schedules, leverage options, and other benefits that ultimately drive down finance costs (Curley 2014). With proceeds earmarked to eligible, eco-friendly projects and assets, newly emerging green bonds stand to bring the advantages of debt instruments to the realm of environmental finance.

1.2. Green bonds for sustainability finance

The over \$100 trillion and growing global debt capital markets are “the dominant global source of capital and the core refinancing component of the capital pipeline” (Kidney, Oliver, & Sonerud, 2014). In fact, history has demonstrated the critical roles that such immense volumes of bond-based capital have played in financing some of the world’s most expensive, large-scale campaigns and infrastructures. The numerous U.S. Liberty Bonds, British War and Victory Bonds, French National Defence Bonds, Russian war bonds under the Tsar, and *Darlehnkassen* loan-backing German war bonds all indicate high degree to which “all countries... relied heavily

on the willingness of their citizens to lend money to the war effort by buying war bonds” at a time when World War I expenditures surpassed \$140 billion for the Allied Powers and \$83 billion for the Central Powers (Ferguson, 1998). Indeed, bond finance scaled up to levels proportionate to large percentages of total prewar economies for major powers in both World Wars, accounting for as low as 31% of the U.S.’s total World War II expenditures to as much as 83% of Frances total World War I expenditures. Table 1.2.1 provides a summary of U.S. and French finance in both World Wars as proxies for some of the largest war expenses of each era.

Since then, performance and payment bonds under the 1932 Miller Act and surety bonds under the 1935 Marshall Act backed by \$25 billion appropriated by the Federal Aid Highway Act of 1956 allowed contractors in the U.S. to undertake government projects to construct 41,000 miles of interstate highways in what became one of the largest American public works

Table 1.2.1: World War I & II Finance for the U.S. and France

	World War I		World War II	
	<i>U.S.</i>	<i>France</i>	<i>U.S.</i>	<i>France</i>
Total expenditure (% prewar GDP)	43	251	188	111
Share financed by:				
<i>taxes</i>	21	4	48	30
<i>debt</i>	70	83	31	36
<i>money</i>	9	13	21	34

Source: Adapted from (Occhino, Oosterlinck, & White, 2008); original sources: Friedman and Schwartz (1963), Ferguson (1998), Goldin (1980), Patat and Lutfalla (1990)

programs in history (U.S. Senate, 2019). More recently, in the wake of the Great Recession from 2009 onward, over 2,275 Build America Bonds financed \$182 billion in new infrastructure investments across all 50 states, Washington, D.C., and two territories. These bonds saved state and local borrowers an estimated \$20 billion by expanding the traditional infrastructure

investment base to well beyond the \$2.8 trillion tax-exempt municipal bond market to the \$30 trillion taxable bond market open to pension funds and institutional investors (Puentes et al., 2013). From these and numerous other examples from around the world throughout the 20th and 21st centuries, it is clear that bonds are staples in some of the largest finance schemes in human history. With the growing expenses related to climate change and sustainability, bonds, and green bonds in particular, stand to serve important roles in expanding finance schemes.

Accordingly, green bonds are gaining salience in climate and sustainability finance, and a number of institutional practices and standards were developed to accommodate a growing base of issuers and investors. Most notably, a consortium of 14 international investment banks united under the International Capital Market Association (ICMA) published a set of voluntary best practices for green bonds known as *Green Bond Principles* (GBP) in 2014. The GBP define green bonds as “any type of bond instrument where the proceeds will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible Green Projects.” These projects include 1) renewable energy; 2) energy efficiency; 3) pollution prevention and control; 4) environmentally sustainable management of living natural resources and land use; 5) terrestrial and aquatic biodiversity conservation; 6) clean transportation; 7) sustainable water and wastewater management, 8) climate change adaptation; 9) eco-efficient and/or circular economy adapted products, production technologies and processes; and 10) green buildings which meet national or internationally recognized standards or certifications (ICMA, 2014). Many green bonds are certified by the Climate Bond Initiative (CBI), which confirms their alignment with Paris Agreement objectives and ensures their proceeds are earmarked to eco-friendly investments. To date, Bloomberg, Environmental Finance, Dealogic, and the Climate Bonds Initiative (CBI) provide their own renditions of green bonds definitions, standards, and practices

that adhere to GBP and largely overlap in content, purpose, and scope. In addition to the databases that these organizations maintain, Bank of America Merrill Lynch (BAML), Standard and Poor's (S&P), Solactive, and ChinaBond also contribute indices for tracking and assessing green bond data. Notably, the CBI database is prominently used throughout the literature.

Eco-friendly earmarking renders green bonds thematically appropriate and functionally useful in financing SDG and Paris Agreement objectives. Those issued alongside fossil fuel divestment are estimated to mitigate 4.7 gigatonnes of CO₂ emissions without affecting the 1.6% rise of gross domestic product (GDP) under a business as usual scenario (Glomsrød & Wei, 2018). This prediction is reasonable given recent green bond investment activities. For example, between 2008 and 2017, nearly \$58 billion (including \$26.7 billion for renewable energy projects) in green bond proceeds were allocated to assets responsible for 108 million tonnes of CO₂ equivalent (tCO₂e) in GHG emissions reductions and over 1,500 gigawatts (GW) in renewable energy capacity. There was also a surge to roughly \$3 billion in annual allocations to both green building and low-carbon transportation projects by 2016 and a rise to more than 200 annual allocations to clean water and wastewater treatment facilities by the same year (Tolliver, Keeley, & Managi, 2019). From these trends, it is clear that increasing volumes of capital are flowing into cleaner production and sustainability investments through green bond finance.

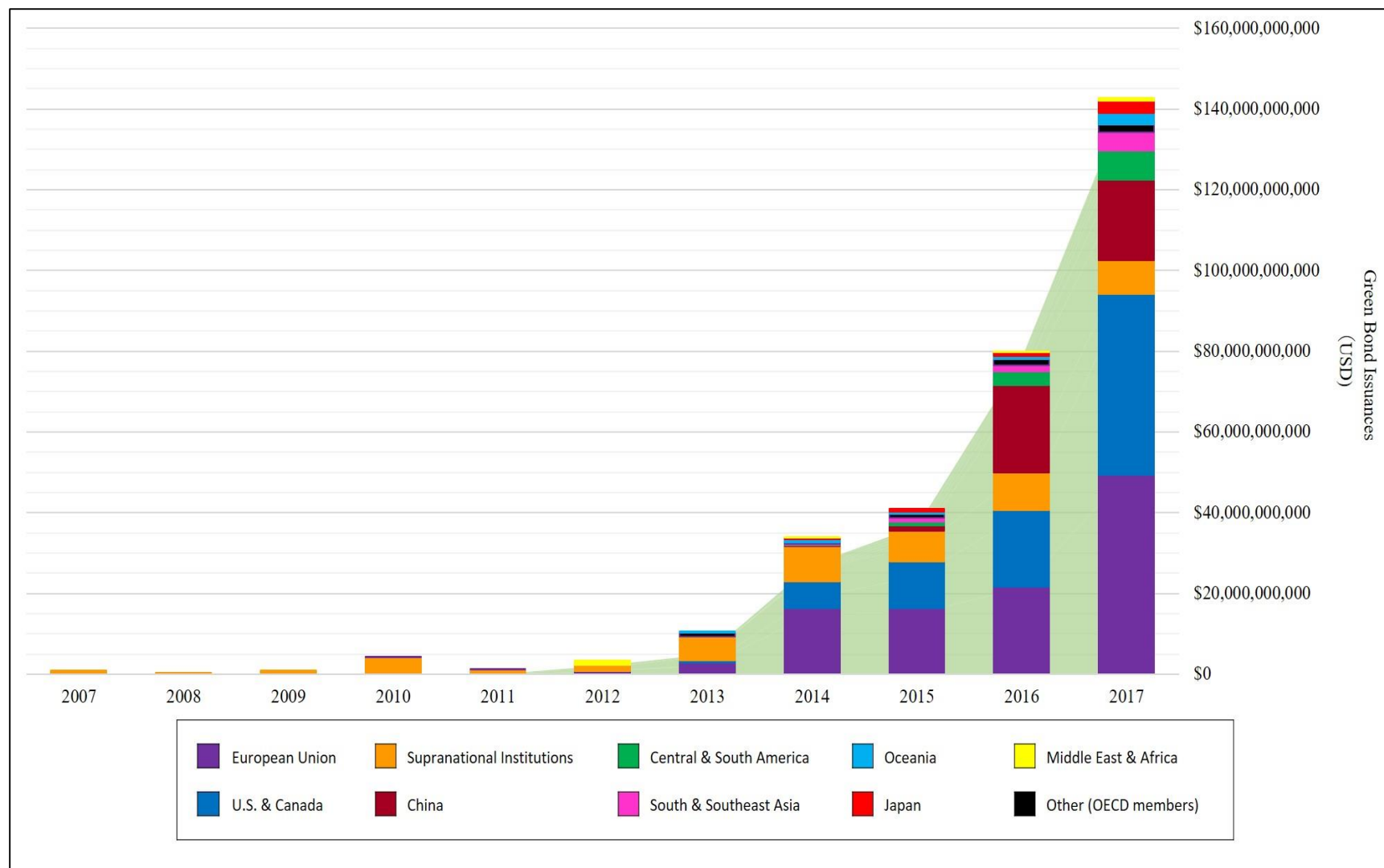
Since the inaugural labelled (i.e. earmarked to certifiably green assets or projects), €600 million (roughly \$848 million) Climate Awareness Bond issued by the European Investment Bank (EIB) in 2007, the volume of climate and green business- aligned bonds issued around the globe has expanded to include some \$1.45 trillion across some 4,800 bonds issued by 869 issuers by 2018 (CBI, 2018a). Common varieties include corporate and SSA (sovereign, supranational,.

Table 1.2.2: Green bond classifications and examples

Issuer	Class	Type	Proceeds	Debt Recourse	Example
National Government	Sovereign	Use of proceeds	Earmarked for green projects	Full recourse to issuer	2017 issuance of €7.5 billion green OAT ¹ under the “Invest for the Future” climate change program by the Republic of France (largest single issuance in market)
Local Government or Municipality	Municipal (“Muni”)	Use of proceeds	Earmarked for green projects	Full recourse to issuer	2014 issuance of \$300 million backed by General Fund of California State Government
		Revenue	Earmarked for green projects or refinancing	To issuer revenue streams	2015 issuance of \$321.5 million backed by water fees and tax-backed State Revolving Fund of Iowa Finance Authority
		Securitization	Earmarked for or flow into green projects	To collateralized assets	2014 issuance of \$150 million Green Infrastructure Fee ABS ² by Hawaii State Government
Government-Related or State-Backed Agency	Sub-Sovereign	Use of proceeds	Earmarked for green projects	Full recourse to issuer	2016 issuance of ₹20 billion (INR ³) Green Masala Bond ⁴ for solar and wind power by NTPC Ltd.
		Revenue	Earmarked for green projects or refinancing	To issuer revenue streams	2016 issuance of \$782.5 million backed by public transportation fees of New York MTA
		Project	Ring-fenced for green projects	To project assets and revenue	2016 issuance of €500 million for clean water and green energy projects by NRW Bank
		Securitization	Earmarked for or flow into green projects	To collateralized assets	2017 Issuance of \$24.9 billion green MBS ⁵ backed by low-carbon buildings or secured energy and water efficiency housing improvements by Fannie Mae
Supranational Organization	Sub-Sovereign	Use of proceeds	Earmarked for green projects	Full recourse to issuer	2005 to 2017 net issuances of \$5.3 billion for renewable energy and energy efficiency projects by the IFC
Commercial Bank	Financial Institution	Use of proceeds	Earmarked for green projects	Full recourse to issuer	2015 issuance of \$600 million (AUD ⁶) for windfarms and low carbon buildings by ANZ Bank
		Secured Loan	Secured on eligible assets	To collateral; potentially to borrower(s).	2017 issuance of \$31.7 million senior secured fixed rate green loan for solar lease financing by MEP Werke
		Covered	Earmarked for eligible covered pool projects	To issuer and covered pool	2014 issuance of €300 million Pfandbriefe ⁷ for housing cooperative refinancing by Münchener Hypothekenbank eG
Corporation	Corporate	Revenue	Earmarked for green projects or refinancing	To issuer revenue streams	2017 issuance of \$1 billion for fighting global warming by Apple Inc.
		Structured Covered	Earmarked for eligible covered pool projects	To issuer and covered pool	2014 issuance of €3.5 billion linked to renewable energy and energy efficiency projects by GDF Suez
		SPV ⁸	Ring-fenced for SPV green projects	To SPV assets and revenue	2015 issuance of €400 million through Rapid Holdings GmbH SPV of Centerbridge Partners for financing the acquisition of Senvion Wind
		Securitization	Earmarked for or flow into green projects	To collateralized assets	2013 issuance of \$54.4 million rooftop solar lease ABS by SolarCity (Tesla Energy Operations, Inc.)

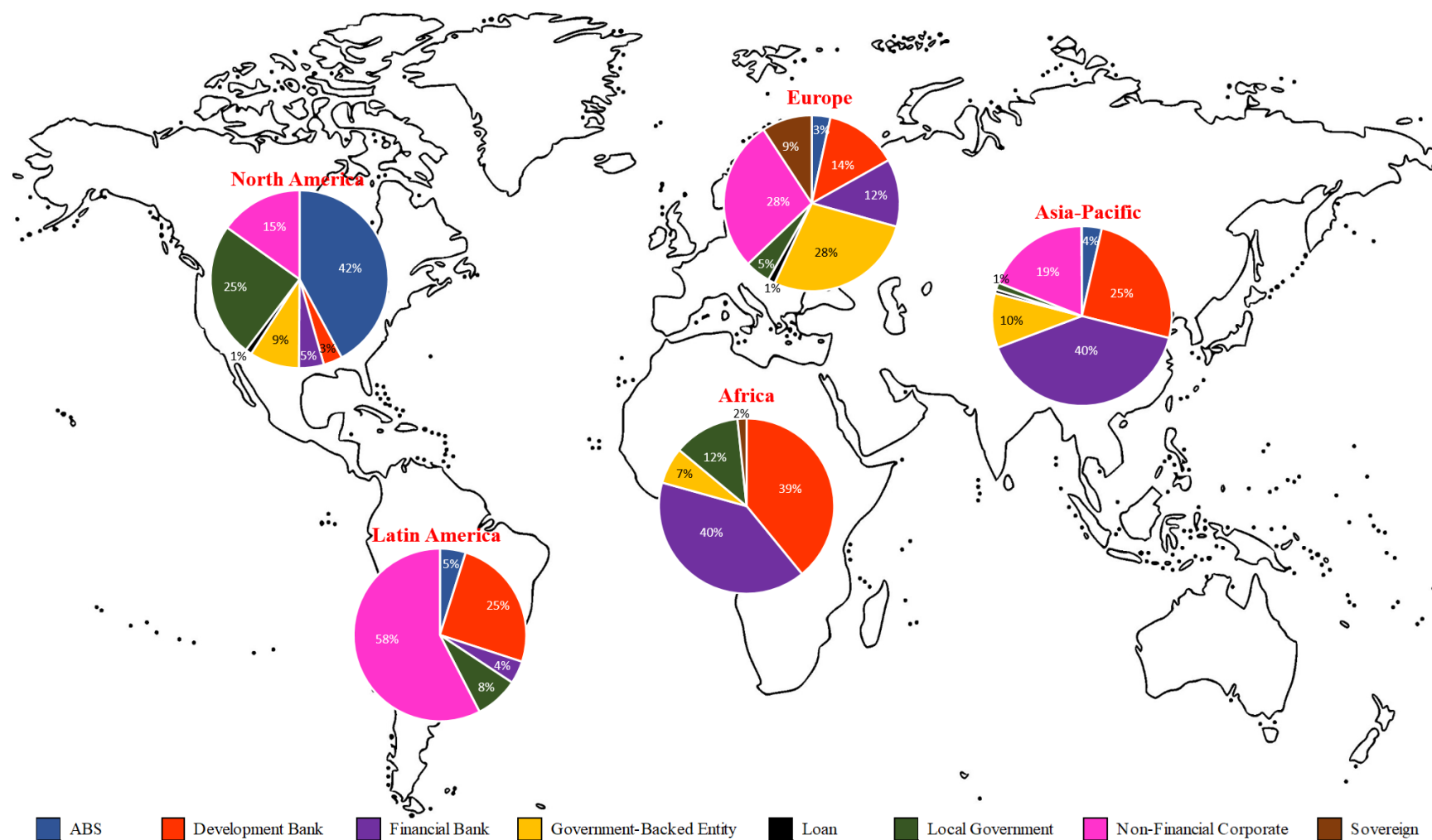
1 – obligations assimilables du Trésor, government bonds issued by the Treasury of France; 2 – asset-backed security; 3 – Indian Rupees; 4 – bond issued outside of India and denominated in INR; 5 – mortgage-backed security; 6 – Australian Dollars; 7 – German bank debentures, generally AAA-rated; 8 – special purpose vehicle; **Source:** Created by author with examples referenced from CBI Green Bonds Q3-2018 dataset (2018b)

Figure 1.2.1: Growth of green bond issuance volumes, 2007-2017



Source: Created by author using data from CBI Green Bonds Q3-2018 dataset (2018b)

Figure 1.2.2: Categorical green bond issuances by region, 2007 - 2017



Source: Created by author using data from CBI Green Bonds Q3-2018 dataset (2018b)

and agency) bonds, project bonds, asset-backed securities, and financial bonds, while prominent issuers include financial and non-financial corporations, national and local governments, international finance institutions, government agencies, and state-backed entities. As with conventional bonds, green bonds can be classified depending upon their uses, debt recourse and other unique features. Table 1.2.2 provides an overview of the common green bond classifications and recent examples of each type. Figure 1.2.1 shows green bond issuance trends by currency from 2007 through 2017, while Figure 1.2.2 shows the regional breakdown of green bond issuances by category over the same period. Due to their links to infrastructures that produce positive environmental outcomes, understanding the fundamental factors that promote green bond market activity is critical to advancing the global climate and sustainable development investment agenda.

1.3. Research methodology and scope

Just as the positive environmental impacts yielded by their underlying assets render green bonds increasingly salient to modern finance frameworks, the function of green bond markets in spearheading eco-friendly growth is of growing importance to climate change and sustainable development agendas. However, since green bonds are still relatively nascent, there is a lack of conclusive, universally accepted consensus on the benefits and effectiveness of green bonds as investment vehicles for environmental outcomes. The primary objective of this Thesis is to investigate the factors that are driving growing global green bond market activity around the world. An additional, directly related objective is to examine the prospects of green bonds as instruments that promote climate-friendly, sustainable development.

Much of the existing qualitative literature on green bonds highlights their potential to bridge finance gaps for low-carbon investments such as renewable energy (Mathews & Kidney, 2012; Ng & Tao, 2016). As green bond markets have developed rapidly, a growing portion of economic literature empirically assesses the yield differences between green and conventional (e.g. “black”) bonds (Ehlers & Packer, 2017; Hyun, Park, & Tian, 2019; Karpf & Mandel, 2018; Zerbib, 2019) and how this affects pricing and investor demand. Far fewer studies, however, have addressed green bond market growth determinants, and there remains a need to “more closely examine the role of individual determinants in contributing to [green bond] market expansion” (Broadstock & Cheng, 2019).

Examining the drivers of green bond market activity, therefore, would require an investigation of the major factors behind conventional capital market growth. Such analyses would ultimately shed light on country-specific aspects that affect not only green bond markets but also the ability of regions, nations, and locales to finance infrastructure with positive environmental impacts.

The literature review in Chapter 2 further elaborates on an additional research gap identified in prominent studies. Sean Kidney, co-founder and chief executive officer (CEO) of the Climate Bonds Initiative that is the leading non-governmental organization striving to mobilize (green) debt capital markets for climate and sustainability, proposed alongside his colleague John A. Mathews that “development banks around the world would... issue their own bonds on the world’s leading bonds markets... to be used solely for climate change-related activities” (Mathews & Kidney, 2010). They add that the bonds would “promise returns to investors in the bond markets through the revenues anticipated to flow as renewable energy projects displace traditional fossil fuel-backed energy projects,” and that as reputable institutions

such as the World Bank's Multilateral Investment Guarantee Agency back credible issuers even in developing countries, green bonds could induce "development banks acting in concert with their governments to fashion bond issues in such a way that they are attractive to investors – particularly to institutional investors – while offering audited means of contributing to real climate change mitigation" (Mathews & Kidney, 2010).

Though such a proposal highlights the importance of green bond finance for eco-friendly development, there nevertheless remains a lack of empirical evidence that supports the argument. In order to address these research gaps, the primary research question of this Thesis is:

- To what extent do green bonds serve as effective investment vehicles for climate-friendly, sustainable development outcomes?

This main question is addressed through a series of interrelated subsequent questions, including:

1. Which climate and sustainability investments are receiving the greatest portions of green bond finance?
2. What are the environmental impacts associated with projects and assets financed fully or partially with green bonds?
3. What factors promote green bond market growth and the positive environmental and sustainability impacts of their underlying investments?
4. Do green bond market determinants differ from conventional bond market determinants?
5. How do global climate and sustainable development agendas affect green bond market growth and their climate and sustainability outcomes?
6. What role does energy consumption play in sustainable development?
7. How does energy security risk affect sustainability through energy consumption?

8. To what degree do climate commitments and supportive policies affect green bond finance for sustainable outcomes through renewable energy investments?

Accordingly, both qualitative and quantitative analyses are employed to address each of these research questions. Specifically, this Thesis employs the following techniques:

1. Descriptive circle plot analysis;
2. Econometric structural equation modeling analysis;
3. Econometric general least squares regression analysis; and
4. Econometric difference-in-differences analysis.

The primary objective of this Thesis contributes to the research into green bond markets by providing the first comprehensive overview of actual green bonds proceeds allocations. Drawing connections between green bond issuances and eventual environmental outcomes presents multiple challenges. To begin with, green bond proceeds earmarked at issuance may only reflect intended uses without guaranteeing allocations to specific undertakings with green impacts. Furthermore, many issuers earmark proceeds for a variety of project or asset types (e.g. clean energy, transportation, or water infrastructure, etc.) within a single issuance, adding complexity to a priori funding estimates for each recipient investment. The first step in assessing the linkages between green bond issuances and the environmental impacts attributable to financed projects, therefore, is to evaluate the actual magnitudes of proceeds allocations to specific green sectors.

The first two sub-questions this study will be addressed using a graphical analysis of the total annual volumes of green bonds issued, green bonds outstanding, and reported green bond proceeds allocations in the overarching context of international debt securities outstanding from 2008 to 2017. The total annual frequencies and volumes of proceeds allocations to 10 specified

Table 1.3: Barriers to and potential measures for green bond market growth

	<u>Jun et al. (2016)</u>	<u>Cochu et al. (2016)</u>	
Barriers	1) General bond market development challenges 2) Lack of awareness of benefits, existing international guidelines, and standards 3) Lack of local guidelines 4) Costs of meeting requirements 5) Lack of ratings, indices, and listings 6) Lack of labelled green bond supply 7) Difficulties accessing local markets from abroad 8) Lack of green investors at domestic level	Supply-side	1) Lack of bankable projects 2) Lack of means to aggregate small projects 3) Lack of standards to identify eligible projects 4) Difficulty obtaining good credit rating 5) Higher perception of risk for green investments
		Demand-side	1) Lack of green bond characterization standards 2) Lack of green bond project impact information 3) Lack of mandatory disclosure from issuers 4) Higher perception of risk for green investments 5) Potential for low quality second opinions
Measures	1) Promote green bond integrity and raise awareness of benefits 2) Provide technical assistance for local green bond guidelines 3) Provide technical assistance for developing local currency bond market 4) Reduce issuance and reporting costs 5) Develop indices, ratings, and stock exchange lists 6) Label qualified bonds 7) Promote international collaboration and cross-border flows 8) Raise local green investors 9) Enhance roles of development finance and public institutions	Supply-side	1) National government issuances 2) Regional, provincial, city, municipal, utility, and other subnational issuances 3) National and international development bank issuances 4) Green bank issuances 5) Public financial institution support for aggregation and securitization 6) Public financial institution and regulator credit enhancements
		Demand-side	1) Public financing institution investment 2) Sovereign wealth fund investment 3) Public pension fund investment
		Supply-side and demand-side	1) Cooperation between all relevant stakeholders, including: a. Ministries of Finance b. Capital market authorities c. Rating agencies d. Public and private financial institutions e. External reviewers f. Municipalities and utility companies 2) Tax incentives from Ministries of Finance 3) Supporting definition and framework standardization among (a) - (f) above 4) Preferential green bond treatment in monetary and central bank regulations

Source: Created by author using information from Jun et al. (2016) and Cochu et al. (2016)

green project and asset categories are then graphically compared. A circle plot is then utilized to display an overview of global green bond proceeds allocations and to assess domestic and transnational proceeds flows from issuing (allocating) organizations to recipient green categories. Finally, total estimated environmental impacts associated with green bond proceeds-recipient projects and assets are calculated and summarized. It should be noted that all green bond allocation data were hand-sourced by the author from hundreds of investor and impact reports published by green bond issuers.

Addressing the third through fifth sub-questions of this Thesis builds upon preceding studies in the theoretical and empirical finance literature to provide an analytical guideline for assessing the determinants of green bond finance for positive environmental impacts. By assessing factors conducive to the enabling environment of green bonds, this Thesis considers a broad array of interconnected conditions including legal, social, political, financial, and economic conditions that influence investor capacity and decision-making at every level of engagement of green bond market activity. The bulk of the green bond literature provides *ex ante* assessments of the systemic barriers to green bond market growth moving forward. Many of these barriers noted in common throughout such literature are listed in Table 1.3. This Thesis departs from this convention by providing an original *ex post* analysis of the factors that have fostered the precipitous green bond market capitalization and finance over the first decade of green bond issuances. The third, fourth, and fifth Thesis questions will thus be achieved by building upon the existing literature on conventional bond market determinants using a structural equation model assessment of how they and additional unique factors have driven green bond market growth

In order to answer the sixth and seventh sub-questions, this Thesis delves into a literature review of the importance of energy consumption to sustainability and the manner by which energy security risk affects sustainable energy consumption. Using energy security risk index scores as proxies for overall energy risk, this Thesis employs a general least squares regression analysis to assess the impact that energy security risk exerts on consumption of both renewable energy sources and conventional, fossil fuel energy sources alike. These results thereby demonstrate the extent to which energy security risk affects the adoption of energy sources with various climate and sustainability-related social and environmental impacts.

Addressing the eighth and final sub-question of this Thesis adds the existing literature on the impact of policy supports on renewable energy deployment by assessing how traditional and additional unique policies affect green bond finance for renewable energy. An original green bond allocation database is constructed to assess green bond proceeds flows to technology specific renewable energies, including wind, solar photovoltaic (PV), co-generation, hydroelectricity, biomass and geothermal technologies. Moreover, the impacts of the robustness of Nationally Determined Contributions to the Paris Agreement is assessed alongside traditional economic, fiscal, and regulatory policy supports for renewable energy deployment to assess their impacts on climate-friendly, sustainability-enhancing renewable energy infrastructure.

The analytical results derived from the aforementioned analyses of this Thesis will:

1. Reveal the actual proceeds distributions of green bond finance
2. Highlight the comparative shares of proceeds received by particular projects and assets financed at least partially using green bonds
3. Quantify the demonstrated positive environmental impacts available in recent green bond post-issuance reporting

4. Demonstrate the effects of conventional and modern green bond market drivers
5. Measure the impact of energy security risk on climate-friendly, sustainability supportive renewable energy adoption
6. Demonstrate the influence that climate agendas and other supportive policies exert on sustainability through renewable energy deployment
7. Produce an analytical guideline for the global green bond enabling environment
8. Indicate the extent to which green bonds have been used to accelerate renewable energy deployment.

The results of this Thesis, therefore, are relevant to a wide range of academic disciplines, including environmental economics, renewable energy finance, and climate and sustainability policy. Moreover, as each objective is assessed using global panel data for both advanced and emerging economy countries, the findings are of interest to stakeholders from every strata of economic development. Finally, as the results quantify environmental impacts and other as measurements of sustainability outcomes, this Thesis contributes unique, observable impacts of green bond investments that will be relevant to economic policy discourse at local, state, and international levels.

1.4. Outline of the Thesis

The discourse on green bonds as investment vehicles for sustainability provided in this Thesis is structured in the following manner:

Chapter 2 provides an overview of the bonds as debt securities and the theories and empirical studies on capital market formation. In the first subsection, the relative merits and demerits of bonds are compared with those of equity and loans from an investor's perspective.

Other key features, including major risk factors, bond ratings, and prominent bond varieties are discussed in advance of an equation-based explanation of general bond pricing techniques. In the second subsection, primary and secondary financial markets are defined and empirical models and theories of capital market formation are provided. Following a literature review of the determinants of capital market growth, the third subsection details the novel theoretical framework for assessing green bonds as investment vehicles for sustainability by linking sustainability concepts discussed in Chapter 1 to the bond and capital market concepts discussed throughout Chapter 2.

Green bond markets are growing rapidly, and yearly proceeds allocation trends reveal increasing disbursements to renewable energy, clean water, low-carbon transportation, and other Paris Agreement and Sustainable Development Goal-related investment categories. **Chapter 3** presents a graphical comparison of green bond issuances in the greater context of total global international debt securities (e.g. bonds). The volume of global green bond proceeds allocations as well as the volume of proceeds allocated with estimated sustainability impacts are also quantified using an original panel dataset that covers 96 green bond proceeds recipient countries, 53 green bond issuing institutions, \$58 billion in proceeds in over 1,851 allocations, and 10 sustainability-related projects and assets to which green bond proceeds were disbursed from the years 2008 through 2017.

The chapter provides a circle plot analysis of domestic and international green bond proceeds allocations since market inception, as well as a summation of some of the total estimated positive environmental impacts of the underlying projects and assets financed at least partially using green bonds. Associated with over 108 million tonnes of carbon dioxide equivalent (tCO₂e) in greenhouse gas emissions reductions and over 1,500 gigawatts in

renewable energy capacity during the nine-year period assessed in this study, the results indicate that green bonds have grown into reliable sources of funding for sustainability-enhancing infrastructure. The chapter concludes with suggestions for improving green bond post-issuance reporting and provides insights for future green bond applications in expanding Paris Agreement and SDG agendas.

Chapter 4 presents an econometric analysis of the drivers of global green bond market growth in 49 developed and developing countries between 2007 and 2017. Upon selecting relevant variables indicated in preceding studies, exploratory factor analysis (EFA) is performed to retain and group exogenous variables under Macroeconomic and Institutional latent variable categories. Based on the EFA factor loadings and findings in literature precedents, five original hypotheses are formulated to guide the construction of a structural equation model (SEM).

An original, normalized index is constructed to generate robustness scores for the Nationally Determined Contributions (NDCs) to the Paris Agreement of each of the countries included in the study sample. These scores and a binary variable for Organization for Cooperation and Economic Development (OECD) membership are included alongside the Macroeconomic and Institutional latent variables generated by the EFA in a SEM analysis of the direct and indirect impacts on green bond issuance volumes as a proxy for global market capitalization. The results show that beyond conventional macroeconomic and institutional drivers of capital market growth, NDCs exert substantial, positive effects on green bond markets. The results also imply that each of the drivers behind the recent precipitous growth of green bond markets stand to bolster sustainability by accelerating green bond capitalization and the positive environmental impacts that arise from green bond investments.

Chapter 5 provides an econometric analysis of the climate agenda and policy supports that promote green bond allocations to renewable energy investments. As green bond markets expand, the majority share of proceeds are being allocated to renewable energy infrastructure. Policy supports for renewable energy are well documented in the literature. There nevertheless exists a gap in the empirical literature on the policy supports behind green bond finance for the renewable energy critical to achieving the emissions reductions and sustainable development targets of the Paris Agreement.

To assess the impact that Nationally Determined Contributions to the Paris Agreement and other economic, regulatory, and financial policy supports have on green bond proceeds allocations to renewable energy, this chapter employed a difference-in-differences analysis using an original panel dataset of \$20 billion in green bonds proceeds allocations in 63 countries between 2008 and 2016. A normalized index of NDC climate agenda robustness is included in the model to measure the unique impacts that Paris pledges exerted on green bond disbursements to renewable energy. Financial policy supports including tax schemes, direct public infrastructure investments, and public loans, grants, and subsidies exert the largest positive, statistically significant impacts on green bond allocations to renewable energy. Feed-in-tariffs, renewable portfolio standards, and tradable renewable energy certificate economic policy supports exert nearly the same magnitude of influence as financial supports with greater statistical significance. Building codes, monitoring requirements, strategic planning, and other regulatory policy supports show the smallest yet positive and statistically significant impacts.

These results are the first in the literature to show that climate agendas exerted impacts comparable to financial and economic policy supports on green bond allocations to renewable energy. These findings suggest that beyond conventional renewable energy policy supports,

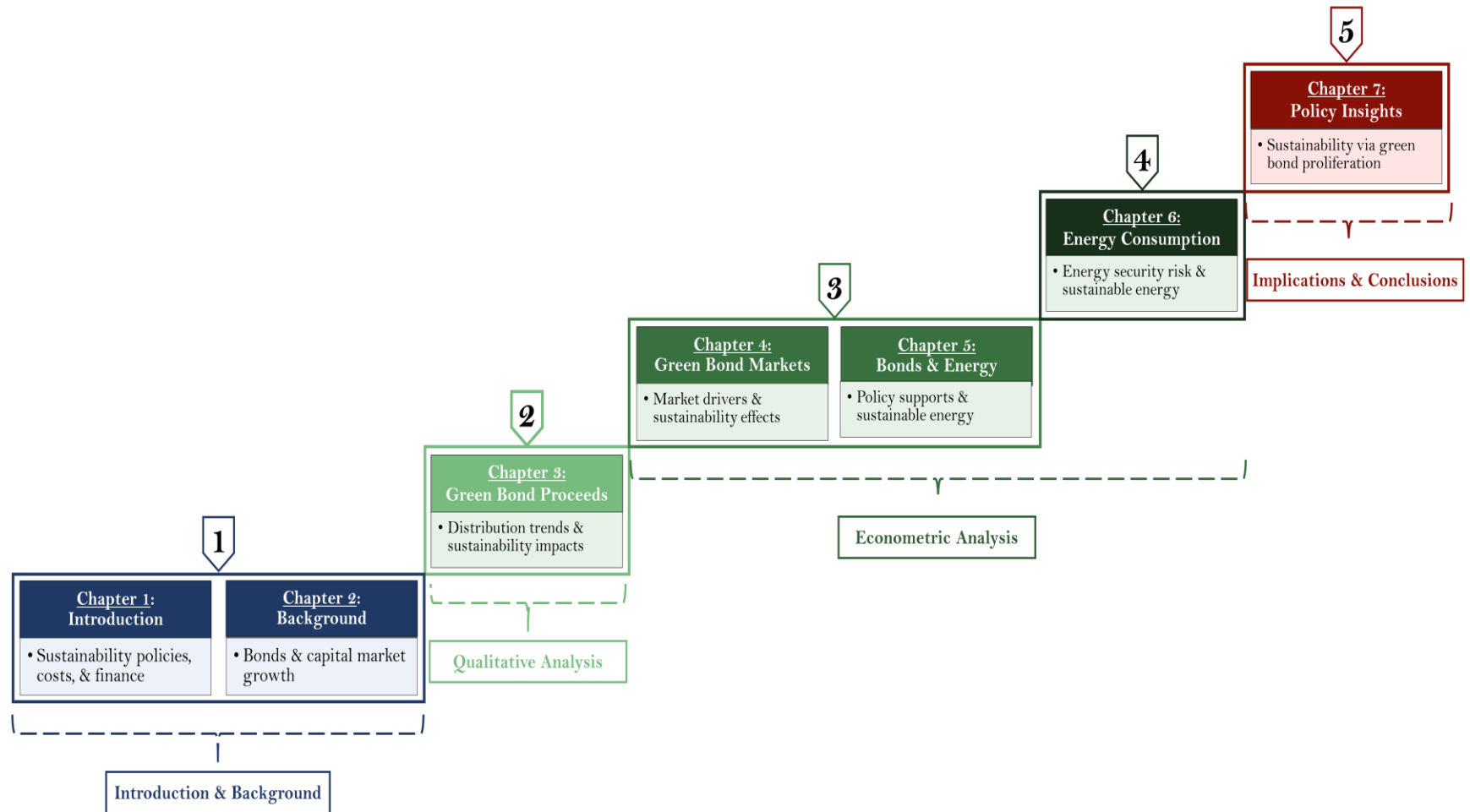
climate commitments promote green bond funding for renewable energy projects linked to eco-friendly impacts. They also suggest that Paris commitments and policy supports have substantially influence financial flows to climate and sustainability investments by promoting green bond proceeds allocations to renewable energy.

Chapter 6 provides a regression analysis of the impact of energy security risk on sustainability via energy consumption. There is renewed interest in energy security worldwide. The interest is sparked by concerns about energy security risk that obstructs energy supplies, hinders energy consumption, and undermines the growth, prosperity, and sustainability of nations. This chapter assesses the impact of energy security risk on energy consumption by analyzing the panel data of 64 countries from 1992 to 2014.

The energy security risk of a country affects its consumption of particular energy resources over time. Energy security risk correlations with nuclear and wind energy consumption are significantly larger than those of coal, oil and natural gas. Therefore, countries with greater energy security risk increase their share of low-carbon energy to a larger extent than they increase their share of conventional fossil fuel energy sources. Overall, these results reveal that low-carbon energy resources are employed in the face of energy security risk, thereby promoting sustainability.

Upon tying the unique findings of each preceding chapter together, the penultimate **Chapter 7** presents the concluding discussion about green bonds for sustainability. Figure 1.4 on the following page provides a visual representation of the analytical framework of this Thesis.

Figure 1.4: Thesis Framework



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Chapter 2: Background

This chapter begins with an overview of the function and features of bonds as capital market debt securities. Next, the predominant factors behind bond market development are described with reference to seminal literature on capital market theory. Subsequently, this chapter will provide an overview of the empirical literature on the determinants of conventional bond market growth that will highlight the research gaps pertinent to green bond market growth. Finally, in order to bridge these existing gaps, this chapter outlines a novel theoretical framework behind the analyses of this Thesis.

2.1. Bonds as capital market debt securities

Similar to conventional bonds, at their core, green bonds are yet another form of fixed-income debt security in which the lender receives a pre-determined level of financial reimbursement over time. For all practical purposes, this renders them fundamentally the same as other types of loans and debts. They are employed by a variety of companies, municipalities, governments, and agencies to finance their investments and upon issuance, they place the issuer in debt to the creditor(s) (i.e. investors) who hold the debt. The basic details of a typical, “plain vanilla” bond include a principal amount of money to be lent, variable or fixed interest rates to be paid to the lender, and a period of time over which the principal and interest will be repaid by the issuer to the lender. Still, bonds themselves present a handful of unique functions and features that set them apart from other market securities.

2.1.1. Features unique to bond debt securities

The major difference between bonds and traditional loans are that the former are issued by a borrowing entity as an “I.O.U” for the capital they will receive from the investing lender who provides the needed capital through the purchase of the bond. In the case of loans, the lender provides capital directly to the borrower directly without the “IOU” originating from the borrower. In essence, then, the major difference between the two is which party issues the initial documentation.

Another key difference is that bonds are usually repaid over anywhere from a one to 30-year time span, greatly outlasting the latter. On the other hand, bank loans are prioritized over bonds for repayment in the event of financial insolvency. Finally, one of the largest key differences between bonds and loans is that the former are generally issued with ratings that reflect the risk the potential investor may incur by purchasing the bond. Ratings will be thoroughly outlined in subsequent paragraphs.

2.1.2. A comparison of bonds, loans, and equity

Issuing institutions generally rely on bonds to avoid creating more equity that dilutes the power of individual shares or to take advantage of the opportunities to borrow with interest rates that are traditionally lower than bank loans. As mentioned above, the long term repayment schedules also mean that issuers can be provided access to capital without having to pay it back in full for up to decades at a time, which can appeal to insurance companies, pension funds, and other institutional investors aiming to line their portfolios with long-term, fixed-income securities. One feature of bonds that could be seen as an advantage over equity from an investor’s perspective is that the former are granted priority access to seizure of a company’s

assets in the event of default. Bond holders are thus termed to be “senior” to equity holders. For brevity, Table 2.1.1 provides a comparative overview of these concepts.

Table 2.1.1: Comparison of equity, bonds, and bank loans

General Characteristics	Equity	Bonds	Bank Loans
Length of term	Perpetual	Medium to long	Short
Growth participation	Yes	No	No
Repayment scheme	Variable	Fixed	Fixed
Creditor ranking	Lowest	Middle	Highest
Voting rights	Yes	No	No
Legal recourse	Company legal code	Incite bankruptcy	Incite bankruptcy
Asset security	Lowest	Middle	Highest
Risk and return	Highest	Middle	Lowest

Source: Created by author

2.1.3. Major bond risk factors

Beyond the above general characteristics, from an investor’s perspective, the decision to purchase bonds is largely related to its underlying primary risk factors. While there are numerous factors, the bond issuer, currency, coupon, and maturity date are the four major considerations. While these will be outlined in subsequent paragraphs, additional risk factors are outlined in Table 2.1.1.

2.1.3.1. Issuer risk

The creditworthiness of the bond issuer is the first influential risk factor. National governments, local governments, and government-related or state-backed agencies enjoy the

highest credit ratings due to their ability to levy taxes and other sources of revenue for full and timely service of debt. This lower risk is reflected in their relatively low weighted average costs of capital (WACC, often 5% or lower) (Curley, 2014; Wood, 2013).

Supranational finance institutions such as the World Bank International Bank for Reconstruction and Development (IBRD) and the European Investment Bank (EIB) also enjoy comparatively high credit ratings due to their strong capital adequacy and liquidity, preferred creditor status, extensive callable capital, and high creditworthiness and commitment from shareholders. (Moody's 2017a, 2017b) Similar can be said about large multinational corporations. By employing cash from operations, equity, and low levels of debt, these organizations can generally maintain WACC levels between 7.5% and 10%, which reflects greater risk aversion than many smaller corporate entities. (Wood, 2013) These factors, plus their large market capitalization, high returns on equity and assets (ROE and ROA), and other financially sound standards translated into healthy credit ratings.

2.1.3.2. Currency risk

The currency the bond issuance also affects its risk, as depreciation or appreciation of the issuance currency affects the value of the yield (e.g. fixed payment) received by the investor over the life of the repayment period. Especially in emerging market economies, where foreign investors that hold bonds denominated in the local currency still value their returns using US dollar or other major currency measurements, “exchange rate movements amplify their gains and losses, thereby magnifying the risks they face in meeting obligations at home in the investor’s home currency” (Hoffman et al., 2019).

2.1.3.3. Coupon risk

The coupon, otherwise defined as the interest rate attached to the principal balance of the bond, is the third aspect that influences a bond's risk. Coupons are paid annually, biannually, semi-annually, or quarterly, and greater coupons are paid to investors to the extent that the risk of issuer default is high. Moreover, coupons that represent the interest rate have an inverse relationship with the bond price. Namely, "when market interest rates rise, prices of fixed-rate bonds fall" (U.S. SEC, 2013).

2.1.3.4. Maturity date risk

The fourth major risk factor that is closely related to the coupon is the maturity date, or the specific date when the bond's face value (i.e. not including interest rates) will be repaid to the investor. In general, the longer the period of time until a bond reaches maturity, the greater the chances are that the bond's value could be impacted by changing interest rates or that bond issuer could become unable to make repayments due to financial trouble. A longer maturity, then, reflects higher risk (U.S. SEC, 2013).

2.1.3.5. Additional risk factors

Though the aforementioned factors exert the greatest influence on the risk associated with investing via bonds, there are a number of additional risk factors that simultaneously impact overall risk. They include interest-rate, reinvestment income or reinvestment risk call risk, credit risk, inflation risk, exchange-rate risk, liquidity risk, volatility risk, and "risk risk." Additional bond risk factors are summed in Table 2.1.2.

Table 2.1.2: Additional bond risk factors

Risk Type	Summary	Underlying factor(s)	Effect on	Mitigating factor(s)
Interest-rate/ market	Change in bond price is inversely related to the change in interest rates	Interest rates	Pricing, Options	Coupon, maturity, options
Reinvestment income	Interest rate at time of reinvestment affect reinvestment rates and strategy	Interest rates	Reinvestment	Shorter holding periods Large, early cash flows (high coupons)
Call	Cash flow pattern is uncertain, incites reinvestment risk, diminishes capital appreciation potential	Interest Price uncertainty	Refinance	Call provision parameters Strong price and market performance
Default (credit)	Issuer fails to satisfy terms of obligation	Credit rating	Credit, issuance viability and pricing, interest payments	Strong credit history and robust financial performance of issuer
Credit spread (credit)	Risk premium attributable to bond compared with U.S. treasury damages its market price	Yield	Credit, issuance viability and pricing, interest payments	Strong credit history and robust financial performance of issuer
Downgrade (credit)	Unanticipated rating downgrade of issuer or issue	Credit rating	Credit, issuance viability and pricing, interest payments	Strong credit history and robust financial performance of issuer
Counterparty (credit)	Transactions between two parties affected by leveraging or derivatives of borrower	Leveraging Derivatives	Credit, issuance viability and pricing, interest payments	Strong credit history and robust financial performance of issuer
Inflation/ purchasing- power	Security cash flow values vary in reponse to inflation	Inflation	Cash flow value	Floating interest rates that reflect expected inflation rates
Exchange- rate	Non-domestic-currency-denonminated bonds have unknown domestic currency cash flows that are dependent upon the exchange rate at the time of payment	Currency exchange rates	Cash flow value	Issuances in strong, global currency denominations
Liquidity/ marketability	Size of spread between bond price and dealer's quoted ask price affects ease with which issuances can be made at or near value	Bid-ask price spreads	Liquidity	Long-term holding
Volatility	Interest rate volatility affects the value of embedded options	Interest rate volatility	Option values	Stable interest rates
Risk	Uncertainty regarding the risk of a security	Uncertainty	Risk	Keep up to date with literature Avoid misunderstood

Source: Created by author

2.1.4. Bond ratings

When bonds are issued, most receive a credit rating from the Moody's, Standard and Poor's (S&P), or Fitch major rating agencies that take the aforementioned risk factors into consideration and thus reflect the chance of default or rating shifts. Each of the ratings and default rates are classified in Table 2.1.3. Highly rated bonds issued by obligors that are deemed to be highly capable of meeting their financial commitments to the bond obligation are known as investment grade bonds. Bonds with speculative characteristics with regards to "ongoing uncertainties or exposure to adverse business, financial, or economic conditions that could lead to the obligor's inadequate capacity to meet its financial commitments on the obligation" (S&P, 2019) are conventionally labelled "high yield," "speculative," "non-investment," or the more colloquially termed "junk" bonds. The rating of a bond largely affects investor confidence and their subsequent investment decision-making. Indeed, some institutional investors are even prohibited from investing in sub-investment grade bonds (Veys, 2010).

2.1.5. Types of bonds

As bond markets mature, so too do the classifications and varieties of bond types. The four primary bond categories are classified according to their issuer and include:

1. Corporate bonds
2. Municipal bonds
3. Government bonds, and
4. Agency bonds

Corporate bonds are issued by companies as an alternative to loan financing due to the often favorable terms and interest rates offered by bond markets. Municipal bonds are issued by states

Table 2.1.3: Long and short-term bond ratings and average default rates

	Standard & Poor's (S&P)		Fitch		Moody's		One year average default rate ²	Five year average default rate
	Long-Term ¹	Short-Term	Long-Term	Short-Term	Long-Term	Short-Term		
Investment Grade	AAA	A-1 (+)	AAA	F1+	Aaa	P-1	0.00%	0.16%
	AA	A-2	AA+		Aa1		0.07%	0.72%
			AA		Aa2			
	A	A-3	AA-	F1+ or F1	Aa3	P-1 or P-2	0.09%	1.26%
			A+		A1			
	A		F1 or F2	A2				
	A-			A3	P-2		0.29%	3.13%
	BBB		BBB+	F2 or F3	Baa1	P-2 or P-3		
BBB			F3	Baa2	P3			
Junk	BB	B	BBB-	B	Baa3	NP	0.29%	3.13%
			BB		Ba1			
			BB+		Ba2			
	B	B	B1	4.03%	22.42%			
			B2					
			B3					
	CCC	C	Caa1	14.28%	41.18%			
			Caa2					
			Caa3					
	CC	C	Ca	D	100%	100%		
	C		C					
	Defaulted	SD ³	D	RD ⁴	RD	D	D	100%
D		D		D				

Source: Created by author using information from S&P (2019a, 2019b), Moody's (2019), and Fitch (2019) reports

and municipal governments and tend to shield investor coupon income from taxes. Government bonds are issued by national governments and are collectively referred to as sovereign debt. Prominent examples include the 1 to 10 years-to-maturity (YTM) notes and 10-plus YTM bonds issued by the U.S. Treasury. Lastly, agency bonds are issued by government agencies or similarly government-affiliated entities.

Additional varieties include:

1. Zero-coupon bonds issued at a discount and generate a return at maturity
2. Convertible or exchangeable bonds that provide the option for bondholders to convert their debt into equity
3. Callable bonds that provide the option for bondholders to demand full repayment before maturity, and
4. Puttable bonds, that allow bondholders to resell the bond back to the issuer before maturity.

Each of the above-mentioned varieties adds complexity to bond valuation. Simultaneously, they provide options or advantages to the investor, depending upon market conditions and their ultimate investment and finance aims.

2.1.6. Bond pricing

In the simplest case of option-free bonds with semi-annual cash flows and a yield that reflects an annual interest rate, one-half the annual interest rate conventionally serves as a proxy for the periodic rate with which to discount cash flows. Bond pricing reflects the present value of the bond cash flows, they can be calculated by summing the present value of semiannual coupon

payments and the present value of the par value at maturity. Taking these considerations into account, the bond pricing can be expressed as noted by Fabozzi (2013) as:

$$P = \frac{C}{1+r} + \frac{C}{(1+r)^2} + \frac{C}{(1+r)^3} + \cdots + \frac{C}{(1+r)^n} + \frac{M}{(1+r)^n} \quad (2.1)$$

Note that the above can also be expressed using the following sigma notation:

$$P = \sum_{t=1}^n \frac{C}{(1+r)^t} + \frac{M}{(1+r)^n} \quad (2.2)$$

where

P = the price of the bond;

n = the number of interest repayment periods;

C = the value of the semi-annual coupon payment;

r = the periodic interest rate;

M = the par value of the bond at maturity; and

t = total time period of repayment.

2.2. Capital market description, formation, and determinants

Bonds exist in capital markets, financial markets where long-term debt and equity-backed securities are issued and exchanged. There are a variety of factors affecting the formation of capital markets and the issuance of securities within them. The following subsections will outline

the varieties of capital markets, the theory behind their formation, and empirical measurements of the determinants of their expansion.

2.2.1. Primary and secondary markets

Bonds and other securities exist primarily within two subdivisions of overall capital markets: the primary market where new securities are created and issued to the public, and the secondary market where they are subsequently traded among investors. Beyond these two distinctive functions, main differences between the two markets include the pricing of securities (i.e. fixed vs. variable), trading methods (i.e. direct vs. indirect), income recipients (i.e. a company vs. investors), number of trades per security (i.e. once vs. multiple times), physical location (e.g. loose vs. strictly determined), and trading entities (i.e. investment bankers vs. brokers and intermediaries). Table 2.2.1 summarizes the key distinctions between the two markets.

2.2.2. Financial market formation theory

Much of the literature precedent argues that capital market formation is an inevitable effect of economic development that has the effect of perpetuating further growth. As early as 1934, influential economist Joseph Schumpeter described finance and the development of financial markets as quintessential to economic development in that it concentrates purchasing power, enhances productive means, and directs the social processes of capitalism and the exchange economy (Schumpeter, 1934). Some decades later, Gurley and Shaw (1960) would note that the “...economy’s capacity for growth is limited by its financial system. With no

financial asset other than money, there are restraints on saving, on capital accumulation, and on efficient allocation of saving to investment that depress the rate of growth in output and income.”

Table 2.2.1: Comparison of primary and secondary capital markets

	<u>Primary Market</u>	<u>Secondary market</u>
Purpose	Create and issue new securities	Trade existing securities
Purchasing type	Direct	Indirect
Financing	Budding and expanding firms	Investor returns
Sales per security	One	Multiple
Parties to transactions	Issuing firms and investors	Investors only
Proceeds recipient	Firms	Investors
Intermediary	Underwriters	Brokers
Price	Fixed	Fluctuate with supply and demand
Geographical location	Transaction location	Physical marketplaces and servers
Example	Initial Public Offering (IPO)	New York Stock Exchange (NYSE)

Source: Created by author

Echoing Shumpeter (1934), Gurley and Shaw (1960) would also note that an economy consists of the three markets of (1) labor services, (2) current output, including consumption goods, government goods, and private investment goods; and (3) money, including financial markets.

2.2.3. *Empirical model of financial market formation theory*

After defining the financial inter-relations ration (FIR) as that the relation between the total value of financial assets (e.g. trade credit, bank credit, consumer credit, mortgages, savings deposits, insurance reserves, government and corporate bonds, corporate stock) and the value of all real assets (e.g. national wealth), Goldsmith (1966) notes that “the statistical data already

available clearly indicate a positive association between FIR and the stage of economic development and a number of regularities.” Assuming

1. An economy is closed,
2. Its growth rate is constant,
3. All economic units operate within the financial institution and non-financial institution sectors
4. Only net financial flows are accounted for,
5. All financial instruments are freely exchangeable at par,
6. No inter-sectoral transactions occur after the issuance of financial instruments, and
7. Coefficients are stable and derivations from the weighted value during the period of assessment can be disregarded,

Goldsmith calculated the determinants of annual financial instrument issuances ($f = f_1 + f_2 + \dots$) as:

$$f_j = y_j \mu_j k_j \epsilon_j [1 + \phi_j (1 + \lambda_j)] \quad (2.3)$$

where

f_j is the total volume of new financial instrument issuances for country j ;

y_j is the total gross national product (GNP);

μ_j is the monetization ratio that depicts the portion of GNP that is sold for money;

k_j is the capital formation ratio that depicts the fraction of monetary capital formation within monetary GNP;

ϵ_j is the ratio of new non-financial institution issuance units (e) to capital formation k ;
 ϕ_j is the ratio of new financial institution instrument issuances (d) to non-financial institution issuances (e); and
 λ_j is the ratio of total financial institution instrument issuances to other financial institutions (d') to total financial institution instrument issuances to non-financial institution issuances (d).

In other words, the monetized GNP ($y_j \mu_j$) subsists within the monetized capital formation depicted by ($y_j \mu_j k_j$), the net non-financial unit issuances shown in ($y_j \mu_j k_j \epsilon_j$), and the total net new issuances reflected in ($y_j \mu_j k_j \epsilon_j [1 + \phi_j (1 + \lambda_j)]$). Furthermore, the long form of the above equation is depicted by the following:

$$f_j = y_j \mu_j \times \frac{k_j}{y_j \mu_j} \times \frac{e_j}{k_j} \times \frac{e_j + d_j}{e_j} \times \frac{e_j + d_j + d'_j}{e_j + d_j} \quad (2.4)$$

2.2.4. *Theories of macroeconomic and institutional drivers of capital market formation*

Numerous studies subsequently indicate that macroeconomic and institutional factors support financial and capital market development. In a seminal paper on the impacts of economic growth on financial market development, Patrick (1966) noted that “as the economy grows, it generates additional and new demands for these [financial] services, which bring about a supply response in the growth of the financial system.” He also emphasizes the importance of “supply-leading” government, financial, and commercial bank institutions that apply their monetary and

regulatory influences to establish the legal, institutional, and economic environment required for financial market expansion.

Greenwood and Jovanovic (1990) similarly stated that economic growth and financial markets were “inextricably linked,” and that growth provides “the wherewithal to develop financial structure.” Noting the importance of institutional arrangements in promoting financial market capital investments, they follow Boyd and Prescott (1986) in stressing the role of institutions in alleviating information frictions and Townsend (1978) in highlighting the insurance role of institutions that enable higher, safer returns for investors. In response to these and many other theoretical contributions, an extensive line of literature empirically assesses both economic and institutional drivers of capital market development.

2.2.5. Empirical studies on capital market formation

The absence of widely accepted empirical results incited researchers to perform a multitude of econometric assessments of the determinants of bond market growth. This section presents a literature review of bond market determinants. In subsequent sections, the macroeconomic and institutional determinants that are prominently identified throughout the literature are separately examined. Table 2.2.2 presents a summary of the major preceding studies with regard to the market factors included in their respective analyses.

La Porta et al. (1997) performed ordinary least squares (OLS) regressions to show that legal codes and their enforcement positively affect both equity and debt security market development. This is due to the protection that such conventions provide financiers, thereby facilitating securities trading and capital market growth. Moreover, these results revealed that countries in the lineage of English common law (e.g. English legal origin) provided stronger

Table 2.2.2: List of reviewed capital market determinants

Category	Factor	References
Macroeconomic Development	<i>Current account balance</i>	Harwood, 2000; Eichengreen and Luengnarumitchai, 2004; Burger and Warnock, 2006; Burger et al., 2010; Smaoui et al., 2017
	<i>Bond market capitalization</i>	La Porta et al., 1997; Levine and Zervos, 1998; Levine, 2005; Eichengreen and Luengnarumitchai, 2004; Burger and Warnock, 2006; Adelegan and Radzewicz-Bak, 2009; Burger et al., 2010; Bae, 2012; Raghavan and Sarwono, 2012; Bhattacharyay, 2013; Mu et al., 2013; Essers et al., 2014
	<i>Size of economy (GDP)</i>	Demetriades and Hussein, 1996; La Porta et al., 1997; Calderon and Liu, 2003; Eichengreen and Luengnarumitchai, 2004; Fabella et al., 2003; 2004; Levine, 2005; Burger and Warnock, 2006; Claessens et al., 2007; Adelegan and Radzewicz-Bak, 2009; Burger et al. 2010; Bae 2012; Raghavan and Sarwono 2012; Bhattacharyay 2013; Mu et al. 2013; Essers et al. 2014; Smaoui et al. 2017
	<i>Stock market capitalization</i>	Eichengreen and Luengnarumitchai, 2004; Bae, 2012, Raghavan and Sarwono, 2012
	<i>Trade openness (exports/GDP)</i>	Rajan and Zingales 1995; Eichengreen and Luengnarumitchai, 2004; Adelegan and Radzewicz-Bak, 2009;
Financial & Monetary Environment	<i>Banking sector size and concentration</i>	La Porta et al., 1997; Eichengreen and Luengnarumitchai, 2004
	<i>Domestic credit to private sector</i>	Bentson, 1994; Levine and Zervos, 1998; Schinasi and Smith, 1998; Harwood, 2000; Hawkins, 2002; Rajan and Zingales, 2003; Eichengreen et al., 2008; Smaoui, 2017
	<i>Interest rate spreads and volatility</i>	Eichengreen and Luengnarumitchai, 2004; Eichengreen et al., 2008; Adelegan and Radzewicz-Bak, 2009; Bhattacharyay, 2013; Mu et al., 2013; Smaoui et al., 2017
	<i>Inflation rates</i>	La Porta et al., 1997; Hausmann and Panizza, 2003; Mehl and Reynaud, 2005; Burger and Warnock, 2006; Claessens et al., 2007; Burger et al., 2010; Essers et al., 2014
	<i>Exchange rate volatility</i>	Goldstein, 1998; Eichengreen and Luengnarumitchai, 2004; Adelegan and Radzewicz-Bak, 2009; Bae, 2012; Mu et al., 2013; Bhattacharyay, 2013; Smaoui et al., 2017
Institutional & Regulatory Quality	<i>Capital controls</i>	Eichengreen and Luengnarumitchai, 2004; Claessens et al., 2007; Adelegan and Radzewicz-Bak, 2009; Bae et al., 2012; Mu et al., 2013; Essers et al., 2014; Fernandez et al., 2015; Smaoui et al., 2017
	<i>Common legal origin</i>	Reynolds and Flores, 1989; La Porta et al., 1997; Levine and Demirgüç-Kunt, 1999; Sharma, 2000; Claessens et al. 2007 Essers et al., 2014;
	<i>Control of corruption</i>	Knack and Keefer, 1995; Hall and Jones, 1999; Acemoglu et al., 2001; Easterly and Levine, 2003; Eichengreen and Luengnarumitchai, 2004; Mu et al., 2013; Adelegan and Radzewicz-Bak, 2009; Essers et al., 2014; Raghavan and Sarwono, 2012; Smaoui et al., 2017
	<i>Fiscal policy</i>	Claessens et al., 2007; Bae et al., 2012
	<i>Regulatory quality</i>	Knack and Keefer, 1995; Hall and Jones, 1999; Acemoglu et al., 2001; Easterly and Levine, 2003; Mu et al., 2013; Essers et al., 2014; Smaoui et al., 2017
	<i>Rule of law</i>	Knack and Keefer, 1995; La Porta et al., 1997; Mauro, 1995; Hall and Jones, 1999; Levine and Demirgüç-Kunt, 1999; Acemoglu et al., 2001; Gwartney et al., 2003; Eichengreen and Luengnarumitchai, 2004; Burger and Warnock, 2006; Adelegan and Radzewicz-Bak, 2009; Bae, 2012; Essers et al., 2014; Smaoui et al., 2017

Source: Created by author

investor protections and therefore more developed capital markets than countries adhering to French civil law.

Using panel generalized least squares (GLS) multivariate regression analysis covering 41 Asian bond markets during the years 1990 through 2001, Eichengreen and Luengnaruemitchai (2006) found that government security market development was positively affected by the size of the economy, trade openness, capital account openness, and distance from the equator while it was negatively affected by banking sector concentration, exchange rate volatility, the size of the fiscal balance, and interest rate spreads (i.e. the magnitude of difference between deposit interest rates and lending interest rates). In addition to the factors with positive impacts on sovereign bond markets, they also found corporate bond markets to be positively affected by control of corruption, the level of domestic credit, and the quality of the bureaucracy. Conversely, corporate bonds markets were negatively impacted by English legal origin, interest rate spreads, and exchange rate volatility.

Burger and Warnock (2006) similarly studied the drivers of both government and private bond market development using a cross-sectional data sample of local bond markets in 49 countries. Their regression results revealed that for both corporate and government securities, levels of inflation and the strength of the rule of law not only had substantial impacts on market size, but also on the ability for host countries to be less reliant on bonds denominated in foreign currencies. They also found a strong correlation between bond market and banking sector development.

Claessens et al. (2007) used panel data for 36 countries between 1993 and 2000 in panel-feasible general least squared (FGLS) and OLS estimations of the institutional and macroeconomic factors behind sovereign bond market magnitude and currency composition.

Their results showed a strong link between bond market development and both the banking system and stock market capitalization. They also found the size of the economy, inflation, and capital account openness to greatly affect bond market development and currency composition.

Adelegan and Radzewicz-Bak (2009) evaluated the factors that impact both government and corporate bond market development in 23 sub-Saharan African countries from 1990 through 2008. They found economic structure and size, the strength of law and order, the size of the banking sector, interest rates, exchange rates, capital controls, and fiscal controls to be among the strongest, statistically significant determinants of bond market deepening. Subsequently, Bae (2012) measured the determinants of government, financial, and corporate bond market development using a sample of 43 countries from 1990 to 2009. In addition to the economic development level, the fiscal balance, stable exchange rates, low interest rates, and domestic credit from the banking sector were strong factors.

Mu et al. (2013) used a generalized method of moments (GMM) estimation for a sample of 36 sub-Saharan African countries during the years 1980 through 2010 to compare the determinants of both government security and corporate bond market capitalization. They found that government security markets are positively correlated with interest rate spread, English legal origin, and fiscal balance and negatively correlated with exchange rate volatility and capital account liberalization. They also demonstrated corporate bond markets to correlate with the size of the economy and negatively correlate with institutional quality. Similarly, Smaoui et al. (2017) employed Prais-Winsten and system GMM estimations to investigate the structural, financial, developmental, institutional, and macroeconomic factors affecting bond market development throughout a sample of 22 countries from 1990-2013. Their results revealed that the size of the economy, banking sector concentration, investment profile, bureaucratic system

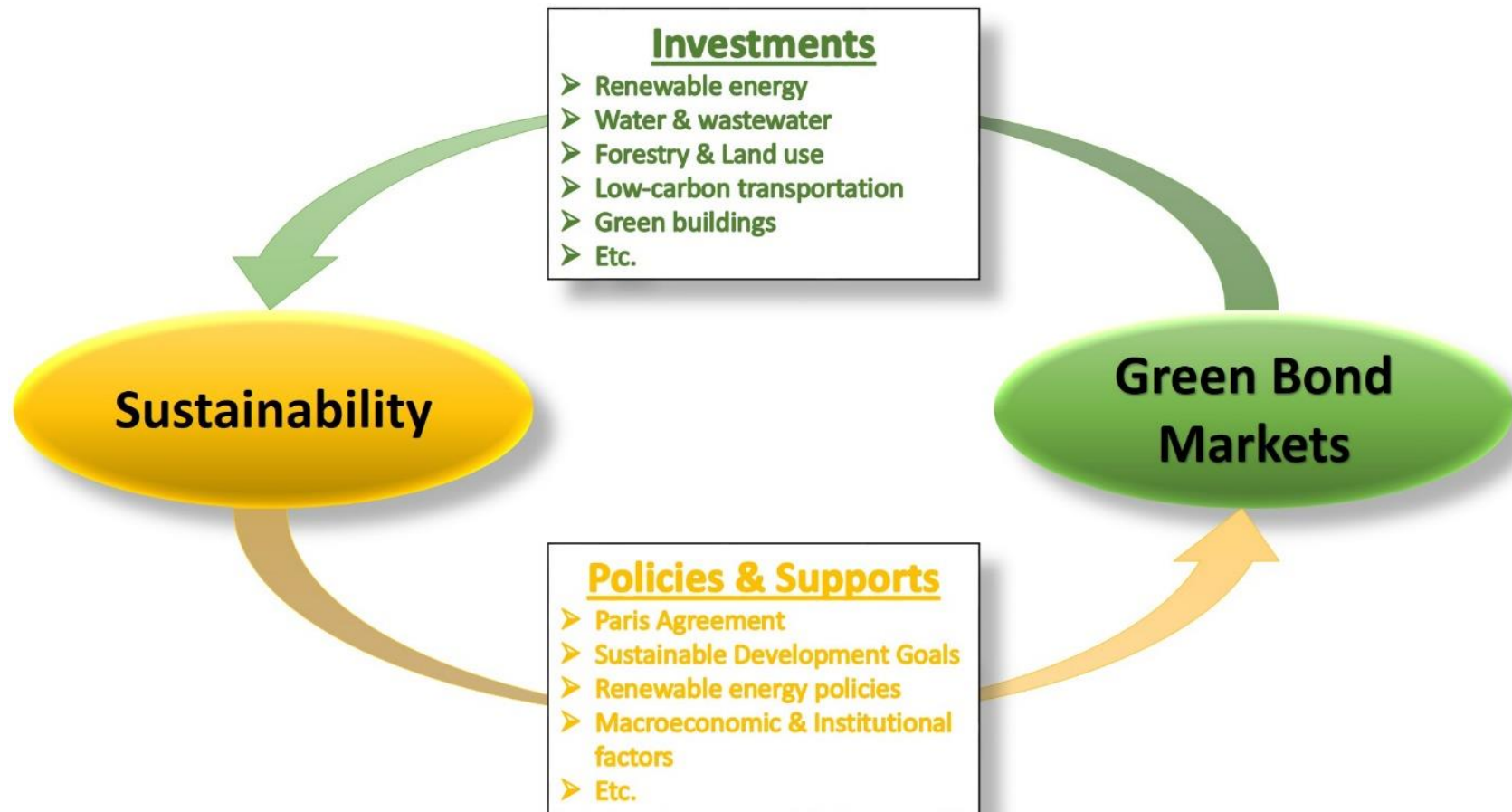
quality, and exchange rate volatility were all positively correlated with both sovereign and corporate bond market development.

2.3. A theory of green bonds for sustainability

As articulated in Chapter 1, green bond markets are expanding rapidly in an era when global policies such as the Paris Agreement and the Sustainable Development Goals call for greater investments climate change mitigation and sustainability. While a much of the existing literature provides a qualitative assessment of the potential for green bonds to finance sustainability-enhancing infrastructures, and another large portion of green bond literature assesses the price differences between green and conventional bonds, none have provided a thorough, *ex post* empirical analysis of green bond finance for global investments in sustainability.

This Thesis provides such an assessment by combining quantitative measurements of the sustainability outcomes already associated the investments financed by green bonds to date with econometric analyses of the factors promoting the green bond markets as enabling environments for such sustainability investments. In these pursuits, this Thesis is the first to combine empirical assessments of field data to build upon existing theoretical and empirical analyses of green bond markets as a subsidiary of capital markets. This Thesis is also the first to demonstrate a theory of the perpetual cycle between green bond market growth and sustainability enhancements, as depicted in Figure 2.3.

Figure 2.3: The green bond market-sustainability feedback loop



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Chapter 3: Green bonds for the Paris Agreement and Sustainable Development Goals

The Sustainable Development Goals (SDGs) within the 2030 Agenda for Sustainable Development of the United Nations Development Programme (UNDP) and the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) are two premier global initiatives for addressing the economic growth-environmental stewardship dichotomy. The former aims to eradicate poverty and hunger, promote peace, justice, and human rights, and realize environmentally-friendly, sustainable economic growth and universal prosperity (UN, 2015). The latter calls to keep 21st century global temperature rises within 2° C (above pre-industrial levels) and to finance low-carbon, climate-resilient global development (UNFCCC, 2015a). Still, both frameworks entail substantial investments. For instance, the U.N. Commission on Trade and Development (UNCTAD) estimates that meeting the SDGs requires \$5 to \$7 trillion in annual investments through 2030 (UNCTAD, 2014), while the International Energy Agency (IEA) estimates that maintaining the 2° C temperature threshold of the Paris Agreement will require \$53 trillion in energy-related investments by 2035 (IEA, 2014). The international community is thereby pressed to mobilize large volumes of public and private capital in pursuit of far-reaching environmental agendas.

In the related context of traditional project finance, the comparative advantages of debt instruments (i.e. loans and bonds) remain important considerations in financial decision-making. Such advantages include an applicability to flexible payment schedules, various credit enhancement techniques, long-term project schedules, leverage options, and other benefits that ultimately drive down finance costs (Curley, 2014). With proceeds earmarked to eligible, eco-friendly projects and assets, newly emerging green bonds stand to bring the advantages of debt instruments to the realm of environmental finance.

3.1. Environmental finance mechanisms

Before green bonds, there were a number of precedent-setting environmental finance instruments that are conducive to advancing SDG and NDC-related environmental targets. Specifically, the Clean Development Mechanism (CDM) and the Green Climate Fund (GCF) both highlight the diversity of options among effective environmental financing schemes.

3.1.1. The Clean Development Mechanism (CDM) and the Green Climate Fund (GCF)

Established under the UNFCCC Kyoto Protocol as an avenue for developed countries to fulfill their greenhouse gas (GHG) emission reduction commitments via qualified projects in developing countries, the Clean Development Mechanism (CDM) was “seen by many as a trailblazer...the first global, environmental investment and credit scheme of its kind, providing standardized emissions offset instruments, CERs [certified emissions reduction credits]” (UNFCCC, 2019). Multiple studies have verified the contributions of the CDM to green outcomes. Ellis et al. (2007) observed that CDM portfolio developments resulted in greater carbon dioxide (CO₂) emissions credits, increased awareness of climate change mitigation options among potential investors, and more robust climate-related institutions. Schneider et al. (2008) combined empirical study assessments with expert testimonies to reveal that CDM perpetuates green technology transfer by increasing commercial viability, reducing barriers to information and capital, and improving institutional frameworks. Most recently, Seres et al. (2009) assessed over 3,000 CDM projects and proposals to demonstrate that after a certain threshold number of projects in a given country, the transfer of emissions-reducing technologies that were previously unavailable in CDM host countries extends beyond the CDM projects themselves.

The Green Climate Fund (GCF) is another important environmental finance mechanism. It was similarly established under the UNFCCC in 2010, but as a more direct means of funneling funds (predominately through grants and loans) into GHG emissions curbing and climate change adaptation in developing countries. Since its inception, 40 contributing countries have allocated \$4.6 billion to 93 green projects, with another \$1.8 billion available for implementation and an additional \$10.3 billion in subsequent funding pledges. Already supporting green projects expected to reduce global CO₂ emissions by 1.4 billion tonnes (GCF, 2018), the GCF will likely to play important role in financing Paris Agreement and other green policy outcomes throughout the developing world.

3.1.2. Green bonds as novel finance mechanisms

The Green Bond Principles (GBP) published by the International Capital Markets Association (ICMA 2018a) define green bonds as “any type of bond instrument where the proceeds will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible Green Projects.” To this end, green bonds appeal to a broad range of institutional and socially responsible investors (SRIs) seeking to bolster their portfolios with eco-friendly, fixed payment securities. An added benefit is that in cases where access to capital markets is limited, bonds can supplement municipal budget shortages in capital-intensive infrastructure finance schemes (Clapp et al., 2015). Moreover, the fact that the projects they are designed to finance fall within the scope of 15 SDGs (ICMA, 2018b) and are similarly relevant to the Nationally Appropriate Mitigation Actions (NAMAs) of Paris NDCs (Hatano, 2018) points to their inherent compatibility with both agendas.

Although their proceeds are earmarked, green bonds are sometimes mistakenly credited for additional environmental benefits derived from the assets they finance. It is important to note, however, that bonds are primarily involved in refinancing schemes (of existing, instead of new projects) and are seldom the sole factor in the project finance decision-making process. Their environmental impacts are therefore not necessarily additional, as projects financed using green bonds often could be financed using other mechanisms. Nevertheless, their potential impacts on weighted actual costs of capital (WACC), investment scaling and planning decisions, portfolio alignments with environmental policy initiatives, and numerous additional factors affecting green investment awareness and decision-making (Dupree et al., 2018) render them capable of affecting environmental investment and policy outcomes.

Though their markets are relatively nascent, the recent, precipitous rise in green bond issuances has prompted a growing number of studies into their applications and effectiveness as environmental finance instruments. Mathews and Kidney (2012) compared renewable energy and low-carbon technology projects in first and third world countries to conclude that even in the latter, climate (green) bonds attract long-term investors who view low-carbon projects as “safe” investments. Ng and Tao (2016) assessed the renewable energy financing gap in Asia and found that while green bonds are capable of bridging the gap, their successful adoption should be supported through policy efforts that level the playing field for renewable energy projects, build deep capital markets, and enhance the robustness of labelling practices. Building on the discrete time overlapping generations model utilized by Sachs (2014), Flaherty *et al.* (2017) employed a nonlinear predictive control to find that by enabling present-day environmental investments that will largely be enjoyed and financed by future generations, climate (green) bonds are effective instruments of Pareto environmental improvements. Furthermore, using both stock market event

studies and regressions of corporate green bond issuances on financial and environmental performance factors, green innovation, long-term orientation, and orientation structure among firms, Flammer (2018) demonstrated that corporate green bonds improve environmental footprints and financial performance among firms and attract environmentally aligned investors.

Many studies have also assessed the existence, scale, and effects of green bond yield premiums. Through ordinary least squares (OLS) regressions of after-tax yields and ownership concentration on green bond indicators and controls, Baker *et al.* (2018) found that green bonds are issued at a negative premium and held in higher concentrations among investors, revealing that “a subset of investors is willing to sacrifice some return to hold green bonds.” Zerbib (2018) employed a matching method to compare yield spreads between green and non-green bond yields as well as two phases of regressions on green bond premiums. Their results indicated that green premiums are small and negative for Euro and U.S. dollar (USD)-denominated bonds, suggesting they do not discourage expansions among green bond-holding investor bases. Both of these studies fall within a growing literature base which finds negative premiums among GBP-aligned green bonds (Preclaw & Bakshi, 2015; Ehlers & Packer, 2017; Hachenberg & Schiereck, 2018), similarly suggesting investors are willing to hold green bonds at a premium.

One substantial gap in the green bond literature involves the role of green bonds in advancing specific environmental policy targets. Particularly, the degree to which green bond financing affects greenhouse gas (GHG) emissions reductions and other explicit NDC and SDG-related targets remains vaguely understood. Although some green bond issuers publish post-issuance reports which detail how proceeds are allocated and the anticipated environmental effects of underlying projects, each individual report offers merely a limited view of the role of green bonds in pursuing environmental policy objectives. A comprehensive assessment of green

bond impacts would aid in measuring their effectiveness in promoting “financial flows consistent with climate and other sustainability objectives, in order to inform the design of policy incentives and climate actions from investors” (Dupree *et al.*, 2018). The aim of this study, therefore, is to trace the linkages between green bond-issuing institutions, the eco-friendly investment categories to which green bond proceeds are allocated, and the anticipated environmental impacts of these investments to evaluate the role of green bond finance in advancing SDG and NDC objectives.

The remainder of this paper is structured as follows. Section 2 outlines the analytical methods employed in this study. Section 3 describes the data and resources utilized in the analyses. Section 4 provides the main results with discussions of each. Section 5 concludes with implications for future post-issuance reporting and green bond applications within SDG and Paris Agreement policy pursuits.

3.2. Methodology

This analysis begins with graphical representations of green bond market activities from 2008 to 2017. First, the total annual volumes of green bonds issued, green bonds outstanding, and reported green bond proceeds allocations are graphically assessed within the context of total annual international debt securities (bonds) outstanding. Next, the total annual frequencies and volume of proceeds allocations to 10 specified green project and asset categories are graphically compared. A circle plot then provides an overview of global green bond proceeds allocations to assess domestic and transnational proceeds flows from issuing (allocating) organizations to recipient green categories. Finally, total estimated environmental impacts associated with green bond proceeds-recipient projects and assets are calculated and summarized in Table 3.4.

3.3. Data

An original panel dataset was constructed using 2008 to 2017-year international and green bond market data from a diverse range of sources. International debt securities (bonds) outstanding data is from the Bank of International Settlements (BIS) debt securities statistics online database (2018). Fourth quarter values served as yearly proxies for the data which is conventionally reported in a quarterly format. Furthermore, total international bonds outstanding data was used to represent global bond market trends in the absence of consistent, reliable domestic bonds outstanding data.

Labelled (e.g. earmarked for green projects or assets) green bond issuance and outstanding data is from the Climate Bonds Initiative (CBI) third quarter 2018 database (2018b). To the authors' knowledge, no similar repository of unlabelled green bonds exists, and post-issuance impact and investor reporting for unlabelled bonds was generally inaccessible, incomplete, or even nonexistent. As such, they were not included in the analyses of this study. This represented a significant data limitation, as the bulk of environmentally-aligned bonds fall into this category. Furthermore, since many of these unlabelled issuances took place in countries that are of critical importance to Paris and SDG outcomes, their inclusion would enhance the results of this study. For example, data gaps and reporting shortages for unlabelled (or not conventionally labelled) Chinese issuances prevented more thorough evaluations of the massive Chinese market that injected \$960 billion into 7,826 low-carbon projects between 2016 and 2017 alone (UNEP, 2017).

Green bond proceeds allocations and environmental impacts were calculated by the authors using annual or semi-annual post-issuance and investor reports published by 53 green bond issuing organizations (see Table 3A in the Appendix of this Chapter). These organizations

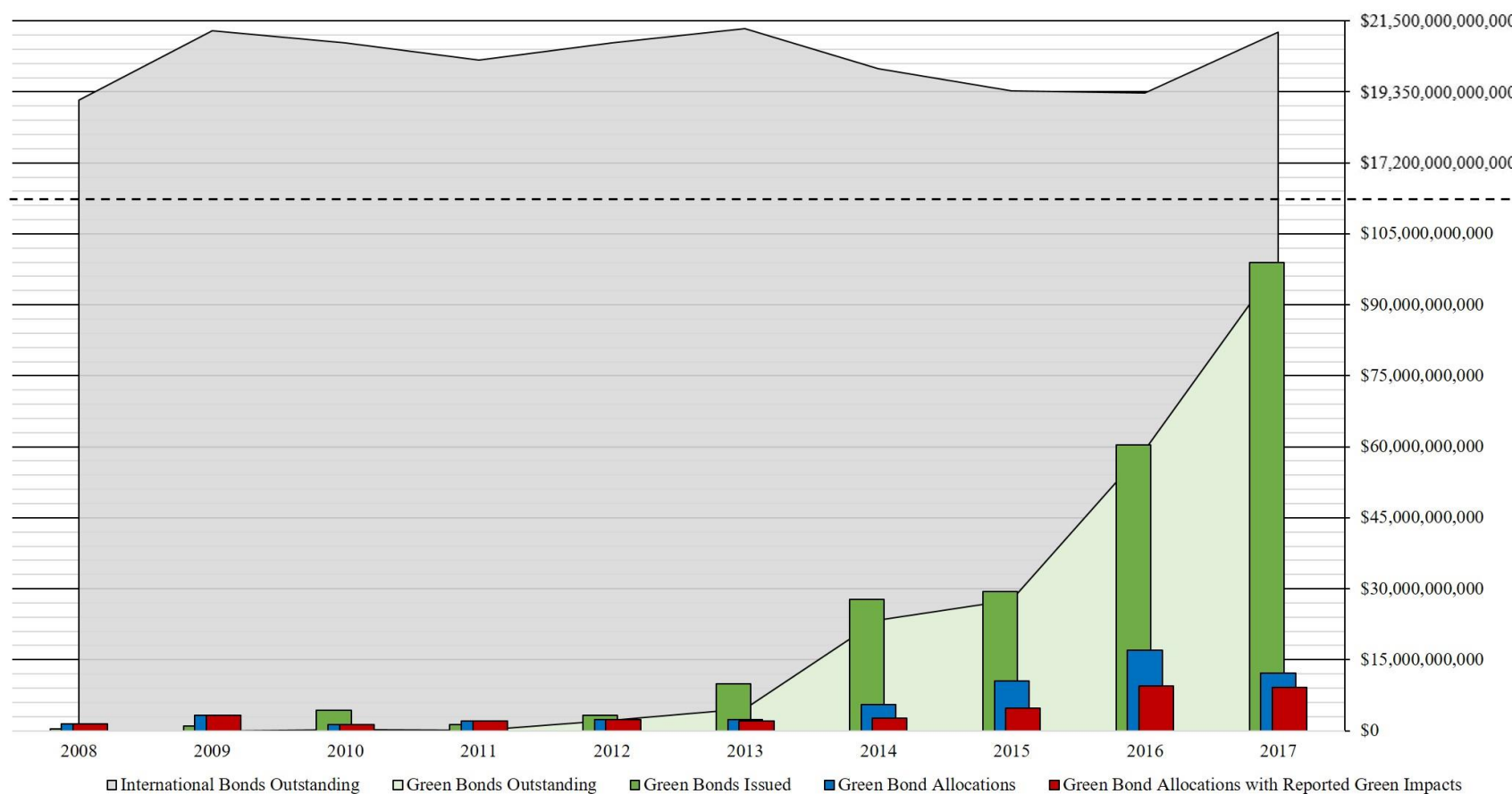
were among the 103 listed in a comprehensive overview of the publicly-available green bond post-issuance reporting complied by the CBI (2017b). From among these potential sources, data was selected based upon the availability of complete information regarding 1) the names, domiciles, and institutional structure of organizations that distributed green bond proceeds; 2) the location, green category (e.g. renewable energy, clean water, low-carbon transportation, etc.), and environmental impacts of projects or assets financed (at least partially) with the proceeds; and 3) the year, frequency, and volume of the proceeds allocations. Notably, an additional 41 green bond-issuing institutions from the source list provided no reporting as of the data collection period of this study. The fact that only about half (53 out of 103) of the organizations that did report did so thoroughly enough to allow for the assessments of this study draws attention to the severe lack (and need) of clear, consistent, instructive reporting.

3.4. Results and discussion

3.4.1. Green bond market growth and increasing proceeds allocations

Figure 3.4.1 demonstrates the upscaling of the labelled green bond market from 2008 through 2017. Specifically, it juxtaposes the total annual volumes of green bonds issued, green bonds outstanding, and reported green bond proceeds allocations with the total annual volumes international bonds outstanding. Note that the dashed line indicates a vast gap in the monetary volumes recorded on the y-axis. Volumes recorded below the line remain within the \$105 billion ballpark of peak, 2017-year green bond issuances, while those recorded above the line extend from \$17.2 trillion to the nearly \$21.5 trillion peak of international bonds outstanding. Moreover, although the monetary values in original data sources were expressed nominally, those in Figure 3.4.1 and all subsequent figures, tables, and discussions are expressed in constant 2010 USD.

Figure 3.4.1: International bonds outstanding, green bonds outstanding, and green bond allocations, 2008 to 2017



Sources: Created by author using BIS debt securities statistics (2018) (international bonds outstanding data), CBI dataset (2018b) (labelled green bonds outstanding and issuance data), post-issuance and investor reports from the 53 institutions assessed in this study (green bond allocation data)

International bond volumes outstanding generally hovered around \$20 trillion, starting at a local low of \$19.1 trillion in 2008 and peaking at over \$21.1 trillion by the fourth quarter of 2017. The volume of green bonds outstanding began at \$230 million in 2010 and rose sharply from around \$2.1 billion in 2013 to roughly \$98.5 billion by 2017 (as of Q3 2018) (CBI, 2018b). The latter growth represents a notable 4,590% increase over four years. Annual green bond issuances showed similar patterns, experiencing a nearly 8,150% increase from just over \$1.2 billion in 2011 to just under \$99 billion by 2017. Overall, the total volume of green bonds outstanding during this period amounted to over \$215 billion, accounting for a small percentage (0.01%) of all international bonds outstanding as of 2017 alone. In the absence of any radical upswings or downturns in international bond markets, sustained upscaling of green bonds by these magnitudes (e.g. thousand-fold increases) could make them account for more substantial proportions of international bond issuances and volumes outstanding in the years to come.

Figure 3.4.1 also displays shifts in the amounts of reported proceeds allocations from green bond issuers, as well as the volume of those allocations that were reported alongside environmental impacts. Note that the latter are a subset of the former and are therefore not stacked. Years where these allocations outstrip total labelled green bond issuances (e.g. in 2008, 2009, and 2011) depict cases where either 1) proceeds from previous year issuances were carried over and applied in subsequent years, surpassing the volume of issuances in the latter (as took place in all three years) or 2) allocations to projects or assets were listed alongside green bond allocations in reporting sources and may have been financed by unlabelled green bonds or some other unspecified finance mechanism in conjunction with later green bonds (as took place in 2008 and 2009). Outside of these few exceptional cases, proceeds allocations resulted from CBI-recognized, labelled bond issuances.

The earliest allocations, including those reported with environmental impact estimates, were from the World Bank International Bank for Reconstruction and Development (IBRD) in 2008. Over time, allocation and impact reporting increased and became more thorough, especially among particular institutions. Similar to the growth of total green bond issuance and amounts outstanding, reported allocations increased abruptly from 2013 onward, rising from \$2.3 billion to roughly \$17 billion by 2016. To a substantial yet lesser degree, allocations with reported environmental impacts also increased, surpassing \$9.4 billion in 2016 after barely exceeding \$2 billion in 2013. While the specifics of where these green bond proceeds were allocated are evaluated in subsequent sections, one key take away from Figure 3.4.1 is that there has been a massive gap between green bonds market growth (i.e. in issuances and outstanding) and reported proceeds allocations. In the long run, this could run counter to the aim of bolstering the eco-friendly image of green bonds and potentially result in missed opportunities attract broader institutional investor bases.

3.4.2. Comparative magnitudes among category-specific proceeds allocations

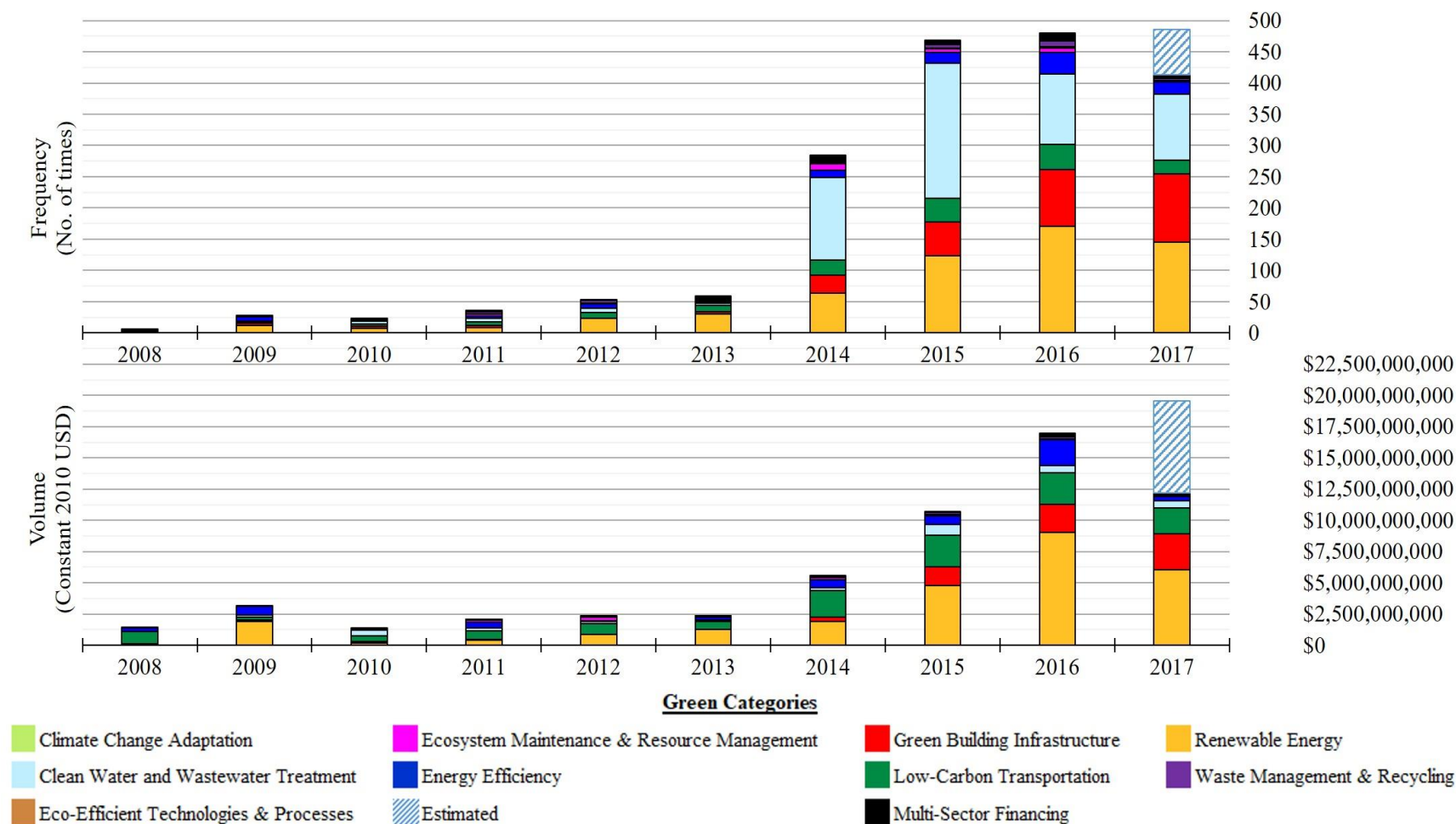
Drawing connections between green bond issuances and eventual environmental outcomes presents multiple challenges. To begin with, green bond proceeds earmarked at issuance may only reflect *intended* uses without guaranteeing allocations to specific undertakings with predetermined green impacts. Furthermore, many issuers earmark proceeds for a variety of project or asset types (e.g. clean energy, transportation, or water infrastructure, etc.) within a single issuance, adding complexity to a priori funding estimates for each recipient investment. The first step in assessing the linkages between green bond issuances and the environmental

impacts attributable to financed projects, therefore, is to evaluate the actual magnitudes of proceeds allocations to specific green sectors.

Figure 3.4.2 reveals the annual trends in both the frequencies and volumes of green bond proceeds allocated to multiple green categories. Note that the total allocation volumes correspond to the “Green Bond Allocations” volumes depicted in Figure 3.4.1, with 2017-year estimations added to account yet unpublished reporting data as of the assessment period of this study. Green categories were created with dual consideration of the ICMA Green Bond Principles (2017) and the CBI Climate Bond Taxonomy (2018a). Listed alphabetically, they include “Clean Water & Wastewater Treatment,” “Climate Change Adaptation,” “Eco-Efficient Technologies & Processes,” “Ecosystem & Resource Management,” “Energy Efficiency,” “Green Building Infrastructure,” “Low-Carbon Transportation,” “Multi-Sector Financing,” “Renewable Energy,” and “Waste Management & Recycling.”

Allocations between 2008 and 2012 were few in number and small in magnitude, generally remaining under \$2.5 million through less than 50 disbursements per year. Thenceforth, they surged beyond \$16 billion through over 450 disbursements per year by 2016. While allocation frequencies leveled off from 2015 onward, volumes continued to rise. This discrepancy between frequency and volumes suggests institutions provided larger volumes per allocation, which is sensible in the backdrop of the more than thousand-fold expansions of the green bonds issuances and volumes outstanding depicted in Figure 3.4.1. More generally, rising proceeds allocations coincided with the labelled green bond market expansion that was catalyzed by the establishment of the GBP in 2014 (Ehlers and Packer 2017). A broad array of additional factors also helped to propel the expansion of the labelled green bond market, including the 1) application of diverse bond instruments, 2) establishment of country- level green bond guidelines

Figure 3.4.2: Category-specific green bond proceeds allocation volumes and frequencies, 2008 to 2017.



Source: Created by author based on post-issuance and investor reports of the 53 institutions assessed in this analysis

that drive national (sovereign) issuances in a growing number of countries, 3) precedents set by supranational development banks as market leaders of best practices, and 4) increasing utilization of transparency-inducing external reviews (CBI, 2017a).

There were substantial differences in the proceeds allocated to each green category. “Renewable Energy” and “Clean Water and Wastewater Treatment” each received the largest, roughly 32% shares of the total number of allocations. Allocations to the former surged from 7 in 2008 to 171 by 2016, largely reflecting the increasing role played by IFIs in clean energy finance schemes throughout developing countries. Allocations to the latter, which rose from 2 in 2009 to surpass 216 through 2015, mainly reflect recent (2014 to 2017-year) municipal bond financing of local water authorities in the United States (as the U.S. municipal green bond market issuance surged from roughly \$3 billion to roughly \$10 billion over the same period) (Chiang, 2017). Other notable increases included the number of allocations to “Green Building Infrastructure,” “Low-Carbon Transportation,” and “Energy Efficiency” categories. The first peaked at 109 instances by 2017, while the latter two respectively peaked at 40 and 35 instances by 2016.

By allocation volume, the trends were similar. The \$26.7 billion provided to “Renewable Energy” accounts for nearly half of the total allocations. “Green Building Infrastructure,” “Low-Carbon Transportation,” and “Energy Efficiency” also received substantial volumes that increased over time. Specifically, allocations to the first of these grew from just over \$107 million in 2009 to peak at over \$2.8 billion by 2017. Over the same period, allocations to the second grew from \$946 million in 2008 to peak at over \$2.5 billion by 2016, while allocations to the third grew from just over \$9 million to peak at over \$684 million by 2015.

By contrast, the “Climate Change Adaptation”, “Eco-Efficient Technologies & Processes,” “Ecosystem Preservation & Resource Management,” “Multi-Sector Financing,” and

“Waste Management & Recycling” categories received far fewer allocations by both volume and frequency. Indeed, few of their yearly allocations surpassed 10 in number or millions of USD in volume, and total allocations for each remained well within a comparatively lower threshold of \$1 billion over 50 allocations. A few key factors help to explain these developments.

First, GHG emissions reductions are long-established, priority objectives among environmental policies, so it is reasonable that “Renewable Energy,” “Low-Carbon Transportation,” and other categories with measureable mitigation effects would receive comparatively greater shares of proceeds. As an example, SDG 13 (“Climate action”) calls for \$100 billion in yearly contributions by 2020 to affect GHG emission reductions throughout developing countries, while GHG emissions reduction targets ranging from 25% to 40% are common among Paris Agreement NDCs (UN, 2015; UNFCCC, 2019b). The fact that energy accounts for roughly 60% of global greenhouse gas emissions (UNDP, 2019) likely underlies the large magnitude of allocations to the “Renewable Energy” category in particular.

At the same time, a lack of investor familiarity and other investment barriers may have resulted in substantially smaller allocations to the other categories. Despite their green alignment, issues with government support (e.g. lack of long-term political commitment, regulatory instability), investor capability (e.g. regulatory barriers, lack of sector expertise, short-term mindsets), and investment conditions (e.g. lack of appropriate investment mechanisms, shortage on infrastructure data, lack of transparency and negative perceptions of infrastructure value) among the many traditional obstacles to institutional investors’ infrastructure allocations (Kaminker & Stewart, 2012) likely influenced the degree to which proceeds were applied to the more recently developed, rather unconventional categories (such as “Ecosystem Preservation & Resource Management”). Ultimately, however, divergences in categorical allocations imply the

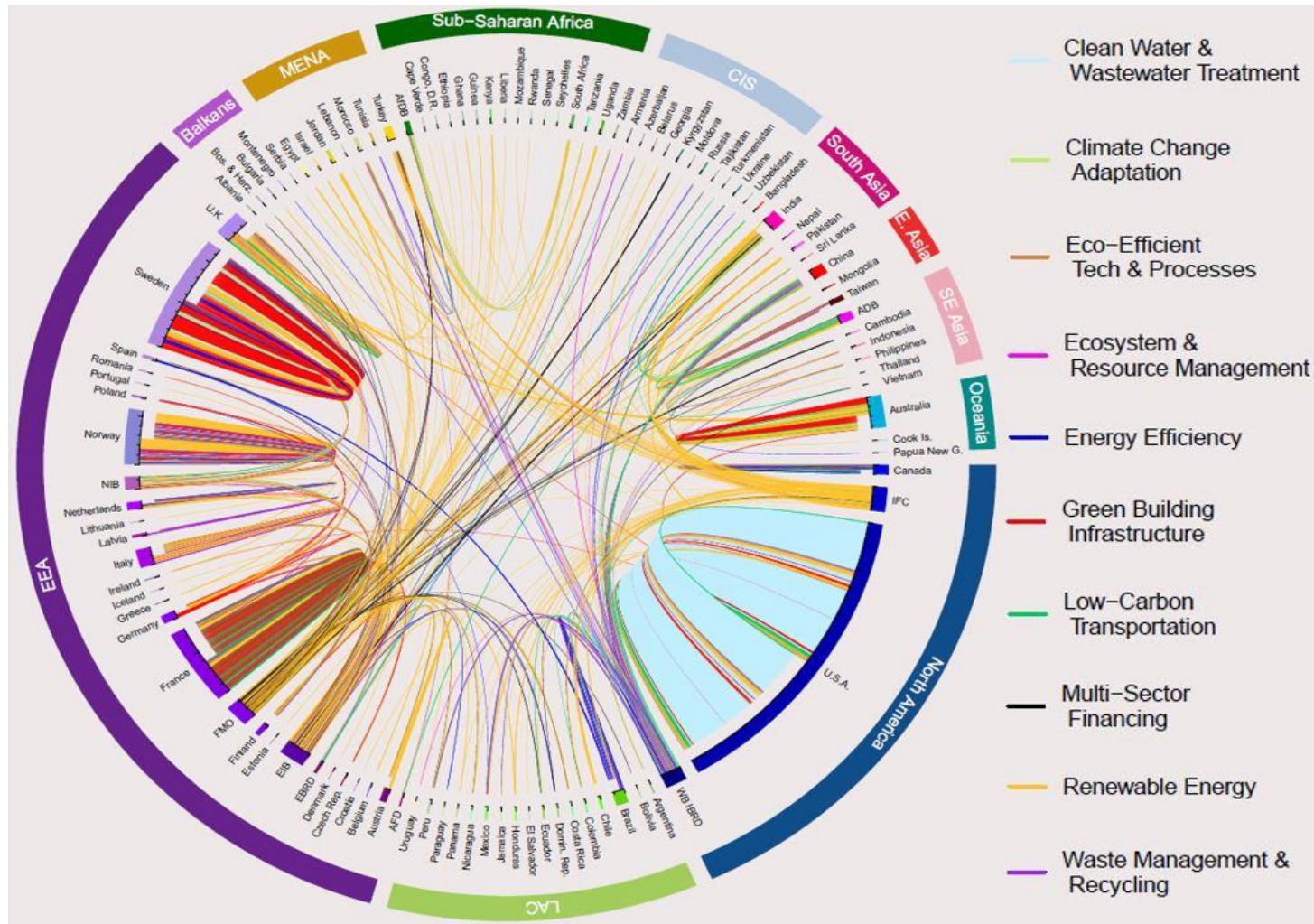
existence of policy-driven green bond allocation priorities (e.g. to reduce GHG emissions). Moreover, growing allocation trends across green categories suggests there is potential to apply greater magnitudes of proceeds in the future to finance a broader base of green categories.

3.4.3. Geographic distribution of reported proceeds allocations

The majority of all green bond listing and trading takes place in the Börse Frankfurt, Luxembourg Stock Exchange, Borsa Italiana, China Interbank, London Stock Exchange, Euronext Paris, SGX (Singapore), Shanghai Stock Exchange, Nasdaq Stockholm, and Nasdaq Oslo international exchanges (Environmental Finance, 2019). With issuances and allocations occurring across national borders, it can be difficult distinguish where green bond finance originates (i.e. the green bond issuing institutions) from where it is applied (i.e. the underlying green projects and assets). This section assesses both the geographic distribution of proceeds allocations to specific green sectors and the prominent institutions and supportive policies of each locale. Then, section 4.4 reveals the cumulative environmental impact estimates associated with the proceeds-recipient projects and assets. Together, these results shed light on the extent to which projects and assets fully or partially financed with green bonds are conducive to SDG and Paris Agreement policy objectives.

Figure 3.4.3 provides a bird's-eye view of green bond proceeds flows from issuing organizations to recipient projects. Nine international finance institutions (IFIs) are listed alongside 96 countries within the region of their domicile. Each listing is color coded using shades of the 11 region colors on the outer circumference. Line segments in the plot center depict

Figure 3.4.3: Global green bond proceeds flows, 2008 – 2017.



1,851 proceeds allocations are categorically color-coded. Abbreviations include the Balkan Peninsula (Balkans), the Commonwealth of Independent States (CIS), East Asia (E. Asia), the European Economic Area (EEA), Latin America and the Caribbean (LAC), the Middle East and North Africa (MENA), and Southeast Asia (SE Asia).

Source: Created by authors based on post-issuance and investor reports of the 53 institutions assessed in this study

proceeds allocations, originating from points that directly touch country labels on the inner circumference (i.e. the domicile of issuing organizations) and ending at points slightly separated from country labels at line segment termini (i.e. the location of recipient projects or assets). Additionally, line segments are color coded according to the green categories of the projects or assets financed, as listed in the figure.

Prominent trends include 1) interregional allocations from IFIs to “Renewable Energy”; 2) allocations to a diverse array of green categories throughout the greater European Economic Area (EEA); 3) high-frequency allocations to “Clean Water and Wastewater Treatment” in North America; and 4) comparatively greater allocations to BRICS (Brazil, Russia, India, China, and South Africa) countries among developing regions.

3.4.3.1. *International finance institutions (IFIs)*

Due to their regular advisory roles and expert knowledge of market policies and regulations, many of the development finance institutions among the IFIs of this study have led sustainable development investing in low-income countries (Clark *et al.*, 2018). Similarly, since the 2012 United Nations Conference on Sustainable Development in Rio de Janeiro, many supranational development banks have spearheaded the call to invest 2% of global GDP into greening ten key sectors of the economy (agriculture, buildings, energy supply, fisheries, forestry, energy efficiency, tourism, transport, waste management, and water). In line with this, each demonstrated steadfast commitments to GHG emission reductions, renewable energy capacity building, and other environmental policy targets. Of the overwhelming majority of green bond proceeds between 2008 and 2017 that were allocated to the “Renewable Energy” category, IFIs provided the largest shares to both developed and developing countries. As

referenced in many post-issuance reports, green bonds were valuable tools within IFI climate change and sustainable development finance initiatives.

For example, in accordance with its Strategic Framework for Development and Climate Change, the World Bank has issued over \$13 billion in green bonds since 2008 to raise funds for mitigating and adapting to climate change. In the scope of this study, the World Bank IBRD allocated over \$6.3 billion to 15 renewable energy projects across 7 regions and 8 countries. Similarly, under its Climate Action Strategy, the European Investment Bank (EIB) commits a minimum of 25% of its total investments to climate change mitigation and adaptation. Since 2007, it has issued over €15 billion in Climate Awareness Bonds (CABs) with nearly \$5.2 billion in proceeds allocated 74 times to renewable energy projects across 5 regions and 24 countries. As with these cases, each of the other IFIs assessed in this study developed similar policy directives that drove their green bond allocations to renewable energy investments.

3.4.3.2. The European Economic Area (EEA)

With 63 binding and 68 non-binding European Union (EU) environmental targets established for the present through 2050 (EEA, 2013), regional frameworks such as the EU 20-20-20 targets steer Europe towards a 20% reduction in total greenhouse gas emissions, a 20% increase in energy efficiency by 2020, and a 20% share of renewables in total energy consumption (EEA, 2016). They also establish precedent for the EU NDC of 40% domestic reductions of 1990-level emissions by 2030 (UNFCCC, 2019b). Each of these policies, in addition to the recent adoption of the European Commission Action Plan on Financing Sustainable Growth, demonstrate expanding NDC and SDG orientations throughout the region.

Moreover, a number of local and national policies provided supportive backdrops for burgeoning green bond market activities.

Overall, the European Economic Area (EEA) received \$25.2 billion over 729 green bond proceeds allocations, making it the largest recipient region. Of this, Sweden, Norway, and France received the largest shares, and the majority these went to the “Renewable Energy,” “Green Building Infrastructure,” and “Low-Carbon Transportation” categories. In the case of Sweden, its National Strategy for Sustainable Regional Growth and Attractiveness 2015 – 2020 targets demographic development, climate, environment, energy, and social cohesion as the core challenges of its national development (Ministry of Enterprise and Innovation of Sweden 2016). Conducive to many of these pursuits, green bond issuers provided \$5.1 billion through 246 allocations to “Green Building Infrastructure” and “Renewable Energy.” The Kommuninvest government agency was the largest financier of both categories, allocating \$994 million over 83 instances to the former and \$817 million over 36 instances to the latter.

As the first country to form a cabinet-level ministry for environmental regulations in 1972, Norway is a climate and sustainable development forerunner with extensive eco-friendly legal precedents. As of June, 2017, its Law on Climate Goals expanded the Norwegian commitment to the EU NDCs to include an 80% to 95% reduction in 1990-level greenhouse gas emissions by 2050 (Ministry of Climate and Environment of Norway, 2017). Of the \$2.5 billion in proceeds allocated to Norway over 117 instances, “Renewable Energy” and “Green Building Infrastructure” received the largest shares. Among prominent issuers, the Bergenshalvøens Kommunale Kraftselskap (BKK) state-backed power company provided \$588 million over 53 instances to “Renewable Energy” while the Kommunalbanken Norway (KBN) government

agency contributed more than \$471 million through 24 allocations to “Green Building Infrastructure.”

France obtained \$3.2 billion in proceeds over 163 allocations. Of this, “Green Building Infrastructure” and “Low-Carbon Transportation,” both received \$1.2 billion, with 73 and 52 respective allocations to each. The largest allocator was the Île-de-France regional government, which applied over \$1.6 billion across multiple green categories in accordance with its SDG-aligned regional development plan. Additionally, the City of Paris disbursed over \$261 million to 7 domestic tram, cycle path, and electric vehicle projects in accordance with its Paris Climate Action Plan (2018). The Plan calls for 1) a 75% reduction of greenhouse gas emissions compared to 2004 levels by 2050, 2) a 25% reduction of greenhouse gas emissions compared to 2004 levels by 2020, 3) a 25% reduction in energy consumption compared to 2004 levels by 2020, 4) a 25% portion of the total energy mix made up of renewable energy or energy, and 5) adapting Paris to climate change and resource scarcity.

3.4.3.3. North America

North America received \$13 billion in green bond proceeds through 634 allocations, making it the second largest recipient region. Canada’s NDC commitments include a 30% reduction of GHG emissions (UNFCCC, 2019b), and its Pan-Canadian Framework on Clean Growth and Climate Change promotes carbon pollution pricing, climate change resilience and clean technology innovation investments, and GHG emissions reductions to under 523 megatonnes (Mt) by 2030 (Government of Canada, 2017). The United States tells a different story. On the one hand, the recent repeal of many federal environmental policies (e.g. the Climate Action Plan, the Clean Water Rule, and the Clean Power Plan) and planned withdrawal

from the Paris Agreement (and its 26% to 28% emissions reduction NDC) (UNFCCC, 2019b) mark a distinct shift away from previous climate-related commitments. On the other hand, many state government members of the United States Climate Alliance vow to pursue Paris objectives through statewide policy coordination, and growing support for the Green New Deal stimulus program stands to realign U.S. economic planning, industrial policy, and infrastructure investments with SDGs and existing U.S. NDCs.

Of the total allocations to the region, \$11 billion was disbursed 614 times to the U.S. Figure 3.4.3 highlights the \$1.5 billion in provided via 536 allocations to “Clean Water and Wastewater Treatment.” Major allocators included the New York State Environmental Facilities Corporation and the State of Connecticut Department of Energy and Environmental Protection. From 2014 to 2016, the former committed \$780 million through 286 allocations to its Clean Water and Drinking Water State Revolving Fund (CW and DW SRF) projects, while from 2015 to 2017, the latter committed \$461 million through 202 allocations to its own CW SRF projects. In both cases, SRFs provided market-rate or below market-rate financing for public health-related water projects that adhere to the Environmental Protection Agency’s Clean Water Act. Over the long run, the green impacts of the wastewater treatment, pump station, waterline, sewer, lake restoration, and drinking water projects funded with these proceeds will likely indicate progress towards SDG 6 (“Clean water and sanitation”) and other sustainability objectives.

3.4.3.4. Developing regions

The final major trend relates to the \$17.3 billion in proceeds provided over 426 instances to the developing regions of the Balkan Peninsula, the Commonwealth of Independent States (CIS), multiple segments of Africa and Asia, and Latin America and the Caribbean (LAC).

BRICS countries received comparatively higher shares of proceeds than their regional counterparts. This includes 1) \$640 million over 9 allocations to Brazil, 2) \$297 million over 5 allocations to Russia, 3) \$2.7 billion over 52 allocations to India, 4) \$2.9 billion over 44 allocations to China, and 5) \$359 million over 10 allocations to South Africa. Each with NDCs that aim to make non-fossil fuel based energy account for at least 40% of their national energy mixes by 2030, Brazil and India were the only two developing nations in this study that received allocations from domestic institutions. Of these, BRF S.A. of Brazil should be noted for providing some of the most thorough post-issuance reporting out of all the non-IFI institutions examined in this study (including estimates of sustainable forest management, waste reductions, and water recycling).

The \$2.9 billion provided through 44 disbursements to China represents the most diverse proceeds allocations among all of the developing nations. Specifically, over \$1 billion was allocated 16 times to “Low-Carbon Transportation,” over \$800 million was allocated 14 times to “Renewable Energy,” and the remaining \$1.2 billion was allocated to “Clean Water and Wastewater Treatment,” “Ecosystem and Resource Management,” “Energy Efficiency”, and “Waste Management and Recycling” categories. The majority of these funds flowed from the World Bank IBRD and aligned with China’s NDCs, which aim for a 1) 60% to 65% reduction of 2005-level CO₂ emissions by 2030, 2) a 25% increase in non-fossil fuel based energy consumption, and 3) a 4.5 billion cubic meter (m³) increase in forest stock (UNFCCC, 2019b). Multiple regulatory developments seemed to encourage the expansion of the Chinese green bond market, including the 1) the joint issuance of the Guidelines for Establishing the Green Financial System by seven ministerial agencies (including the People’s Bank of China and the Chinese

Ministry of Finance); 2) the establishment of pilot green finance zones in five provinces; and 3) the inclusion of green development in the Belt and Road Initiative (HKEX 2018).

3.4.4. Environmental impact estimates

There is an intricate overlap among many SDG and Paris NDC targets. Just as SDG 7 (“Affordable and clean energy”) calls for substantial increases in global energy efficiency and renewable energy, NDCs for over 60 countries commit their signatory countries to renewable energy capacity and generation increases through the 2020s. Similarly, while SDG 15 (“Life on land”) calls for the protection of terrestrial ecosystems, biodiversity, and land productivity, the NDCs of Belarus, Georgia, Burkina Faso, Chile, Lebanon, Vietnam, Bhutan, and Honduras each commit them to protecting or restoring forests and otherwise developing land in a sustainable manner (UN, 2015; UNFCCC, 2019b). Though many green bond issuers are SDG and NDC-conscious (or operate under the sovereignty of governments that are), to what were green bond allocations in line with SDG or NDC outcomes?

Overall, more than \$58 billion in proceeds was allocated 1,851 times by the 53 institutions included in this study (see Table 3A). Of this, 74% of the total allocation volume (\$43 billion) and 56% of the total number of allocations (1,041) of this study were reported alongside the estimated environmental impacts of proceeds-recipient projects. Though these estimates are not explicitly additional, they are nevertheless informative and are summarized in Table 3.4. About half (29) of the institutions in the study sample clearly articulated such green impact estimates. GHG emission reductions were the most consistently reported, and less consistently reported impacts (e.g. waste reduction and wastewater treatments volumes, etc.) were excluded from Table 3.4 due to general sparseness of data. Total annual GHG emission

reduction estimates surpassed 108 million tCO₂e. Green bond proceeds-recipient projects and assets were also estimated to provide net increases in renewable energy capacity, annual renewable energy generation, and annual energy savings of over 1.5 million megawatts (MW), over 57 million megawatt hours (MWh), and over 737 million MWh, respectively.

The results in Table 3.4 provide reveal key insights. First, it is clear that IFIs provided the bulk of environmentally impactful green bond finance. The two main factors underlying this are that these institutions have 1) each implemented initiatives that leverage green bonds within their greater financing schemes (e.g. the initiatives outlined in section 4.3.1); and 2) jointly contributed to establishing a harmonized framework for green bond post-issuance reporting (ICMA 2015) and greenhouse gas accounting (World Bank 2015). Next, although there was a lack data and reporting for impacts related to broad array of SDG and NDC targets, available GHG emission reduction and clean energy-related impact estimates highlight demonstrable (though not necessarily additional) contributions to overarching SDG and NDC policy targets. Expanding green bond market activities also allude to greater support of these policy objectives in years to come. Furthermore, the fact the majority of total reported allocations (e.g. those included in Table 3.4) generated unique impact information is a positive signal to potential environmentally-friendly investors. In many ways, green bonds did in fact “act as a feedback loop giving a degree of credibility to statements and promises that countries will achieve ‘such and such emissions reductions by such and such a date’” (Mathews *et al.* 2010).

3.5. Conclusions and policy implications

This paper investigated the extent to which green bond proceeds were allocated to projects and assets aligned with SDG and NDC-related environmental outcomes. It is evident

Table 3.4: Green bond proceeds allocations with reported environmental impact estimates

<u>Proceeds Allocation Details</u>				<u>Environmental Impact Estimates</u>			
Institutions	Years	Amount ¹	Frequency	Annual GHG emissions reduced/avoided (tCO ₂ e) ²	RE capacity added (MW) ³	Annual RE generation added (MWh) ⁴	Annual energy savings (MWh)
ABN AMRO	2015 - 2016	\$1,516,348,341	9	22,332		22,419	91,507
ASE	2015	\$279,403,821	10	114,000			
AfDB	2009, 2012 - 2016	\$988,349,554	18	3,207,161	302	841,280	277,676
ADB	2010 - 2016	\$1,404,080,121	35	10,618,300	3,173	9,903,720	4,276,632
Bank of America	2013 - 2016	\$1,365,025,154	16	1,531,800			
BRF S.A.	2016	\$8,343,574	16	7,545	900	49,200	42,608
City of Gothenburg	2013 - 2015	\$399,562,801	11	7,088		26,500	
City of Paris	2016	\$148,777,442	9	27,889	1		44,833
EBRD	2012 - 2013	\$177,089,604	6	199,060			
EIB	2016 - 2017	\$5,195,725,181	99	11,594,244	3,721	39,711	
Fortum Värme	2015	\$272,673,210	6	641,000			71,000
Groupe BPCE	2013 - 2016	\$143,985,312	15	282,365	220	428,822	
Hera S.P.A.	2008 - 2017	\$500,751,227	21	1,138,571		3,158,597	291,141
HSBC	2016	\$799,716,471	21	7,067,500	2,663		
Île-de-France	2014 - 2017	\$1,601,338,139	120	232,207		141	
IFC	2015 - 2017	\$3,144,251,904	101	8,456,329	3,842	10,193,347	638,397,712
KBN	2008 - 2016	\$1,694,585,748	63	40,789	348,000		148,657
Kommuninvest	2016 - 2017	\$2,107,885,659	146	514,944		2,058,640	137,104
NAB	2017	\$872,368,012	31	2,062,663			12,647,084
FMO	2011 - 2017	\$835,838,806	88	373,333	2,571	1,502	
NIB	2011, 2013 - 2017	\$2,377,744,037	53	616,800	1,174,736	3,416,000	
Ontario Financing Authority	2017	\$1,814,946,619	13	600,000			
Örebro Municipality	2014 - 2016	\$119,183,038	14	40,000	0.042	48	2,434
Regency Centers, L.P.	2017	\$219,768,683	9			201	5,907
Southern Company	2015 - 2017	\$2,837,581,787	11	6,643,136	1,657	8,991,370	
TD Bank	2015	\$524,768,641	7	16,195			26,781
TenneT Holding B.V.	2015 - 2017	\$5,043,550,771	8	7,460,000	6,156	14,160	
World Bank IBRD	2008 - 2016	\$7,473,235,366	83	42,939,116	3,781	18,158,260	80,810,670
Yes Bank	2015	\$86,479,944	2	2,300,000	132		
Total	2008 - 2017	\$43,953,358,968	1,041	108,754,366 tCO₂e	1,551,854 MW	57,303,917 MWh	737,235,746MWh

1 - Allocation amounts expressed in constant 2010 USD; 2 - Annual greenhouse gas (GHG) emission reductions measured in tonnes of carbon dioxide equivalent (tCO₂e); 3 - Renewable energy (RE) capacity added measured in megawatts (MW); 4 - Annual RE generation and energy savings measured in megawatt hours (MWh);

Source: Created by author based on post-issuance and investor reports of the 53 institutions assessed in this study

that green bond markets are expanding, and renewable energy and other projects that address high-priority GHG emissions reduction targets received greater proportions of green bond proceeds. While many IFIs provided detailed, consistent, up-to-date post-issuance assessments, other institutions often failed to publish reports that articulate environmental impact estimates of proceeds-recipient projects and assets. This not only obfuscates the marginal impact of proceeds on progress towards policy targets in key countries (especially BRICS economies with high climate and sustainable development investment needs), but also may lead to information gaps that undermine or fail to bolster investor confidence.

Importantly, many post-issuance reports also do not clearly identify the additionality of green bond impacts. This renders it difficult to derive the connections between SDG and NDC-oriented environmental outcomes and green bond finance vehicles. In order to address this issue and more effectively aid investors, financiers, and policymakers in environmental finance decision-making, future reporting should, as a rule of thumb, provide explicit, accurate, and transparent information regarding additional versus non-additional environmental impacts.

Moreover, current reporting often does not track a wider array of sustainability and climate metrics. While energy and greenhouse gas-related measurements are more routinely provided, those pertaining to water and wastewater systems, waste management and recycling, ecosystem preservation, sustainable forest management, and other aspects pertinent to multiple SDGs and climate change adaptation objectives of the Paris Agreement are lacking. At a time when explicit adaptation criteria are needed to measure country-level progress and guide international discourse (Magnan & Ribera, 2016), forthcoming reporting should include a broader spectrum of impact criteria. This would lay the groundwork for the universal environmental standards crucial to investors in assessing the green risks of their investment

portfolios (Clapp *et al.*, 2015). Improved impact reporting thus would make green investment opportunities more identifiable, thereby expanding the transnational, green-conscience investor bases needed to achieve the SDGs by 2030 (Vorosmarty *et al.*, 2018).

Finally, recent reporting suggests that current proceeds allocation trends are insufficient for addressing the pressing, global investment challenges of the 21st century. For example, investing \$26 billion to renewable energy over nine-year time periods (as occurred with green bonds in the scope of this study) would stop short of the “\$53 trillion by 2035” energy investment directive of the IEA (2014). In the meantime, should global GDP continue to grow at up to 3.9% per year (as it did in 2018), the environmental benefits generated by recent green bond investments would provide only minor contributions to what would be needed to curb the effects of the roughly 37 gigatonnes (Gt) of CO₂ emissions estimated to result from such growth (Jackson *et al.*, 2015). This shortfall is exacerbated by recent projections that by 2020, overlooked “damage and loss” costs of climate change could reach \$50 billion per year (Nature Climate Change, 2017). Thus, it is clear that a drastic scaling up in green bond financing, in conjunction with substantially greater applications of other environmental finance mechanisms, will be required to address a potentially broadening scope of SDG and Paris Agreement investments. Nevertheless, the rate at which green bond proceeds allocations are growing suggests that they are gaining prominence within the broader context of environmental finance and still stand as viable financing instruments for advancing the outcomes of both agendas.

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Appendix 3A

Since the first European Investment Bank (EIB) Climate Awareness Bond in 2007, the green bond market has expanded to include some \$895 billion outstanding among 3,493 labelled (e.g. earmarked for green projects or assets) and unlabelled (e.g. conceptually aligned with low-carbon initiatives) bonds from 1,128 issuers by 2017 (CBI, 2017a). Common varieties include corporate and SSA (sovereign, supranational, and agency) bonds, project bonds, asset-backed securities, and financial bonds, while prominent issuers include financial and non-financial corporations, national and local governments, international finance institutions, government agencies, and state-backed entities. As with conventional bonds, green bonds can be classified depending upon their uses, debt recourse and other unique features. Table 3A provides a detailed list of the aforementioned 53 impact-reporting issuers assessed in this study and the frequency and volumes of their respective proceeds allocations

Table 3A: Green bond allocating institutions

Institutions (#)	Domicile		Allocations		
	Region (#)	Country (#)	Period	Frequency ^a	Volume ^b
Corporation: Financial Institutions (9)	(4)	(8)	2013 - 2017	158	\$9,787,385,637
ABN AMRO	European Economic Area	Netherlands	2015 - 2016	9	\$1,516,348,341
Bank of America	North America	United States	2013 - 2017	18	\$1,456,573,196
Berlin Hyp AG	European Economic Area	Germany	2017	15	\$546,781,391
Groupe BPCE	European Economic Area	France	2013 - 2016	15	\$143,985,312
HSBC	European Economic Area	United Kingdom	2016 - 2017	40	\$1,333,598,233
National Australia Bank (NAB)	Oceania	Australia	2015, 2017	48	\$1,557,443,652
Toronto Dominion (TD) Bank	North America	Canada	2015	7	\$524,768,641
Toyota Motor Credit Corporation	North America	United States	2014 - 2016	3	\$2,605,619,951
Yes Bank	South Asia	India	2015, 2017	3	\$102,266,921
Corporation: Non-Financial Institutions (12)	(5)	(7)	2014 - 2017	125	\$6,544,946,538
Abengoa Greenfield, S.A.	European Economic Area	Spain	2014	7	\$607,610,584
Advanced Semiconductor Engineering (ASE)	East Asia	Taiwan	2015	10	\$279,403,821
Belectric GmbH	European Economic Area	United Kingdom	2014 - 2015	4	\$21,933,970
BRF S.A.	Latin America and Caribbean	Brazil	2016	16	\$8,343,574
Digital Realty Trust, Inc.	North America	United States	2016	9	\$447,958,934
Fastighets AB Förvaltaren	European Economic Area	Sweden	2015-2016	4	\$74,480,028
NRG Yield, Inc.	North America	United States	2014	1	\$460,545,389
Regency Centers, L.P.	North America	United States	2017	9	\$219,768,683
Southern Company	North America	United States	2015 - 2017	11	\$2,837,581,787
Stångåstaden AB	European Economic Area	Sweden	2015 - 2017	16	\$146,876,611
Stockland Trust Management Ltd.	Oceania	Australia	2015 - 2017	24	\$888,040,999
Vasakronan	European Economic Area	Sweden	2016	14	\$552,402,157
Government Agencies (6)	(2)	(4)	2008 - 2017	286	\$6,258,303,853
Central Puget Sound Transit Authority	North America	United States	2015 - 2016	15	\$1,386,311,716
Kommunalbanken Norway (KBN)	European Economic Area	Norway	2008 - 2016	63	\$1,694,585,748
Kommuninvest	European Economic Area	Sweden	2016 - 2017	146	\$2,107,885,659
Overseas Private Investment Corporation (OPIC)	North America	United States	2014 - 2016	13	\$274,329,689
San Francisco Public Utilities	North America	United States	2015 - 2016	44	\$302,582,033
Transport for London (TfL)	European Economic Area	United Kingdom	2016	5	\$492,609,007
International Finance Institutions (9)	(4)	(8)	2008 - 2017	500	\$22,859,963,043
African Development Bank (AfDB)	Sub-Saharan Africa	Côte d'Ivoire	2009 - 2016	20	\$1,020,240,560
Agence Française de Développement (AFD)	European Economic Area	France	2011 - 2016	6	\$765,699,020
Asian Development Bank (ADB)	Southeast Asia	Philippines	2010 - 2016	35	\$1,404,080,121
European Bank for Reconstruction and Development (EBRD)	European Economic Area	United Kingdom	2008 - 2013	12	\$635,342,436
European Investment Bank (EIB)	European Economic Area	Luxembourg	2016 - 2017	99	\$5,195,725,181
International Finance Corporation (IFC)	North America	United States	2015 - 2017	101	\$3,144,251,904
Netherlands Development Finance Company (FMO)	European Economic Area	Netherlands	2009 - 2017	91	\$843,644,418
Nordic Investment Bank (NIB)	European Economic Area	Finland	2011 - 2017	53	\$2,377,744,037
World Bank International Bank for Reconstruction and Development (IBRD)	North America	United States	2008 - 2016	83	\$7,473,235,366
Municipal Governments (4)	(2)	(3)	2013 - 2016	52	\$1,009,118,439
City of Gothenburg	European Economic Area	Sweden	2013 - 2015	11	\$399,562,801
City of Paris	European Economic Area	France	2015 - 2016	15	\$261,068,890
City of Saint Paul, Minnesota	North America	United States	2016	7	\$2,807,225
Örebro Municipality	European Economic Area	Sweden	2014 - 2016	14	\$119,183,038
State or Provincial Governments (6)	(2)	(5)	2014 - 2017	634	\$4,987,341,655
Île-de-France	European Economic Area	France	2014 - 2017	120	\$1,601,338,139
New York State Environmental Facilities Corporation	North America	United States	2014 - 2016	289	\$834,102,853
Province of Ontario Financing Authority	North America	Canada	2017	13	\$1,814,946,619
State of California	North America	United States	2014	10	\$276,167,684
State of Connecticut Department of Energy and Environmental Protection	North America	United States	2015 - 2017	202	\$460,786,360
Stockholm County Council	European Economic Area	Sweden	2014 - 2015	5	\$226,496,485
State-Backed Enterprises (4)	(1)	(4)	2008 - 2017	79	\$1,589,856,539
Bergenshalvøens Kommunale Kraftselskap (BKK)	European Economic Area	Norway	2014 - 2017	43	\$346,795,743
Fortum Värme	European Economic Area	Sweden	2015	6	\$272,673,210
Hera S.P.A.	European Economic Area	Italy	2008 - 2010	21	\$500,751,227
Verbund AG	European Economic Area	Austria	2013 - 2015	9	\$469,636,360
State-Owned Enterprises (3)	(1)	(3)	2015 - 2017	17	\$5,198,814,826
Latvenergo	European Economic Area	Latvia	2015	6	\$102,158,676
TenneT Holding B.V.	European Economic Area	Netherlands	2015 - 2017	8	\$5,043,550,771
Uppsalahem AB	European Economic Area	Sweden	2016	3	\$53,105,379
53 Institutions	8 Regions	20 Countries	2008 - 2017	1851	\$58,235,730,531

a - Total number of green bond proceeds allocations; b - Total allocation volumes in constant 2010 USD;

Source: Created by author based on post-issuance and investor reports from the 53 institutions assessed in this study

Chapter 4: Green bond market drivers and implications for sustainability

In 2018, United Nations World Meteorological Organization data (2018) showed that the past two decades included 18 of the 20 warmest years since the earliest global temperature measurements in 1850. The following year, a record 197 billion tons of Greenland ice sheets melted in the month of July alone (Danish Meteorological Institute, 2019), and the Proceedings of the National Academy of Sciences of the United States of America found it plausible that accelerated polar ice melting could lead 21st century sea level rises to exceed 2 meters (Bamber et al., 2019). This estimate more than doubles that of Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and would result in the loss of 1.79 million square kilometers (km²) of land and the displacement of 187 million people (Bamber et al., 2019). The summer of 2019 also exhibited unprecedented, lightning-sparked wildfires in warmer-than-usual areas. The 648,000 and 140,000 hectare blazes across Alaska and Siberia, respectively, (NASA, 2019) illustrate the upswing of widespread burning even in high latitudes. These and other environmental phenomena invoke the stark warning to humanity issued in 2017 by 15,000 Alliance of World Scientists signatories from 184 countries, which stated that “To prevent widespread misery and catastrophic biodiversity loss, humanity must practice a more environmentally sustainable alternative to business as usual” (Ripple et al., 2017).

The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) is the premiere global policy accord that heeds this call to action. Specifically, it directs signatories to finance low-carbon development to keep 21st century global temperature rises within 2° Celsius (C) (UNFCCC, 2015). At the core of the agreement are Nationally Determined Contributions (NDCs), country-specific pledges to reduce greenhouse gas

(GHG) emissions and adapt to climate change in a sustainable manner. Prominent NDC target actions include implementing renewable and efficiency-enhancing energy technologies, preserving natural ecosystems, improving land use practices, upgrading water supply and management systems, and adopting other sustainability enhancing infrastructures and processes.

Though developed country signatories of the Paris Agreement plan to mobilize \$100 billion per year between 2020 and 2025 (UNFCCC, 2015), the International Energy Agency (2014) estimates that \$53 trillion in energy-related investments alone will be required by 2035 to achieve the 2° temperature target. Additionally, NDCs could require \$97 to \$191 billion by 2030 (Hof et al., 2017). A variety of finance mechanisms that leverage both public and private resources are thus crucial to channel global capital into Paris Agreement and NDC initiatives.

4.1. Green bonds for sustainability

In recent years, green bonds are gaining salience among the climate and sustainability finance schemes at the core of this international mobilization of capital. Many green bonds are certified by the Climate Bond Initiative (CBI), which confirms their alignment with Paris Agreement objectives and ensures their proceeds are earmarked to eco-friendly investments. Eco-friendly earmarking renders green bonds thematically appropriate and functionally useful in financing Paris Agreement objectives. Those issued alongside fossil fuel divestment are estimated to mitigate 4.7 gigatonnes of CO₂ emissions without affecting the 1.6% rise of gross domestic product (GDP) under a business as usual scenario (Glomsrød & Wei, 2018). This prediction is reasonable given recent green bond investment activities. For example, between 2008 and 2017, nearly \$58 billion (including \$26.7 billion for renewable energy projects) in green bond proceeds were allocated to assets responsible for 108 million tonnes of CO₂

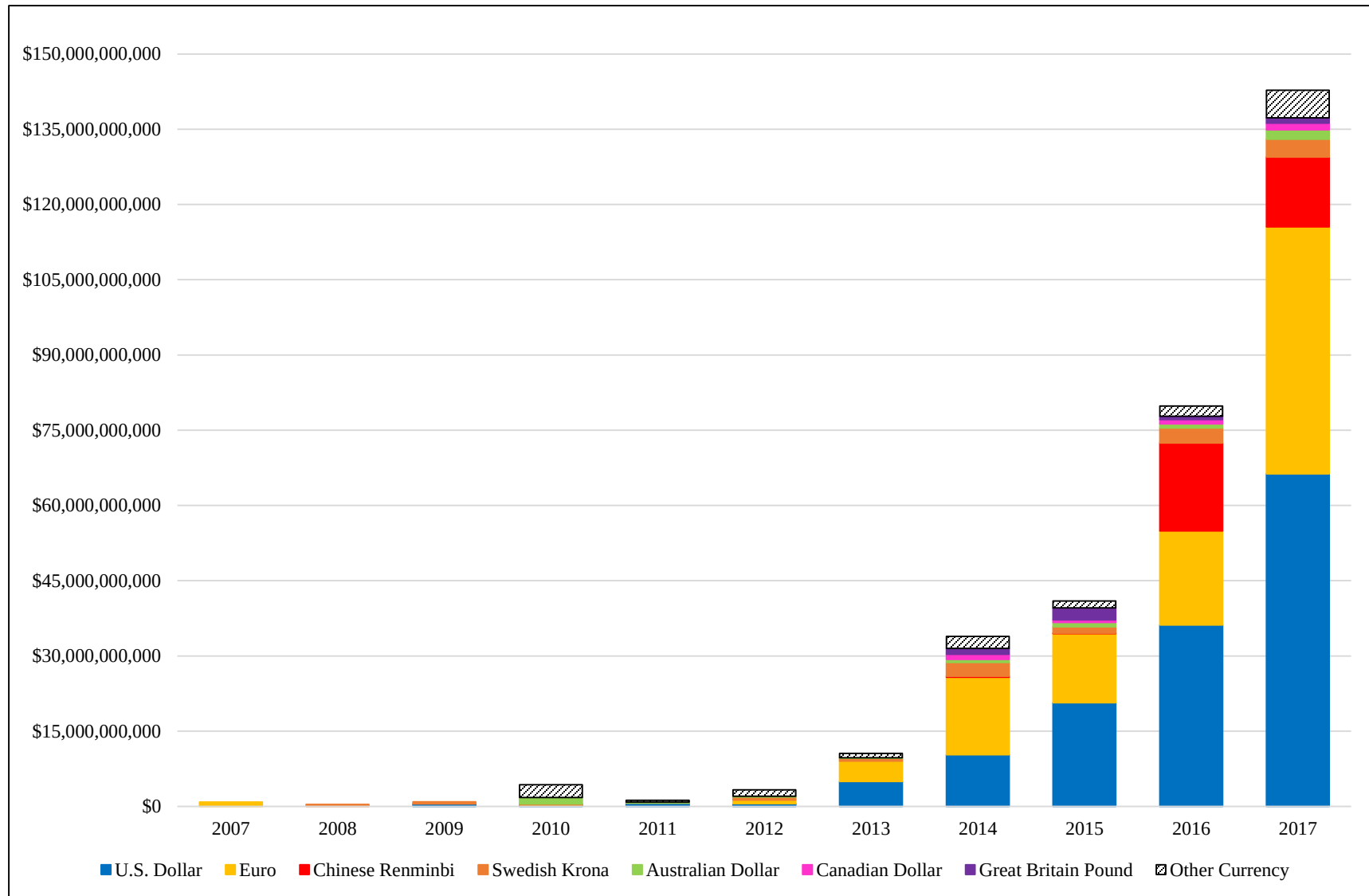
equivalent (tCO₂e) in GHG emissions reductions and over 1,500 gigawatts (GW) in renewable energy capacity (Tolliver et al., 2019). From these trends, it is clear that increasing volumes of capital are flowing into climate, sustainability, and cleaner production investments through green bond finance.

Since the inaugural €600 million (roughly \$848 million) Climate Awareness Bond issued by the European Investment Bank (EIB) in 2007, the volume of climate and green business-aligned bonds issued around the globe has expanded to include some \$1.45 trillion by 2018 (Climate Bonds Initiative, 2018a). Figure 4.1 shows green bond issuance trends by currency from 2007 through 2017. Due to their links to infrastructures that produce positive environmental outcomes, understanding the fundamental factors that promote green bond issuances is critical to advancing the global climate and sustainable development investment agenda. This paper therefore focuses on the drivers of green bond market growth.

Part of this rapid market expansion due to the ability for green bonds to bring the advantages of flexible payment schedules, credit enhancement techniques, alignment with long-term project schedules, leverage options, and other cost-reducing benefits of debt securities (Curley, 2014) to the realm of environmentally friendly investing. To municipal issuers, they are useful as supplements to budget shortages in capital-intensive infrastructure finance schemes (Clapp et al., 2015). Corporate issuers additionally benefit from the tendency of green corporate bonds to improve firm-level environmental footprints and financial performance (Flammer, 2018). Issuers in general also benefit from paying interest rates that end up lower than the costs of obtaining certification by the CBI (Gianfrate & Peri, 2019).

From the perspective of investors, the tax privileges, guarantees, and other benefits commonly attached to green bonds appeal to long-term interests of those seeking the hedge

Figure 4.1: Global green bond issuances by currency, 2007-2017



Source: Created by author using data from Climate Bonds Initiative Green Bonds Q3-2018 dataset (2018b)

against inflation, default, and market volatility (Veys, 2010). Moreover, labelling standards require post-issuance reporting that provides stakeholders throughout international capital (e.g. bond) markets with information about issuer sustainability that “is complementary to the development of a relatively more dynamic green financing system” (Ng, 2018). Finally, the myriad of positive environmental outcomes that green bonds are linked to appeal to a wide range of socially responsible investors (SRIs) and environmental profit-seeking investors, each aiming to line their portfolios with eco-friendly, fixed payment securities (Chatzitheodorou et al., 2019).

Despite the remarkable increase in issuance volumes over the past decade, green bond markets are still relatively nascent and substantially smaller than conventional (or “black”) bond markets. As such, there exists a gap in the experimental literature on the factors affecting green bond market growth. Since they are fundamentally another form of debt security, green bond issuances are likely driven by many of the same factors that drive conventional bond issuances. On the other hand, the fact that their proceeds are earmarked to eco-friendly assets suggests that green bond issuances are determined at least in part by climate and sustainability investment initiatives of the Paris Agreement. Especially in the years leading up to 2020, when countries will need to demonstrate measureable environmental improvements in accordance with their submitted Paris Agreement NDCs, the scale and scope of host country NDCs are likely behind the recent surge in issuance volumes throughout green bond markets. The objective of this portion of the Thesis, therefore, is to investigate the determinants of the green bond market growth depicted by growing issuance volumes. In doing so, this study is the first to quantify the relative robustness of NDCs of 49 developing and developed countries. It is also the first to measure the magnitude and significance of NDC and conventional capital market drivers behind growing green bond issuance volumes.

4.1.1. Barriers to green bond market growth

In 2016, two reports provided qualitative assessments of the impediments to green bond market growth. Addressing the Group of 20 (G20) Green Finance Study Group (GFSG), Jun et al. (2016) detailed eight major barriers to scaling up the size of green bond markets and nine potential options to eliminate such barriers. That same year, Cochu et al. identified five supply-side and five demand-side issues that cause development bottlenecks and eight solutions to those bottlenecks in their report for the European Commission. A list of the specific barriers and adaptive measures cited by each report are listed in Table 4A in the Appendix.

Major barriers that they noted in common included: (1) general bond market development challenges; (2) a lack of green bond definitions, frameworks, and guidelines; (3) a lack of existing green bonds with good credit ratings; (4) risk information asymmetries and an overall lack of market knowledge; and (5) a lack of identified bankable projects and green project pipelines. Suggested solutions provided by both reports included: (1) increasing green bond issuance and investment activity by national and local governments and multilateral development banks; (2) standardizing green bond definitions and labelling practices; (3) coordinating action between all green bond market actors, domestic and international; (4) providing credit enhancements, tax incentives, aggregation and securitization options, and other supply-side measures; and (5) reducing issuance, certification, reporting, and other administrative costs

As evidenced by this line of literature, there multiple systemic barriers to green bond market growth moving forward. In a departure from this type of *ex ante* assessment of remaining obstacles, this study provides an empirical, *ex post* analysis of the factors that have fostered the enabling environment for growing market capitalization in the first decade of green bond issuances. In this manner, this study extends beyond the developed country focus to include

factors affecting developing country market growth as well. Barrier (1) and solution (1) in the previous paragraph will therefore be of particular interest in a subsequent literature review of capital (e.g. green and conventional bond) market drivers.

4.1.2. Green bond premiums and price benchmarks

Much of the empirical literature on green bonds is devoted to measuring the magnitude of yield differences between green bonds and equivalent conventional bonds. Known as the green bond premium, such yield differences are often thought to reflect how markets price “greenness,” though studies show they are associated more with “sizeable excess demand” (Hyun et al., 2019). Regardless, eco-friendly earmarking of green bond proceeds must make issuer and investor demands match, and the extent to which this affects pricing (yields), liquidity, and volatility certainly matters to overall market growth. Though a lack of access to premium data represents a limitation of the analytical scope of this work, the effect of premiums on green bond market activity remains relevant to identifying their underlying growth drivers.

Ehlers and Packer (2017) compared the credit spreads of green and conventional bonds to find that although the former are priced at issuance premiums on average, they perform similar to conventional bonds in secondary markets. Karpf and Mandel (2018) compare yield curves, regressions of bond details, transactions, issuer creditworthiness, and U.S. Treasury bond rates, and Oaxaca-Blinder decomposition regressions for both green and conventional bond markets. They found that conventional bond returns are higher on average and that green bonds trade at lower prices and higher yields in municipal markets. Zerbib (2019) used a matching method to compare yield spreads between green and conventional bonds and subsequently performed two phases of regressions on green bond premiums, revealing green bond premiums are small and

negative for Euro and U.S. dollar- denominated bonds. Finally, Gianfrate and Peri (2019) used propensity score matching techniques to find that green labels do have a significant impact on bond pricing and that the negative premiums of green bonds issued by corporations make green bonds more convenient, *ceteris paribus*, than conventional bonds.

Additionally, a handful of studies compare green and conventional bonds through the lens of price benchmarks. Reboredo (2018) used copula model to measure co-volatility between green bond and financial markets to find that green bond markets and corporate and treasury bond markets are dependent while stock and energy commodity price swings have negligible effects on green bond prices. This allows green bonds to offer greater diversification benefits to investors in stock and energy markets than to those holding other bonds. Broadstock and Cheng (2019) identify (1) changes in financial market returns and volatility, (2) economic policy uncertainty, (3) daily economic activity, (4) oil prices, and (5) news sentiment towards green bonds as the macro-level factors that determine correlations between green and conventional bond price benchmarks. While this is evidence that macroeconomic conditions affect green bond market stabilization and development, there remains a need to “more closely examine the role of individual determinants in contributing to market expansion” (Broadstock & Cheng, 2019).

In light of this need, the following subsection provides an overview of leading theoretical and empirical finance literature on factors behind capital market growth in general. Variables consistently shown to have marked, significant impacts will be employed in the quantitative assessments in Section 5.

4.1.3. Macroeconomic determinants of bond market formation

Macroeconomic factors are some of the most influential determinants of bond market development. Most commonly, the size of the economy (represented by GDP) is a strong determinant of the capacity to issue bonds. This positive correlation could be the result of economies of scale, in which lending costs and associated risks would decrease as economies grow (Eichengreen & Luengnaruemitchai, 2004). Conversely, smaller economies are acknowledged as key causes of “original sin,” rendering it impossible borrow abroad in local currency (Eichengreen, Hausmann, & Panizza, 2002; Ozmen & Arinsoy, 2005). Moreover, the inability of smaller economies to issue bonds large enough to attract multinational companies and foreign investors, as well as the tendency for such small issuances to not be included in global bond market indices (Eichengreen & Luengnarumitchai, 2004; Mu et al., 2013), renders the size of the economy a critical component of bond and thus green bond issuance capacity. Other important factors related to the macroeconomic environment include stock market capitalization and the amount of trade openness. The former serves as a relevant indicator of overall capital market development (Bae, 2012) and can either compliment bond markets by providing alternative sources of external finance to companies, or compete with bond markets due to their less stringent regulations and comparative ease of raising funds (Raghavan & Sarwono, 2012). Regarding the latter, more open economies are less suppressive of securities markets because international competition limits the ability of banks and other entities with entrenched interests to effectively promote policies that run counter to supply competition (Rajan & Zingales, 2001).

4.1.4. Institutional determinants of capital market formation

Institutional and regulatory factors are also noted as substantial determinants of bond market development throughout previous literature. Indeed, some financial markets can be “underdeveloped because of the unreliability of contract enforcement and uncertainty of investor rights that are characteristic of less developed economies (Eichengreen & Luengnaruemitchai, 2004). Moreover, countries with greater institutional and regulatory quality are less affected by political pressure (Bae, 2012).

In addition to La Porta et al. (1998) and Adelegan and Radzewicz-Bak (2009), Essers et al. (2014) found such institutional factors as capital controls, regulatory quality, and rule of law to be strong determinants of bond market development. Lower capital controls entail openness to foreign portfolio investments. In turn, this enables greater access of foreign investors to domestic debt and incentivizes higher quality governance among local firms (Adelegan & Radzewicz-Bak, 2009). The quality of regulatory (e.g. bureaucratic) institutions largely affects investments, with “disclosure standards, penalties for accountants and auditors providing false information, and sanctions for insider trading and market manipulation” among the vital components of quality regulatory institutions and frameworks (Eichengreen & Luengnaruemitchai, 2004). Finally, with regard to rule of law countries with English legal system origins enable market-based financial systems (Demirgüç-Kunt & Levine, 1999) and promote financial market development (La Porta et al., 1998).

4.2. Methodology

This section outlines the analytical methods employed in this assessment phase of the Thesis. Specifically, the functions and objectives of exploratory factor analysis (EFA) and

structural equation modelling (SEM) methodologies are presented with references to preeminent studies behind the development of each methodology.

4.2.1. *Exploratory Factor Analysis (EFA) and hypothesis formulation*

Factor analysis is employed in a broad range of professional and scholastic disciplines and can take either the confirmatory factor analysis (CFA) or exploratory factor analysis (EFA) forms. CFA is employed to examine the explanatory power of hypotheses, while EFA is employed to test predictions in order to reduce complex patterns into simpler representations (Child, 2006). Aiming to group variable relationships under the umbrella of more general variables, the core of factor analysis includes an assumption that a limited number of underlying, latent factors can shed light on the covariances among a selected group of observed variables.

With the ultimate aim of curtailing “the limited dimensionality of the original space and to give the interpretation to the new space, spanned by a reduced number of new dimensions which are supposed to underlie the old ones,” (Rietveld & Van Hout, 1993) factor analysis can enables thorough assessments of available data by generating outputs that could possibly be incorporated into subsequent analyses. Specifically, the factor loadings produced represent correlations between latent factors and original variables. In turn, these loadings function as “classification axes along which measurement variables can be plotted,” depicting the “substantive importance of a particular variable to a factor” (Field, 2000). Thus factor loadings assist not only in labelling and assessing the most appropriate latent factors.

Mathematical models for factor analysis generally include p -number of variables ($X_1, X_1, \dots, X_p$) and m -number of latent factors ($F_1, F_2, \dots, F_m$). For any given variable X_j , observed

variables are assumed to be explained by a linear function of m latent factors and a residual, such that:

$$X_j = a_{j1}F_1 + a_{j2}F_2 + \cdots + a_{jm}F_m + e_j, \quad (4.1)$$

where $j = 1, 2, \dots, p$, and $a_{j1}, a_{j2}, \dots, a_{jm}$ are the factor loadings. In this case, a_{j1} represents the j th variable loading on the 1st factor, while e_j represents the unique factor (residual). As larger factor loadings denote greater impacts of a variable on a factor, they tend to reveal “how much [the] variable has contributed to the factor” (Harman, 1976). Calculations in factor analysis are computed using matrix algebra. Moreover, since they depict the magnitude and nature (e.g. positive or negative) or the relationships between variables, correlation coefficients provide the fundamental measurements of statistical importance.

The first step in factor analysis is to employ a model-fitting method to identify latent factors. From principal factor (PF) to principal components factor (PCF), iterated principal factor (IPF), and maximum likelihood (ML) estimations, each technique has unique benefits and drawbacks. In PF, the first m loadings are multiplied by the square root of their eigen value. Unhindered by the assumption of multivariate normality, the iterated principal factor method is less likely to produce improper solutions (Finch & West, 1997) Moreover, although it stands to generate highly correlated errors, it often matches the results of other model fitting methods in cases where there are 30 or more variables and their communalities are greater than 0.6 (Hair et al., 1998; Habing, 2003).

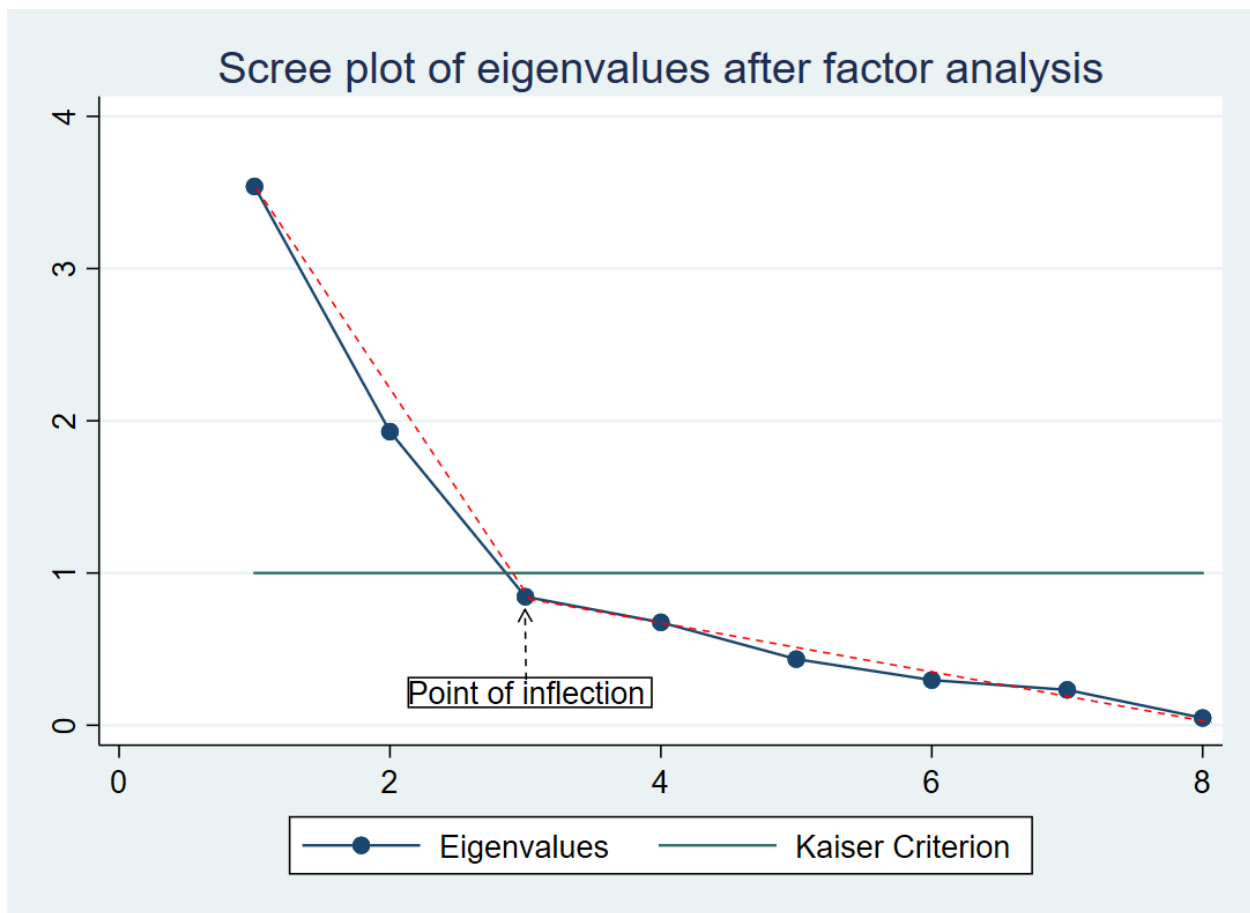
In PCF, the first m loadings are taken, and either “the absolute value of the maximum correlation of that variable with any of the others, the squared multiple correlation coefficient for predicting that variable from the others in multiple regression, and the corresponding diagonal

element from the inverse of the correlation matrix” are used to estimate initial communalities for each variable that replace diagonals in the correlation matrix (Habing, 2003). Next, IPF uses a fitted model to get more robust communality estimates using the PF method. One drawback is its failure tendency when the estimated communalities are greater than one and there are negative error variances (e.g. the Heywood case).

Finally, ML provides a wide range of fit indexes and “permits statistical significance testing of factor loadings and correlations among factors and the computation of confidence intervals for these parameters” (Cudeck & O’Dell, 1994), though on potential drawback is its multivariate normality assumption which may lead to distorted results if it is not upheld (Hu, Bentler, & Kano, 1992; Curran, West, & Finch, 1996). Ultimately, the appropriate method should be selected according to the data sample size and reliability, as well as the scope of research. Particularly, the communalities and error variance sizes, as well as (lack of) assumptions of multivariate normality, may render one preferable to others.

Upon specifying a model-fitting method, the number of factors to be retained in the model must be determined. This step is crucial because “extracting too many factors may present undesirable error variance by extracting too few factors might leave out valuable common variance.” (Yong & Pearce, 2013) One method for achieving this is the Hasamikomi method, which compares the Minimum Average Partial (MAP) test and parallel analyses to interpret the appropriate number of latent factors. (Hori, 2005) Based upon prevalence in existing literature, however, this study follows the Kaiser criterion, in which all factors above an eigenvalue of 1 are retained (Kaiser, 1960). Fundamentally, this criterion is based on the fact that the total of all eigenvalues is equivalent to the total number of items, and the larger the eigenvalue associated with a factor, the more the factor accounts for model variance. Importantly, the Kaiser criterion

Figure 4.2.1: Scree plot test for retaining factors after factor analysis



Source: Created by author

is judged as reliable when the averaged extracted communalities is greater than or equal to .70 in cases of 30 or fewer variables or when the averaged extracted communalities is greater than or equal to .60 when the sample size surpasses 250. (Field, 2009)

A scree test in which factors and eigenvalues are plotted can be used to validate the retained factors (Cattell, 1978). The number of data points above the point of inflection (where the slope of the plot levels off) of a scree plot determine the number of retained factors (as shown in Figure 4.2.1). Fitting for this analysis, the scree test is reliable when sample sizes exceed 200.

Once the number of latent factors is decided, the factors themselves are rotated. Specifically, this factor rotation process alters the factor loading patterns and allows for clearer interpretation of each manifest variable loading per factor. The utility of this process is in maximizing the number of high loadings per variable while minimizing the number of comparatively smaller factor loadings per variable (Rummel, 1970). Factors can be rotated in oblique and orthogonal methods, the former of which assumes correlation among factors and avoids performing a 90-degree rotation among them, and the latter of which assumes no correlation among factors and performs a 90-degree rotation among them. While orthogonal rotation “defines only uncorrelated patterns,” oblique rotation seeks the “best definition of uncorrelated and correlated cluster patterns of interrelated variables” and has “greater flexibility in searching out patterns regardless of their correlation” (Rummel, 1967). Beyond the direct oblimin (DO) technique, the promax oblique rotation is known to produce greater factor correlations and simple structures by raising factor loadings to the fourth power (Gorsuch, 1983). In its first step, promax rotation defines the target matrix derived from a varimax rotation, and in its second step, it computes a least square fit from the varimax solution to the target matrix (Abdi, 2003).

Though it is generally suggested that latent factors consist of a minimum of three manifest variables, (Anderson & Rubin, 1956; Comrey, 1988; Floyd & Widaman, 1995; Tabachnick & Fidell, 2007) depending upon the degree of correlation between manifest variables within the same and between other latent factors, there are cases where two manifest variables per factor could be appropriate (Yong & Pearce, 2013). In general, each variable should consist of at least five to ten observations (Comrey & Lee, 1992), and sample sizes of should be at least 300 because larger sample sizes diminish errors in the data (Yong & Pearce, 2013). Though this

is so, few strict rules regarding sample sizes remain as the nature of the data affects sample size adequacy (Fabrigar et al., 1999; MacCallum et al., 1999; Costello & Osborne, 2005).

Furthermore, data with “uniformly high communalities without cross loadings, plus several variables loading strongly on each factor” is considered to be “strong” (Costello & Osborne, 2005). This in turn affects factor communality cut-off line when determining the appropriate number of manifest variables within factors. Specifically, as is the rule of thumb, variables with factor loadings below a certain threshold number (e.g. cut-off line) are discarded. Though larger sample sizes allow smaller factor loadings to be considered significant (Pituch & Stevens, 2016), in general, previous studies suggest minimum factors from as low as 0.32 (Tabachnick & Fidell, 2007) to as high as 0.70 or greater (Fabrigar & Wegener, 2012).

Commonly reported indices for assessing model data suitability can be classified into absolute fit index and incremental fit index categories. Absolute fit indices “provide the most fundamental indication of how well the proposed theory fits the data” (Hooper *et al.*, 2008) without comparison to a baseline model and instead measures how well the model fits compared the complete absence of a model (Jöreskog & Sörbom, 1993). These include 1) the chi-squared (χ^2) test, which “assesses the magnitude of discrepancy between the sample and fitted covariances matrices” (Hu & Bentler, 1999), where $p \geq 0.05$ indicates good fit; 2) the goodness of fit index (GFI), which measures the similarity between the sample and model covariance matrices to calculate the proportion of variance the estimated population covariance accounts for, with values greater than 0.90 indicating better fit (Shevlin & Miles, 1998; Tabachnick & Fidell, 2007); 3) the root mean square error of approximation (RMSEA), which assesses how closely target models with unknown but optimal parameters estimates fit the populations of the baseline model, with values below 0.08 (MacCallum et al., 1996), 0.07 (Steiger, 2007), and 0.06 (Hu &

Bentler, 1999) commonly accepted in the literature as upper limits of values that represent acceptable model fit; and 4) the root mean square residual (RMR) and standardized root mean square residual (SRMR) which “are the square root of the differences between the residuals of the sample covariance matrix and the hypothesized covariance model” (Hooper et al., 2008), with upper limit of values that represent good model fit in the latter (more easily interpreted) of these ranging from 0.05 (Byrne, 1998; Diamantopoulos & Siguaw, 2000) to 0.08 (Hu & Bentler, 1999). By comparison, incremental fit indices compare the chi-square of a hypothesized model to the chi-square the baseline model, with a null hypothesis that all variables are uncorrelated (McDonald and Ho, 2002). Two varieties are 1) the normed fit index (NFI) that “assesses the fit of a model relative to the fit of a null model by scaling the chi-square value from 0 to 1” (Bentler & Bonett, 1980), with values greater than 0.90 (Bentler & Bonett, 1980) or (more recently) greater than or equal to 0.95 indicating a good fit (Hu and Bentler, 1999); and 2) the comparative fit index (CFI) that allows NFI assessments to be applied to small sample sizes (Tabachnick & Fidell, 2007), with values greater than 0.90 or even 0.95 considered to be the lower limit values that indicate good fit (Hu & Bentler, 1999).

In order to assess the fitness of the data employed in the model of this Thesis, the “Kaiser-Meyer-Olkin Measure of Sampling Adequacy” (KMO) is used to compare partial and observed correlation coefficients. Ranging from 0 to 1, KMO values greater than 0.50 considered suitable for factor analysis (Williams, Brown, & Onsman, 2010). Another test of data fit is “Bartlett’s Test of Sphericity,” which checks for redundancy between variables through comparisons of correlation and identity matrices (Snedecor & Cochran, 1989). Accordingly, it should show statistically significant values ($p < 0.05$) to ensure suitability for factor analysis.

Conventionally, explanatory factor analysis can be performed with a wide variety of econometric and statistical software (e.g. Eviews, SPSS). This study employs Stata. After extracting latent factors and their observable variables through EFA, they are used to construct a model for analysis in structural equation modeling. However, before the variables that are found to be statistically significant in EFA are employed in SEM analysis, model hypotheses are created based on the EFA factor loadings and implications derived from literature precedents. This serves three functions. First, because hypotheses are based on EFA factor loadings, they indicate observed variable groupings. Second, because hypotheses are based on previous studies, they indicate the direction of the arrows employed in the SEM model. Finally, due to both of these aspects, they provide an advance guideline for the overall model design.

4.2.2. *Structural Equation Modeling (SEM)*

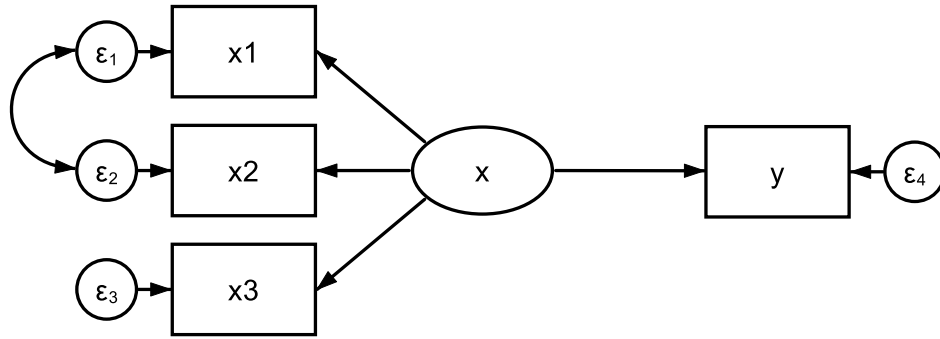
Suitable for both practical and complex, theoretical analysis, structural equation modeling (SEM) is a preferred method for studying the causal relationships and latent factors among variables (Cangur & Ercan, 2015). The ultimate aim of the method is “to understand the patterns of correlation/covariance among a set of variables and to explain as much of their variance as possible with the specified model” (Kline, 2015), while some of its advantages are that it “takes a confirmatory (i.e., hypothesis-testing) approach to the analysis of a structural theory bearing on some phenomenon” while specifying intervariable relationship patterns a priori (Byrne, 1998). Like multiple regression, “values of...coefficients are corrected for the presence of correlated predictors,” while the statistical interpretation and data screening techniques in SEM are the same or similar to those employed in multiple regression (Kline, 2015). Unlike regression analysis, however, SEM allows variable treated as dependent variables in one model equation to

be treated as independent variables in additional areas of the overall structural equation model (Bollen, 2009).

SEM measures the causal relationships both between endogenous and exogenous variables and among endogenous variables. Variables are further classified as 1) manifest (e.g. observed) variables that can be categorical, ordinal, or continuous and are included in the dataset, or 2) latent (e.g. unobserved) variables that are continuous and correspond to hypothetical constructs or factors such as those extracted from EFA. Path diagrams portray the causal pathways derived in SEM. Within these, rectangular nodes represent manifest variables, elliptical nodes represent latent variables, and circular nodes represent the error terms of each corresponding manifest variable. Straight arrows that connect the nodes depict direct effects from the exogenous variable at the arrow base to the endogenous variable at the arrow head. Furthermore, curved, double-headed arrows portray the covariances between the variables.

As an example, $s \rightarrow d$ represents an addition of β_{ks} to the linear equation for dependent variable d , where β_k is the path coefficient. An additional feature of SEM is that it can measure indirect effects from exogenous variables through intervening variables to endogenous variables (Kline, 2015). For example, the causal pathway through variable d_1 that measures the indirect effects of s on d_2 would be depicted by the $s \rightarrow d_1 \rightarrow d_2$ path diagram. Figure 4.2.2 depicts a standard SEM path diagram:

Figure 4.2.2: Standard structural equation model path diagram



Source: Created by author

The above path diagram can also be expressed using the following equation:

$$x_1 = \alpha_1 + \beta_1 X + \varepsilon_1 \quad (4.2)$$

$$x_2 = \alpha_2 + \beta_2 X + \varepsilon_2$$

$$x_3 = \alpha_3 + \beta_3 X + \varepsilon_3$$

$$y = \alpha_4 + \beta_4 X + \varepsilon_4$$

where α_1 , α_2 , and α_3 are the respective statistical significances, β_1 , β_2 , and β_3 are the respective path coefficients, and ε_1 , ε_2 , and ε_3 are the error terms of manifest endogenous variables x_1 , x_2 , and x_3 of latent exogenous variable x . Accordingly, α_4 , β_4 , and ε_4 are the statistical significance, path coefficient, and error term of the main endogenous variable y .

Though general least squares (GLS), ordinary least squares (OLS) and other model estimation methods are applicable to SEM, “use of an estimation method other than ML [maximum likelihood] requires explicit justification” (Hoyle, 2000) and ML is usually the

default due to its efficiency. By assuming multivariate normality for endogenous variable population distributions, estimates maximize the likelihood that data were drawn from the population. When using ML in SEM parameter estimation, values that provide the best match between the implied and observed covariance matrices are selected, requiring the discrepancy function between them to be minimized. Values that minimize the maximum likelihood fitting function also maximize the likelihood of the data. This is depicted by the following equation:

$$F_{ML} = \log[\Sigma(\theta)] + tr(S \Sigma^{-1}(\theta)) - \log[S] - (p + q) \quad (4.3)$$

where $(p + q)$ depict the number of variables, and $\Sigma(\theta)$ and S respectively depict the implied and observed covariance matrices. To minimize the fitting function, the algorithm is employed to adjust initial values according to the function that fits. This process recurs until the minimum fitting function is achieved. Once the model has been estimated, its fit is subsequently measured. Three commonly reported indices for assessing the fitness of model data are discussed in this Thesis: the standardized root mean square residual (SRMR), the root mean square error of approximation (RMSEA), and the comparative fit index (CFI) and the Tucker-Lewis index (TLI).

The SRMR is an absolute fit index that directly assesses how well the model accounts for covariances using the average of the standardized residuals of the observed and hypothesized covariance matrices (Chen, 2007). It can be expressed using the following equation:

$$SRMR = \sqrt{\frac{\sum_{i=1}^p \sum_{j=1}^i [(s_{ij} - \hat{\sigma}_{ij}) / (s_{ii} s_{jj})]^2}{p(p+1)/2}} \quad (4.4)$$

where s_{ij} represents a component of the sample covariance matrix $\mathbf{S}$, $\hat{\sigma}_{ij}$ depicts a component of the hypothesized model $\Sigma(\hat{\theta})$, and p represents the number of observed variables. SRMR values range from a minimum of 0.0 to maximum of 1.0. Though values less than 0.10 indicate an acceptable fit, values less than or equal to 0.05 are generally considered to indicate a good fit (Hu & Bentler, 1999; Schermelleh-Engel & Moosbrugger, 2003; Hooper, 2008, Kline, 2015; Cangur & Ercan, 2015).

RMSEA is an “absolute measure of fit based on the non-centrality parameter” (Kenny, 2015) that reveals “how well the model, with unknown but optimally chosen parameter estimates would fit the populations covariance matrix” (Byrne, 2013). Formulaically, it can be expressed as:

$$RMSEA = \sqrt{\frac{(x^2 - df)}{[df(N-1)]}} \quad (4.5)$$

where N is the sample size and df is the degrees of freedom of the model. Notably, “its penalty for complexity is the chi square to degrees of freedom ratio”, and it tends to be positively biased depending upon the sample size and degrees of freedom (Hu & Bentler, 1999; Kenny et al., 2014).

As an incremental fit index which “assesses fit by the degree to which the model accounts for the sample covariances relative to a more restricted null-model,” (Hammervold &

Olsson, 2012) the CFI measures the “relative reduction in the non-centrality parameters of the estimated and the independence model” (Bentler, 1990). A covariance matrix, expressed using the following equation, is evaluated to assess the superiority of the tested model over the alternative model:

$$CFI = 1 - \frac{\max[(\chi_t^2 - v_t), 0]}{\max[(\chi_t^2 - v_t), (\chi_i^2 - v_i), 0]} \quad (4.6)$$

where *max* is the maximum values of the terms in the brackets, χ_i^2 and χ_t^2 respectively represent the test statistics of the independence and target models, and v_i and v_t respectively represent the degrees of freedom of the independence and target models in relation to the chi-square test statistics (Ding et al., 1995; Schermelleh-Engel & Moosbrugger, 2003; Cangur & Ercan, 2015). The index lies between 0 and 1, and values of acceptable fit are generally greater than or equal to 0.90. Moreover, values greater than or equal to 0.95 are commonly accepted to indicate good fit (Hooper *et al.*, 2008; Kline, 2015).

Lastly, the Tucker-Lewis index (also known as the non-normed fit index, or NNFI) favors parsimony, adjusts for model complexity, and is well-suited to simulation studies (Sharma et al., 2005; McDonald and Marsh, 1990). Similar to the normed fit index (NFI) that is “additive for nested model comparisons” as “the additive sum of component fits [of models]” which “permits isolating relative sources of fit or of model misspecification” (Bentler, 1990), it was developed to overcome the NFI disadvantage of being affected by sample size (Schermelleh-Engel & Moosbrugger, 2003; Ding et al., 1995; Gerbing & Anderson, 1992). Accordingly, it can be expressed through the formula:

$$TLI = \frac{\frac{\chi_i^2}{v_i} - \frac{\chi_t^2}{v_t}}{\frac{\chi_i^2}{v_i} - 1} \quad (4.7)$$

where , χ_i^2 and χ_t^2 respectively represent the test statistics of the independence and target models, and v_i and v_t respectively represent the degrees of freedom of the independence and target models in relation to the chi-square test statistics (Ding et al., 1995; Schermelleh-Engel & Moosbrugger, 2003; Cangur & Ercan, 2015). Like the CFI, TLI values range from 0 to 1 with values of acceptable fit greater than or equal to 0.90 (Forza & Filippini, 1998) and values of good fit greater than or equal to 0.95 (Hooper et al., 2008; Kline, 2015).

This study follows the suggestion of Kline (2015) in reporting the RMSEA, SRMR, and CFI as measures of model fit. It also adheres to Hu and Bentler (1999) two-index presentation advocacy, additionally reporting TLI alongside SRMR. The large sample size of $N = 2,114$ in this study makes TLI, CFI, and SRMR ideal due to their compatibility with complex models (Kenny, 2015). In particular, “In very large samples, residuals of no practical significance can lead to statistical rejection of a model...” (Anderson & Gerbing, 1984) and TLI and CFI can overcome these obstacles while measuring the degree to which models approximate data. We do not report the chi squared (χ^2) test because it is sensitive to sample size, and with large sample sizes (as in this study), the chi-square values will be inflated (statistically significant), thus might erroneously implying a poor data-to-model fit (Schumacker & Lomax, 2004).

Furthermore, the coefficient of determination is reported as a model fit measure because it represents the percentage of variance explained by an equation within the model. Similar to the R^2 of linear regression, it therefore serves to bolster the findings of the above-mentioned

conventional model fit estimators. Finally, the structural equation modeling and subsequent analyses of this work were all performed using STATA 15 econometric software.

4.3. Data

Data for green bond issuances were obtained from privileged access to the confidential the third quarter (Q3) 2018 green bond database of the Climate Bonds Initiative (CBI, 2018b). This data includes green bond issuance volumes expressed in both local currency and nominal United States dollar (USD) values. The author subsequently converted nominal USD values into 2010 constant USD values using consumer price index (CPI) ratios calculated using CPI data from the World Bank World Development Indicators (WDI). This data was used as a proxy for total green bond market capitalization in countries throughout the world. Additional data not used to perform the econometric analysis but employed for initial assessments of global green bond markets include issuance and maturity dates, issuing organizations, issuance countries and regions (including 49 countries across all regions of the world), and issuance structure types (e.g. asset backed securities, development bank bonds, financial corporation bonds, non-financial corporation bonds, government-backed entity bonds, loans, local government bonds, and sovereign entity bonds).

Green bond issuance and volume data were used as proxies for total green bond market capitalization in countries throughout the world. As there is technically no universal definition for what constitutes a green bond, though this study incorporates a sizeable portion of the global \$1.45 trillion in climate and green business-aligned bonds outstanding (CBI, 2018a), many additional “green” bonds issued outside of the scope of such frameworks were not included in the CBI Q3-2018 dataset (2018b) and thus unavailable for assessment in this study. However, the

CBI dataset represents one of the most comprehensive, thorough, and accurate sources of information, it can reasonably stand as a representative sample of green bond market capitalization.

Based on the collected data, the first green bonds were issued in Euros in 2007. Subsequently, there was an exponential increase in green bond issuances between 2013 and 2017, the majority of which were made in U.S. dollars and Euros. Refer to Figure 4.1 for the trends of green bond issuances by currency from 2007 through 2017.

In 2007, the European Investment Bank issued the first ever, £600 million Climate Awareness (green) Bond, equivalent to roughly \$848 million in constant 2010 USD. Between 2013 and 2017, global green bond market capitalization rose precipitously from the equivalent of roughly \$10.5 billion (constant 2010 USD) over 49 issuances to nearly \$143 billion over 1,557 issuances in 46 countries and from ten supranational institutions. Countries include developed and developing economies throughout all regions of the globe, and the ten supranational organizations include the African Development Bank (AfDB), the Asian Development Bank (ADB), the Central American Bank for Economic Integration (CABEI), the European Bank for Reconstruction and Development (EBRD), the European Investment Bank (EIB), the International Finance Corporation (IFC), the New Development Bank (NDB), the Nordic Investment Bank (NIB), the North American Development Bank (NADB), and the World Bank International Bank for Reconstruction and Development (IBRD).

Throughout the 2007 to 2017 period of assessment of this study, 2,532 green bond issuances totaled \$318,985,292,151 in value. Using the frequency and volume of green bond issuances as dependent variables, an exploratory factor analysis (EFA) followed by structural equation modeling (SEM) were used to model structured relationships between the variables.

Table 4.3.1: EFA and SEM variable definitions and sources

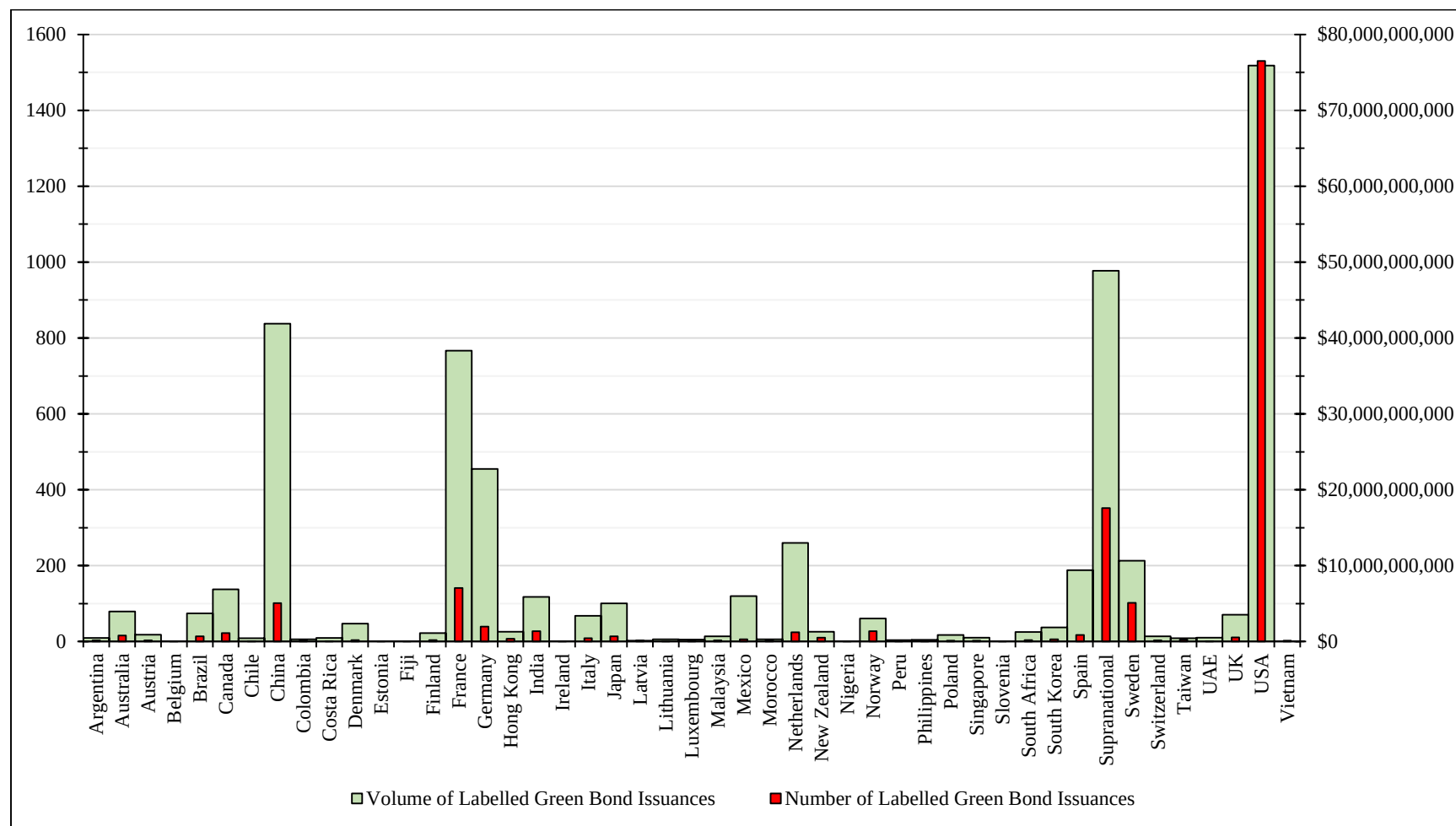
Variable	Definition	Data Source
<i>Green Bond Issuance Volume (GBVOL)</i>	Sum of gross value of green bond issuances	Climate Bonds Initiative (CBI)
<i>Green Bond Issuance Number (GBNO)</i>	Presence of absence of green bond issuances	Authors; CBI
<i>Gross domestic product (GDP)</i>	Sum of gross value of all products and taxes less any subsidies not included in product values	World Bank World Development Indicators (WDI)
<i>Trade openness (TO)</i>	Trade openness measured as the ratio of exports to GDP	WDI
<i>Domestic credit to private sector from banks (DCPSB)</i>	Financial resources provided to the private sector by banks as a percentage of GDP	WDI
<i>Stocks traded (ST)</i>	Total number of shares traded domestically and internationally multiplied by their respective prices	WDI
<i>Rule of law (RL)</i>	Extent to which agents have confidence in and abide by the rules of society	The Heritage Foundation
<i>Regulatory Quality (RQ)</i>	Ability of the government to formulate and implement sound policies and regulations	The Heritage Foundation
<i>Real Effective Exchange Rate (REER)</i>	Nominal effective exchange rate divided by a price deflator (2010 = 100)	WDI
<i>Interest Rate Spread (IRS)</i>	Bank lending interest rate minus bank deposit interest rate	WDI
<i>Inflation Rate (INF)</i>	Annual inflation growth rate of the GDP implicit deflator	WDI
<i>Market Capital of Domestic Companies (MCDC)</i>	Share price times the number of shares outstanding for listed domestic companies	WDI
<i>Nationally Determined Contributions (NDC)</i>	Strength of country-level nationally determined contributions (NDCs) of Paris Agreement	Authors' calculations, World Resources Institute (WRI) data
<i>Nationally Determined Contributions Rank (NDCR)</i>	Ranking of strength of country-level nationally determined contributions (NDCs) of Paris Agreement	Authors; WRI
<i>OECD Membership (OECD)</i>	Dummy variable where 1 is assigned to OECD member countries	Created by author

Table 4.3.2: Green bond issuances per country in study sample, 2007 – 2017

Country	Volume²	Frequency
United States of America	\$75,905,957,277	1530
Supranationals	\$48,846,632,199	352
China	\$41,879,161,527	101
France	\$38,332,603,352	141
Germany	\$22,739,592,371	39
The Netherlands	\$12,986,661,899	24
Sweden	\$10,660,638,064	102
Spain	\$9,393,868,896	17
Canada	\$6,857,138,636	22
Mexico	\$5,967,059,523	6
India	\$5,859,436,682	27
Japan	\$5,021,522,737	14
Australia	\$3,949,720,105	16
Brazil	\$3,724,224,939	14
United Kingdom	\$3,539,420,918	11
Italy	\$3,388,263,399	9
Norway	\$3,038,495,963	27
Denmark	\$2,342,620,404	4
South Korea	\$1,862,293,072	6
Hong Kong	\$1,287,256,905	7
New Zealand	\$1,273,034,759	10
South Africa	\$1,268,955,756	4
Finland	\$1,113,559,934	4
Austria	\$899,437,205	3
Poland	\$844,425,488	2
Malaysia	\$670,018,813	3
Switzerland	\$666,214,861	3
United Arab Emirates	\$520,615,475	1
Singapore	\$506,708,745	2
Costa Rica	\$454,268,727	1
Argentina	\$452,323,496	3
Chile	\$443,454,408	1
Taiwan	\$428,568,679	5
Lithuania	\$303,562,280	1
Colombia	\$295,978,275	3
Morocco	\$285,511,753	3
Luxembourg	\$243,329,043	1
Philippines	\$205,091,337	1
Peru	\$187,902,519	1
Latvia	\$124,993,813	3
Estonia	\$51,294,567	1
Belgium	\$46,550,130	1
Fiji	\$43,077,161	1
Nigeria	\$26,358,930	1
Vietnam	\$24,545,089	2
Slovenia	\$13,046,251	1
Ireland	\$9,895,790	1
Grand Total	\$318,985,292,151	2532

Source: Created by author using data from CBI Green Bonds Q3-2018 dataset (2018b)

Figure 4.3.1: Labelled green bond issuances for select, 2007 - 2017



Source: Created by author using data from Climate Bonds Initiative Green Bonds Q3-2018 dataset (2018b)

CBI data revealed comparative differences in the frequencies and volumes of green bond issuances at the country and supranational institution level. These are reported in Table 4.3.2. The United States was by far the largest green bond issuer, with generating \$75.9 billion over 1,530 issuances. This represents 23.8% and 60.4% of total global green bond issuance volumes and frequencies, respectively. Supranationals, China, and France were also top green bond utilizers, respectively accounting for 15.3% (roughly \$49 billion) and 13.9% (352), 13.1 % (roughly \$42 billion) and 3.9% (101), and 12% (roughly \$38 billion) and 5.6% of total global issuance volumes and frequencies. Conversely, 24 countries, or 52% of all green bond issuing countries, generated less than \$1 billion over 5 or fewer issuances, each individually accounting for less than 1% of global totals by both volume and frequency.

Two original variables were created to reflect contextual considerations: an Organization for Cooperation for Economic Development (OECD) membership binary variable, and a Paris Agreement NDC robustness score variable. Throughout the OECD, bonds are “a well-established asset class in the investment portfolios of mainstream institutional investors that have significant potential to finance a low-carbon transition” (OECD, 2015). This is at least partially due to efforts by member states in the 1980s and 1990s to improve primary and secondary markets in order to “strengthen the role of market principles in government debt management” (Blommestein, 2002). Correspondingly, companies from OECD member states tend to be the largest and most frequent corporate bond issuers (Çelik et al., 2015). As such, to shed light impact that OECD membership has on green bond issuances in particular, this study includes an original OECD binary variable with a value of “1” allocated to issuances made in OECD member states and a value of “0” allocated to those made outside of OECD member states.

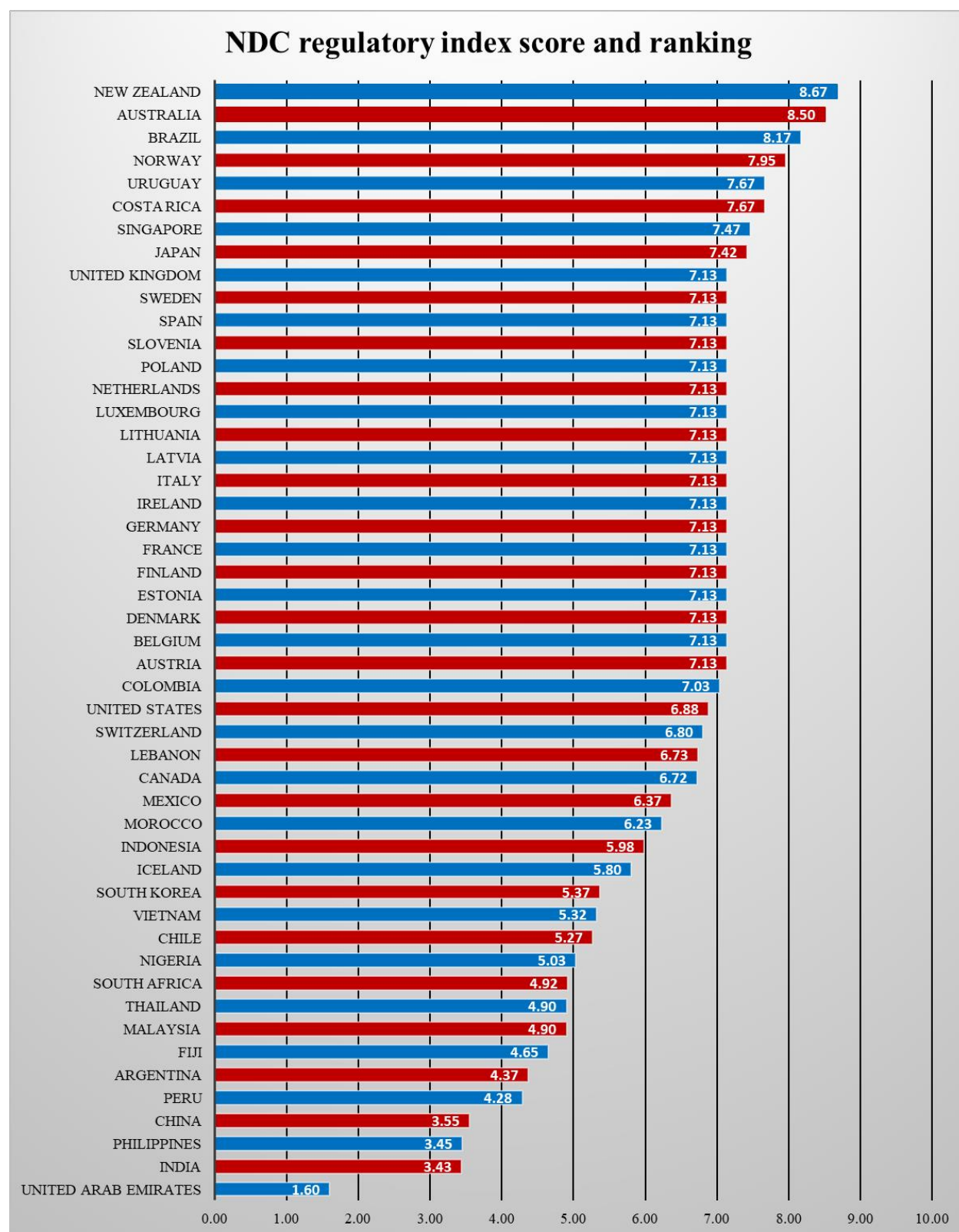
Paris NDCs are country-specific pledges to reduce GHG emissions and adapt to climate change impacts through the implementation of sustainability enhancing and cleaner production infrastructures. The renewable energy adoption, forest maintenance, water and wastewater management, and other NDC target actions encourage investments in the projects and assets to which labelled green bond proceeds are earmarked.

To measure the correlation between NDCs and green bond issuances, an original NDC regulatory index was constructed. The index consists of 11 categories, and scores were applied to each category based upon the relative strength of the underlying policy for each NDC assessed. Table 4A in the Appendix section reveals the categories, conditions, and scores of the NDC regulatory index. Scores for each category were normalized and summed to calculate final index scores for each country in the data sample. These scores are subsequently included in the SEM analysis of this study as a proxy for country-specific NDC robustness.

Figure 4.3.2 ranks NDC index scores for the countries in the data sample. Based on an index methodology that was designed to measure NDC strength in an equitable manner without regard to comparative developmental levels, a number of developing countries (Brazil, Uruguay, Costa Rica) are among the top scorers. Nevertheless, due to their placement in an economic bloc where “corporate action on climate change is more strongly mandated and regulated” and business leaders “accept the presence of regulation and government policy interventions on climate change, and want to optimize their engagement with this,” (Littlewood et al., 2018) European countries were prominent among top NDC scorers.

The remainder of the data were sourced from The Heritage Foundation (2018), The World Bank World Development Indicators (WDI) (2019a), and The World Bank World

Figure 4.3.2: NDC regulatory index score and rankings for select countries



Source: Created by author using originally calculated NDC index scores

Governance Indicators (WGI) (2019b). The sources and descriptions of each variable included in this study are outlined in the Table 4.3.1.

4.4. Results

4.4.1. Explanatory factor analysis (EFA) results

Exploratory factor analysis was performed for the years in which green bonds were issued. The cut-off line for statistically meaningful rotated factor loadings was set at 0.7 based on previous literature (Comrey & Lee, 1992; Tabachnick & Fidell, 2007; Hair et al., 2014). The model fitting was performed using the iterated principal factor method along with oblique rotation with Kaiser normalization. Moreover, the 14 independent variables detailed in Table 4.3.1 of section 4.3 are included in the analysis.

Leading up to the analysis, Cronbach's alpha was estimated using the correlations and covariances of the 14 variables. Table 4.4.1 displays these results. The alpha is 0.7033, which is over the 0.70 minimum cut-off line. Moreover, the alpha column depicts the degree to which the alpha would change if either variable was dropped.

The scope of the factor analysis results includes green bond issuing countries from the market inception year of 2007 through 2017. Results of the first round of analysis are displayed in Table 4.4.2. Factors 1 through 3 are the latent factors, and values highlighted in blue are above the 0.7 cut-off line. Additionally, the values written in red are below the 0.7 cut-off line, values highlighted in light red are above the upper limit of uniqueness, and each of these values are rejected in subsequent factor loading assessments. Following these results, Table 4.4.3 displays the latent factor correlation, while Table 4.4.4 displays the Bentler Test for Sphericity and Keyser-Meyer-Olin Measure of Sampling Adequacy.

Table 4.4.1: Cronbach's alpha

Item	Obs.	Sign	item-test correlation	item-rest correlation	average inter-item covariance	alpha
TF	2411	+	0.4082	0.3782	87.3049	0.6987
RL	2411	+	0.3902	0.3868	90.29595	0.7063
RQ	2411	+	0.4465	0.4435	90.27126	0.7063
GDP	2411	+	0.8339	0.8307	88.24597	0.7007
ST	2114	+	0.7866	0.779	86.26103	0.6976
TO	2411	-	0.7616	0.671	61.75313	0.6337
NDC	2411	+	0.6023	0.5898	87.49668	0.6988
NDCR	2411	+	0.5288	0.4603	79.66495	0.681
OECD	2411	+	0.4055	0.404	90.52142	0.7069
REER	2411	+	0.5933	0.4739	71.11419	0.666
IRS	2411	-	0.2325	0.211	89.3499	0.7041
INF	2411	-	0.1347	0.1153	90.08954	0.706
MCDC	2411	+	0.9186	0.8042	33.70205	0.6005
DCPSB	2411	-	0.8508	0.6876	41.5877	0.6238
Test scale					77.70172	0.7033

Factor loadings for the real effective exchange rate (REER), interest rate spread (IRS), market capitalization of domestic companies (MCDC), and domestic credit provided to the private sector by banks (DCPSB) were below the 0.6 cut-off line. The uniqueness of the factor loading for IRS was also above the 0.6 threshold of acceptance. Among the variables with acceptable factor loadings, trade freedom (TF), rule of law (RL), regulatory quality (RQ), and Organization for Cooperation and Economic Development membership (OECD) were manifest variables of Factor 1; gross domestic product (GDP), stocks traded (ST), trade openness (TO), nationally determined contributions to the Paris Agreement (NDC), and the rank of those nationally determined contributions (NDCR) were manifest variables of Factor 2; and inflation (INF) was the sole manifest variable of Factor 3.

The latent factor correlation matrices revealed the highest correlation between any two factors to be the 0.4105 between Factor 1 and Factor 2. The Bartlett test of sphericity and Kaiser-

Meyer-Olkin Measure of Sampling Adequacy also indicated good model fit, the former showing a statistically significant p-value (0.000) and the latter displaying a value above the acceptable minimum of 0.70.

Table 4.4.2: EFA results, stage 1

Variable	Factor 1	Factor 2	Factor 3	Uniqueness
TF	0.9744	-0.1076	0.079	0.0986
RL	0.9703	-0.057	0.097	0.0656
RQ	0.9674	-0.007	0.0372	0.0582
GDP	0.0427	0.8658	0.2491	0.1175
ST	0.0552	0.8362	0.3282	0.1015
TO	0.0592	-0.8413	0.0843	0.3329
NDC	0.1668	0.7307	-0.2186	0.3272
NDCR	-0.3739	0.886	-0.0218	0.3477
OECD	0.9093	-0.0073	0.0963	0.1446
REER	0.1512	0.4794	0.496	0.3813
IRS	-0.4987	0.0231	-0.247	0.6655
INF	-0.2694	0.0647	-0.6966	0.4069
MCDC	0.4325	0.566	0.0131	0.2886
DCPSB	-0.5053	-0.461	0.511	0.1915

Table 4.4.3: Correlation matrix of Kaiser promax-rotated common factors, stage 1

Factors	Factor 1	Factor 2	Factor 3
Factor 1	1.0000		
Factor 2	0.4105	1.0000	
Factor 3	0.1409	0.08291	1.0000

Accordingly, it is appropriate to perform a second round of analysis after eliminating the aforementioned variables with factor loadings below the 0.6 cut-off mark. Tables 4.4.5, 4.4.6.,

and 4.4.7 display the factor loadings, latent variable correlations, and fitness indices of the second stage of analysis, respectively.

Table 4.4.4: Determinant of the correlation matrix, Bartlett test of Sphericity, and Kaiser-Meyer-Olkin Measure of Sampling Adequacy, stage 1

Determinant of the correlation matrix		
Det	=	0.000
Bartlett test of sphericity		
Chi-square	=	36674.963
Degrees of freedom	=	91
p-value	=	0.000
H0: variables are not intercorrelated		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		
KMO	=	0.735

Table 4.4.5: EFA results, stage 2

Variable	Factor 1	Factor 2	Uniqueness
TF	0.9608	-0.0545	0.1077
RL	0.9724	-0.0066	0.0584
RQ	0.9559	0.0299	0.0668
GDP	0.1601	0.8622	0.1418
ST	0.193	0.8328	0.1654
TO	0.0329	-0.8263	0.3337
NDC	0.149	0.7246	0.383
NDCR	-0.3495	0.8773	0.3062
OECD	0.9159	0.0534	0.1267
INF	-0.4719	0.0185	0.7826

Table 4.4.6: Correlation matrix of Kaiser promax-rotated common factors, stage 2

Factors	Factor 1	Factor 2
Factor 1	1.0000	
Factor 2	0.3230	1.0000

Table 4.4.7: Determinant of the correlation matrix, Bartlett test of Sphericity, and Kaiser-Meyer-Olkin Measure of Sampling Adequacy, stage 2

Determinant of the correlation matrix		
Det	=	0.000
Bartlett test of sphericity		
Chi-square	=	27461.809
Degrees of freedom	=	45
p-value	=	0.000
H0: variables are not intercorrelated		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		
KMO	=	0.772

Of the ten variables assessed, only INF had unacceptable factor loadings and uniqueness. Moreover, the number of latent factors was truncated to Factor 1 and Factor 2, with TF, RL, RQ, RQ, and OECD observed in Factor 1 and GDP, ST, TO, NDC, and NDCR observed in Factor 2. There was thus a near-even split in the number of manifest variables in each latent factor, which will provide unique implications for the determining and labelling the latent variables for subsequent structural equation modelling.

The latent variable correlation matrices reveal a 0.3230 correlation between the variables, which is neither exceptionally low nor high. Moreover, the Bartlett test of sphericity p-value of 0.000 and KMO value of 0.772 in both indicate acceptable model fit. Upon dropping the INF

variable that lacked appropriate factor loadings and uniqueness, a third and final round of EFA was performed to isolate the remaining variables within the latent variables to which they are most suited. Tables 4.4.8, 4.4.9, and 4.4.10 provide the EFA results, correlation between latent factors correlations, and model fitness indices for this analytical stage.

Table 4.4.8: EFA results, stage 3

Variable	Factor 1	Factor 2	Uniqueness
TF	0.9631	-0.0549	0.1030
RL	0.9787	-0.0085	0.0474
RQ	0.9641	0.0271	0.0532
GDP	0.1601	0.8629	0.1419
ST	0.1857	0.8364	0.1672
TO	0.0155	-0.8194	0.3364
NDC	0.1618	0.7195	0.3821
NDCR	-0.3511	0.8781	0.3016
OECD	0.9259	0.0499	0.1109

As with the second round of EFA, TF, RL, RQ, GDP, and OECD all revealed high factor loadings above 0.9 for Factor 1. Though not quite as high, factor loadings for GDP, ST, TO, NDC, and NDCR generally remained above 0.80 (with the exception of the 0.7295 loading for the NDC variable), similarly expressing high values. Once again, none of these variables showed unacceptably high uniqueness, so they will be retained. Furthermore, correlations between latent Factor 1 and Factor 2 dropped only slightly to 0.3179, and both Bartlett and KMO values for model fitness remained above acceptable lower limits. As such the observed variables will be retained for SEM analysis.

Table 4.4.9: Correlation matrix of Kaiser promax-rotated common factors, stage 3

Factors	Factor1	Factor2
Factor1	1.0000	
Factor2	0.3179	1.0000

Table 4.4.10: Determinant of the correlation matrix, Bartlett test of Sphericity, and Kaiser-Meyer-Olkin Measure of Sampling Adequacy, stage 3

Determinant of the correlation matrix		
Det	=	0.000
Bartlett test of sphericity		
Chi-square	=	26894.679
Degrees of freedom	=	36
p-value	=	0.000
H0: variables are not intercorrelated		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		
KMO	=	0.769

At this stage, latent variables are labelled based upon the nature of their underlying observed variables. It is first worth mentioning that OECD, NDC, and NDCR will be retained as exogenous variables instead of manifest variables of their latent factors for few specific, exceptional cases. In the case of the former, the majority of green bonds were issued in the U.S., France, and other OECD member states (CBI, 2018), a substantial number and volume of green bonds proceeds were allocated in OECD member states (Tolliver, Keeley, & Managi, 2019), and the majority of green bonds are issued in OECD member states in the Eurozone (Environmental Finance, 2019), including OECD membership as an exogenous dummy variable is reasonable. In the case of the latter two, this study created a normalized index of the strength of Paris NDCs for

each of the assessed countries. Due to the novelty of the variables themselves, as well as to a priori observations of the many factors that influence the strength of each country's NDCs (including those beyond the scope of the latent factors assessed in the previous EFA), including the NDC and NDCR variables as exogenous variables would allow for more meaningful assessments of the correlation between precedent-setting climate policies (i.e. Paris NDCs) and the green bond branch of environmental finance.

With the aforementioned exogenous variables accounted for, the remaining manifest variables of each Factor were used to determine and label the latent variables assessed in the SEM analysis. Comprised of the TF, RL, and RQ variables that relate to the quality of governance, regulatory procedures, and institutional legitimacy of their underlying societies, Factor 1 was labelled "Institutional and Regulatory Environment." Consisting of the TO, GDP, and ST variables linked to economic development, financial market maturity, international trade capacity, Factor 2 was labelled "Macroeconomic Conditions." Both of these labels were supported by similar factor groupings and labels in existing literature (Bae, 2012). Furthermore, these latent and manifest variable grouping are listed alongside the independently observed exogenous variables in Table 4.4.11.

Table 4.4.11: Latent factors and constructs for green bond issuances

<u>Factor 1:</u> Institutional and Regulatory Environment	<u>Factor 2:</u> Macroeconomic Conditions	Exogenous Variables
TF	TO	NDC
RL	GDP	NDCR
RQ	ST	OECD

The nature of the NDC, NDCR, and OECD variables and the aims of this study justify their inclusion as exogenous variables in the SEM analysis. As investment target frameworks, NDCs are separate from yet interrelated with institutional and macroeconomic drivers, and measuring their direct impacts on green bond issuances is the primary focus of this study. Though OECD membership reflects an institutional affiliation, it requires that countries possess both macroeconomic features (e.g. rules-based open market economies, stable and transparent financial systems) and institutional features (e.g. governmental, administrative, and monetary institutions and regulations) before becoming member states (OECD, 2017). As such, this study treated it as separate from yet interrelated with both factors and included it alongside NDC as a unique exogenous variable.

4.4.2. *Literature justifications of retained variables*

Capital controls (TF). Openness to foreign portfolio investments via financial liberalization and the easing of capital controls can reduce financial repression and expand markets by allowing interest rates to rise to market equilibrium (McKinnon, 1973). This can also enable greater access of foreign investors to domestic debt as well as incentivize higher quality governance among local firms and create pressure for financial infrastructure reform (Claessens et al., 2001). However, measures that try to describe the extent and intensity of capital controls “fail to fully capture the complexity of real-world capital controls for a number of reasons” (Chinn and Ito, 2006). This study, therefore, uses the index value of trade freedom (TF, which comprises financial market investment restrictions and direct government interventions) developed by The Heritage Foundation (2018) as a proxy for the level of capital controls.

Regulatory quality (RQ). Investments in both human and physical capital, the availability and extent of economic incentives, and the efficiency of resource allocations in an economy are

largely affected by the quality of regulatory institutions (Mauro, 1995). In this study, regulatory quality is measured using the regulatory quality index value (RQ) of The World Bank WGI (2019b). Regulatory quality is a country-level aggregate indicator that is measured using units of a standard normal distribution from -2.5 to 2.5. It “captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.” In doing so, it is relevant to the economic environments that underlie bond markets, and countries with stronger regulatory quality score higher in the index.

Over the ten-year sample period of this study, Brazil, had the largest, 349% positive change in regulatory quality. This represents nearly seven times the magnitude of South Africa and Mexico which saw the second and third largest 52% and 49% respective positive increases in regulatory quality. Still, the 2017-year RQ index value in Brazil was -0.114, suggesting that there is much room for improvement to Brazilian regulatory quality. Indeed, through Brazil is among the biggest economic powers in the world along the lines of GDP and ranks higher than its regional counterparts in other indexes such as the UN’s Human Poverty and Human Development, Brazil’s regulatory situation is still at the level of lower-ranking, less economically developed countries as Panama, El Salvador, and Costa Rica. This suggests that there is “an urgent need to pursue different approaches towards a new regulatory system” (Moreira de Castro et al., 2014).

Particularly through its Programme for the Strengthening of Institutional Capacity for Regulatory Management (PRO_REG), Brazil aims to: (1) strengthen policy analysis capacity of ministries that formulate public policies in the sectors in which regulatory agencies operate; (2) create institutional mechanisms to improve coordination between ministries and agencies under the Federal Administration and strategically align policies and regulatory processes; (3)

strengthen the autonomy, transparency, and performance of federal regulatory agencies, and; (4) provide civil society organizations and consumers with easier access to regulatory process in a manner that supports social control (Moreira de Castro et al., 2014). Each of these would be conducive to regulatory impact analysis and lead to greater regulatory quality. Moreover, similar programs could enable other countries in pursuit of regulatory improvements.

Rule of law (RL). Law enforcement is attractive to investors and bolsters bond market development, while corruption undermines law enforcement and therefore should be negatively correlated with bond market development (Eichengreen and Luengnarumitchai, 2004). In this study, rule of law is measured using the rule of law index value (RL) of The World Bank WGI (2019b). Rule of law is a country-level aggregate indicator that is measured using units of a standard normal distribution from -2.5 to 2.5. Accordingly, it “captures perceptions of the extent to which agents have confidence in and abide by the rules of society” and “the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence” (World Bank 2019b). Thus, to the extent that these factors are robust in a given country, it’s rule of law indicator score will be higher.

In this study sample, South Africa experiences the largest, 111%, positive increase in the rule of law index. This is slightly ahead of the 94% increase attained by India as the country with the second largest increase, and over three times the 32% increase of Italy as the country with the third largest increase. Still, the South African rule of law index score of -0.011 as of the year 2017 is negative and places it far below the scores of some of it’s developing country counterparts (e.g. the 2017-year 1.011 and 0.604 scores of Chile and Uruguay, respectively).

Much of the increase in the rule of law index value for South Africa coincides with the constitutional and institutional reforms that took place following the abolition of the apartheid

system in 1994. Specifically, the South African government made explicit commitments to uphold a broader conception of legality. Specifically, more than simply recognizing such procedural legality concepts as actions by government officials that are backed by warrants of the law, the new government enshrined in its Constitution such substantive legality concepts as reasonableness in the execution of legal duties and the protection of individual liberties even when procedural legality is not violated (Dyzenhaus, 2006). These substantive protections are paramount to bolstering the rule of law, which is in turn integral to sustaining firm competitiveness and attracting FDI (Roxas et al., 2012), among other economic growth pursuits. Moreover, the state and enforcement agencies are the primary actors that either succeed or fail in bolstering the rule of law.

In addition to the WGI, most indexes that measure the rule of law combine institutional make-up and perception data. However, public records and survey data that measure individual behavior may be a better measure of law enforcement and compliance (Bergman, 2012). Even well-known indexes such as that of Skaaning (2010) are based on expert opinion surveys that are biased by contextual considerations and are more useful in evaluating trends within a given country than in comparing trends across countries. Contrary to this, the WGI index provides longitudinal depth through yearly data for each country that are hard to find (Bergman, 2012).

Stock market capitalization (ST). Economies with greater stock market capitalization have larger domestic currency bond markets (Claessens et al., 2007). In this study, the level of stock market capitalization (ST) is measured as the total value of stocks traded as a percentage of GDP and sourced from The World Bank WDI (2019a).

Size of the economy (GDP). The size of the economy (represented by GDP) is a strong determinant of the capacity to issue bonds. This positive correlation could be the result of

economies of scale, in which lending costs and associated risks would decrease as economies grow (Eichengreen and Luengnaruemitchai, 2004). This study employs GDP data from The World Bank WDI (2019a) as a proxy for the size of the economy.

Trade openness (TO). Entrenched interest groups such as banks attempt to protect their market dominance by lobbying to limit policies that bolster competition. However, these efforts are undermined to the extent that trade is open and exposed to international competition. (Rajan and Zingales, 2003). This study measures trade openness (TO) as the total exports of goods and services as a percentage of GDP as calculated by The World Bank WDI (2019a).

Organization for Cooperation for Economic Development (OECD) membership. Throughout the OECD, bonds are “a well-established asset class in the investment portfolios of mainstream institutional investors that have significant potential to finance a low-carbon transition” (OECD, 2015). This is at least partially due to efforts by member states in the 1980s and 1990s to improve primary and secondary markets in order to “strengthen the role of market principles in government debt management” (Blommestein, 2002). Correspondingly, companies from OECD member states tend to be the largest and most frequent corporate bond issuers (Çelik et al., 2015). As such, to shed light impact that OECD membership has on green bond issuances in particular, this study includes an original OECD binary variable with a value of “1” allocated to issuances made in OECD member states and a value of “0” allocated to those made outside of OECD member states.

Paris Agreement NDCs (NDC and NDCR). Paris NDCs are country-specific pledges to reduce GHG emissions and adapt to climate change impacts through the implementation of sustainability enhancing and cleaner production infrastructures. The renewable energy adoption,

forest maintenance, water and wastewater management, and other NDC target actions encourage investments in the projects and assets to which labelled green bond proceeds are earmarked.

To measure the correlation between NDCs and green bond issuances, an original NDC regulatory index was constructed. The index consists of 11 categories, and scores were applied to each category based upon the relative strength of the underlying policy for each NDC assessed. Table 4A in the Appendix section reveals the categories, conditions, and scores of the NDC regulatory index. Scores for each category were normalized and summed to calculate final index scores for each country in the data sample. These scores (*NDC*) and rankings (*NDCR*) are subsequently included in the SEM analysis of this study as proxies for country-specific NDC robustness.

4.4.3. SEM hypotheses formulation and model construction

In the second analytical stage, the following hypotheses were formulated to guide the construction of a structural equation model and its subsequent analyses:

H1: Macroeconomic factors positively influence green bond issuance volumes.

H2: Institutional factors positively influence green bond issuance volumes.

H3: OECD membership positively affects green bond issuance volumes.

H4: The strength of Nationally Determined Commitments (NDCs) positively affects green bond issuance volumes.

H5: Countries with higher quality institutional environments have better macroeconomic conditions.

H1 and H2 are based off of the findings in existing literature on bond market drivers discussed in Section 2. H3 is based off of the contextual considerations of OECD membership described in Section 4.3 and the aforementioned qualifications of it as a unique exogenous variable. H4 draws from Tolliver et al. (2014) which measured a growing number and volume of annual green bond proceeds disbursements to Paris Agreement and sustainable development goal (SDG)-related investments. H5 cites Keeley and Ikeda (2017) which found some of the institutional factors that this study also employs (e.g. regulatory quality, rule of law) to strongly effect economic factors similar to those employed in this study (e.g. market size and trade related variables). Intuitively, this hypothesis implies that institutional quality can affect other variables (including green bond issuance volumes) indirectly through its effects on macroeconomic conditions.

Table 4.4.12. displays the summary statistics for the variables included in the SEM analysis. Other than ST, each variable had 2,411 observations. However, due to the importance of stock trading as a determinant of bond market growth, as well as the similar number of 2,114 observations, it is retained as a variable. The TO variable showed the largest standard deviation, with RQ and RL showing the smallest deviation out of the non-dummy variables. Moreover, note that GDP and ST are expressed in natural logarithm form. GBNO and GBVOL are the additional dependent variables for the SEM analysis.

Table 4.4.13. displays the matrix of correlations between the variables. The majority of variables are positively correlated with coefficients greater than 0.3. TO represents an exception, where it is negatively correlated with every other variable, particularly with NDC, GBNO, GDP, and ST. Note also the high correlations between manifest variables of the same latent variable. Specifically, there were high correlations between the TF, RQ, and RL manifest variables of the

“Institutional and Regulatory Environment” latent variable, as well as high correlations between GDP, TO, and ST manifest variables of the “Macroeconomic Environment” latent variable.

Table 4.4.12: Summary statistics of SEM variables

Variable	Obs	Mean	Std. Dev.	Min	Max
GBNO	2,411	0.899212	0.30111	0	1
GBVOL	2,411	15.53411	5.437172	0	22.63
TF	2,411	85.33467	4.659809	58.8	90
RQ	2,411	1.371949	0.576723	-1.07426	2.260543
RL	2,411	1.419852	0.626068	-1.18154	2.100273
TO	2,411	16.40341	26.03227	0	230.0164
GDP	2,411	29.46501	1.618944	21.86765	30.48
ST	2,114	30.19045	2.51516	17.3816	31.46699
NDC	2,411	5.210142	2.897642	0	8.67
NDCR	2,411	21.41601	13.21397	0	49
OECD	2,411	0.884695	0.319456	0	1

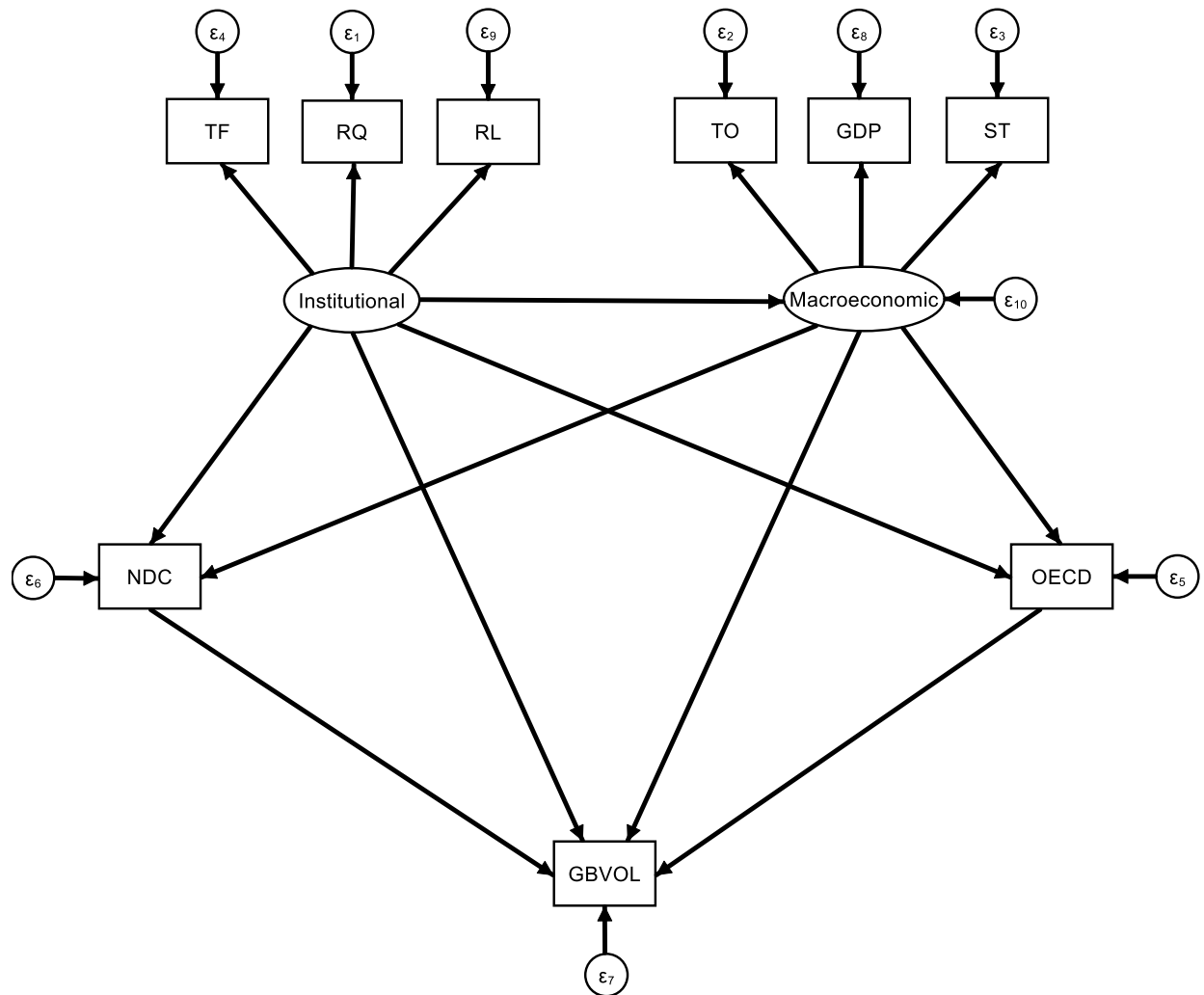
Table 4.4.13: Correlation matrix for SEM variables

	GBNO	GBVOL	TF	RQ	RL	TO	GDP	ST	NDC	NDCR	OECD
GBNO	1.0000										
GBVOL	0.9607	1.0000									
TF	0.2676	0.1748	1.0000								
RQ	0.3100	0.2094	0.9166	1.0000							
RL	0.3467	0.2469	0.8937	0.9628	1.0000						
TO	-0.5562	-0.4646	-0.1513	-0.2202	-0.2112	1.0000					
GDP	0.6840	0.5865	0.3365	0.3993	0.4148	-0.7505	1.0000				
ST	0.6744	0.5810	0.3597	0.4236	0.4392	-0.7107	0.9791	1.0000			
NDC	0.5440	0.4619	0.3647	0.4711	0.3693	-0.5011	0.5448	0.5260	1.0000		
NDCR	0.4965	0.4564	-0.0352	0.0053	-0.0543	-0.4198	0.5235	0.5086	0.7069	1.0000	
OECD	0.3646	0.2683	0.8477	0.8712	0.8940	-0.3211	0.4622	0.4533	0.3621	-0.0603	1.0000

The structural equation model was developed using GBNO and GBVOL as the main dependent variables. The “Institutional and Regulatory Environment” and “Macroeconomic Environment” factors from EFA were retained as latent variables, and their underlying TF, RQ, RL, TO, GDP, and ST variables were retained as the observed variables of the latent factors in accordance with the groupings determined in the EFA. As shown in Table 4.4.11, OECD, NDC, and NDCR are retained as exogenous variables. OECD is a binary variable with values of “1” for OECD member countries and values of “0” for OECD non-member countries attributed to the 49 countries for which relevant data of this study was assessed. NDC is a normalized index score of NDC robustness for each country for which relevant data was assessed, and NDCR is a ranking of that NDC value for each country.

Figure 4.4.1 displays the hypothesized structural equation model, connecting each latent, manifest, and exogenous variable with path arrows. Each path ultimately leads to the GBVOL dependent variable. Note that in subsequent analyses, the exogenous NDC variable will be replaced with the exogenous NDCR variable, and the GBVOL dependent variable will be replaced with the GBNO dependent variable. Moreover, the circles with “ ϵ ” labels depict the error term of the variable to which their attached arrows point.

Figure 4.4.1: Hypothesized structural equation model



4.4.3.1. Model 1

Figure 4.4.2 shows the analytical results for the model with the volume of green bond issuances as the dependent variable. As the OECD and NDC exogenous variables were shown to covary to a reasonable degree of 0.3621, they were connected with a curved arrow in this model. The theoretical underpinning is that OECD countries generally have the means and aspirations to construct more robust. Moreover, as GDP and ST had covariance of 0.9721, they were also

connected with a curved arrow in this model. This is also reasonable, as explained by Beck, Demirgüç-Kunt, and Ross (2009):

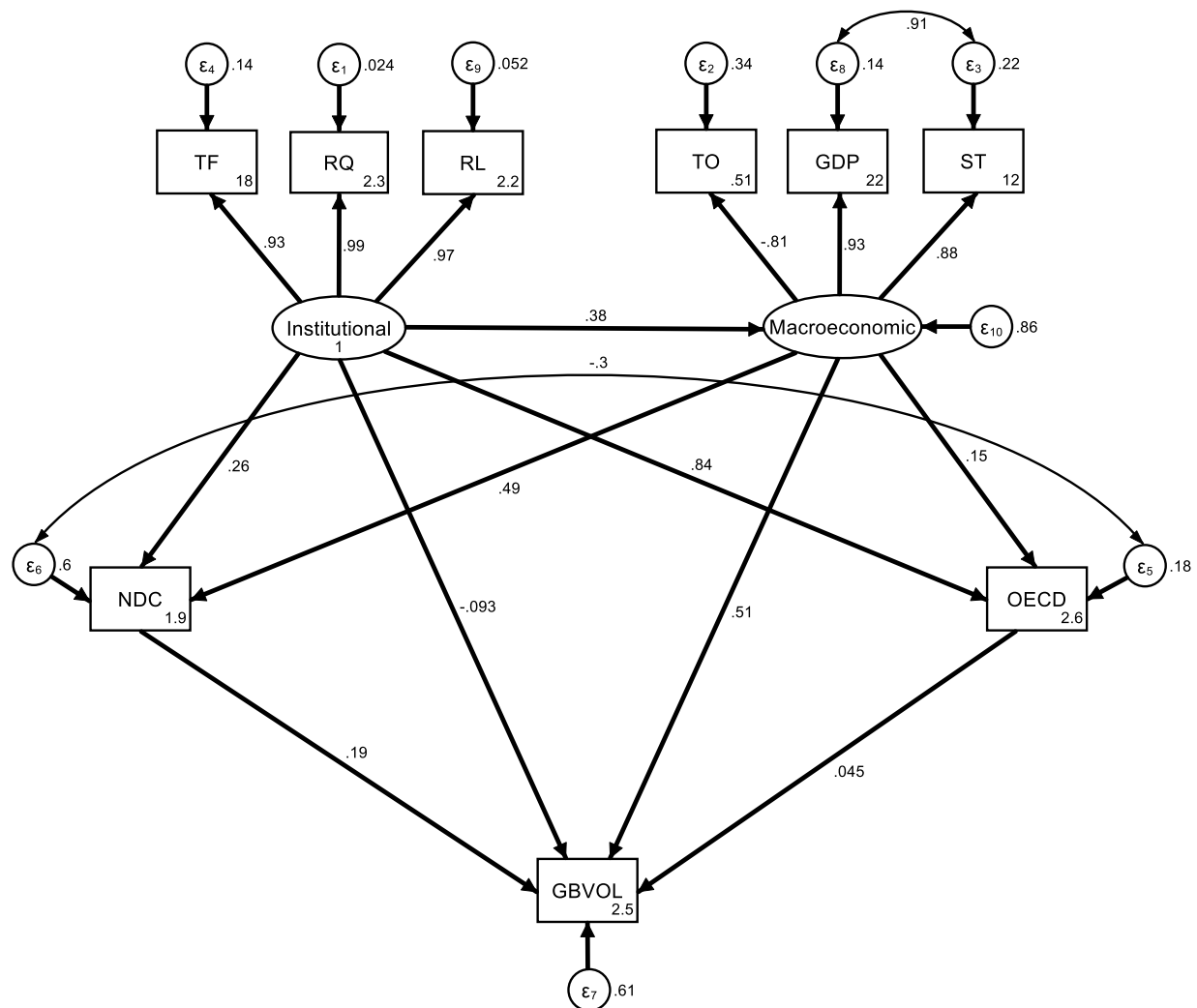
“...the size of the stock market relative to the size of the economy [GDP]...varies positively with the level of economic development and has trended upwards over the past three decades, with steep increases since 2003. This increase has been equally strong across all income groups.”

The values beside the path arrows in Figure 4.4.2 depict the mean standardized correlation coefficients of the variables. Notably, the institutional and regulatory environment latent variable had a considerable impact on the macroeconomic conditions latent variable. Moreover, it had a greater than 90% correlation with each of its manifest variables, as well as a more than 80% correlation with the OECD dummy and a more than 25% correlation with the normalized NDC index variable. The smallest, negative value is the -0.093 with the GBVOL dependent variable. While this direct effect does suggest that Institutional had a negligible, negative impact on green bond issuances, subsequent analyses will reveal that positive indirect effects that outstrip these negative direct effects.

The Macroeconomic variable had unique correlations with each of its underlying variable, each of which was greater than 0.8 in magnitude. The largest was the GDP value of 0.93, while the -0.81 correlation with trade openness was the smallest. Moreover, the roughly 50% correlation between Macroeconomic and both NDC and GBVOL was more double those between Institutional and the same variables, while the 15% correlation with OECD represented the second smallest value among all latent variable correlation coefficients.

Finally, NDC showed a 0.19 correlation coefficient with GBVOL, showing that NDC impact on green bond issuances is not negligible. The value for the path from OECD to GBVOL,

Figure 4.4.2. Structural equation model 1 – NDC scores, green bond issuance volumes



on the other hand, measured 0.045. This represents the smallest inter-variable correlation coefficient in the model and suggests that OECD membership was a negligible determinant of green bond issuances.

Table 4.4.14 displays the statistical significance of every intervariable path in Figure 4.4.2. 12 of the 13 paths portrayed 99% statistical significance, with the path from OECD to GBVOL showing the only path far above the maximally acceptable p-value of 0.1. This implies

that in this model, OECD membership was not a coercive determinant of green bond issuances among the 49 countries assessed.

Table 4.4.14: P-value for each path in Model 1

i	j	p-value
Macroeconomic	Institutional	0.000
OECD	Macroeconomic	0.000
OECD	Institutional	0.000
NDC	Macroeconomic	0.000
NDC	Institutional	0.000
RQ	Institutional	0.000
TF	Institutional	0.000
RL	Institutional	0.000
TO	Macroeconomic	0.000
ST	Macroeconomic	0.000
GDP	Macroeconomic	0.000
GBVOL	OECD	0.569
GBVOL	NDC	0.000
GBVOL	Macroeconomic	0.000
GBVOL	Institutional	0.225

Table 4.4.15 depicts a matrix of total effects of each variable on every other variable, while Table 4.4.16 provides a breakdown of the indirect, direct, and total effects of each latent and exogenous variable on the green bond volume dependent variable. The Macroeconomic latent variable had the largest, negative, highly statistically significant effect on TO, as well as substantial, positive effects on both NDC and ST. The largest, negative impact of Institutional was similarly on TO, while the variables it had the largest positive effects on are TF and NDC.

Regarding the total effects on the GBVOL dependent variable, Macroeconomic had the largest, statistically significant effect value of 0.609. Nevertheless, Institutional and NDC also exerted statistically significant, positive effect.

Finally, the goodness-of-fit measures depicted in Table 4.4.17 showed acceptable values in four indices, as well as a high coefficient of determination. Specifically, the 0.947 CFI and 0.901 TLI were both above the 0.9 minimally acceptable values and the SRMR was less than the 0.05 maximally acceptable value. Note that Satorra-Bentler CLI (CLI-SB) and TLI (TLI-SB) values were tested versus the saturated model because the Satorra-Bentler adjustments are robust to nonnormality. This was an important consideration due to the large sample size and diversity of data included in the analysis. Moreover, note the high 0.986 coefficient of determination for the model, which reinforced the goodness of fit.

Table 4.4.15: Total effects of each variable in Model 1

	Macroeconomic	Institutional	NDC	OECD	TF	RQ	RL	TO	GDP	ST	GBVOL
Macroeconomic	1.000	0.376***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Institutional	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NDC	0.492***	0.442***	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OECD	0.154	0.895***	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TF	0.000	0.926***	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
RQ	0.000	0.988	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
RL	0.000	1.065***	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
TO	-0.810***	-0.305***	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
GDP	0.928***	0.349***	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
ST	0.882***	0.332***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
GBVOL	0.609***	0.221***	0.187***	0.045	0.000	0.000	0.000	0.000	0.000	0.000	1.000

***p<0.01, **p<0.05, *p<0.1

Table 4.4.16: Total effects of latent and exogenous variables in Model 1

Determinants	Indirect Effects	Direct Effects	Total Effects
NDC	0.000	0.187***	0.187***
OECD	0.000	0.045	0.045
Macroeconomic	0.099***	0.510***	0.609***
Institutional	0.315***	-0.093**	0.221***

***p<0.01, **p<0.05, *p<0.1

Table 4.4.17: Goodness-of-fit measures for Model 1.

CFI_SB	0.947	Satorra-Bentler comparative fit index
TLI_SB	0.901	Satorra-Bentler Tucker-Lewis index
SRMR	0.043	Standardized root mean of squared residual
CD	0.986	Coefficient of determination

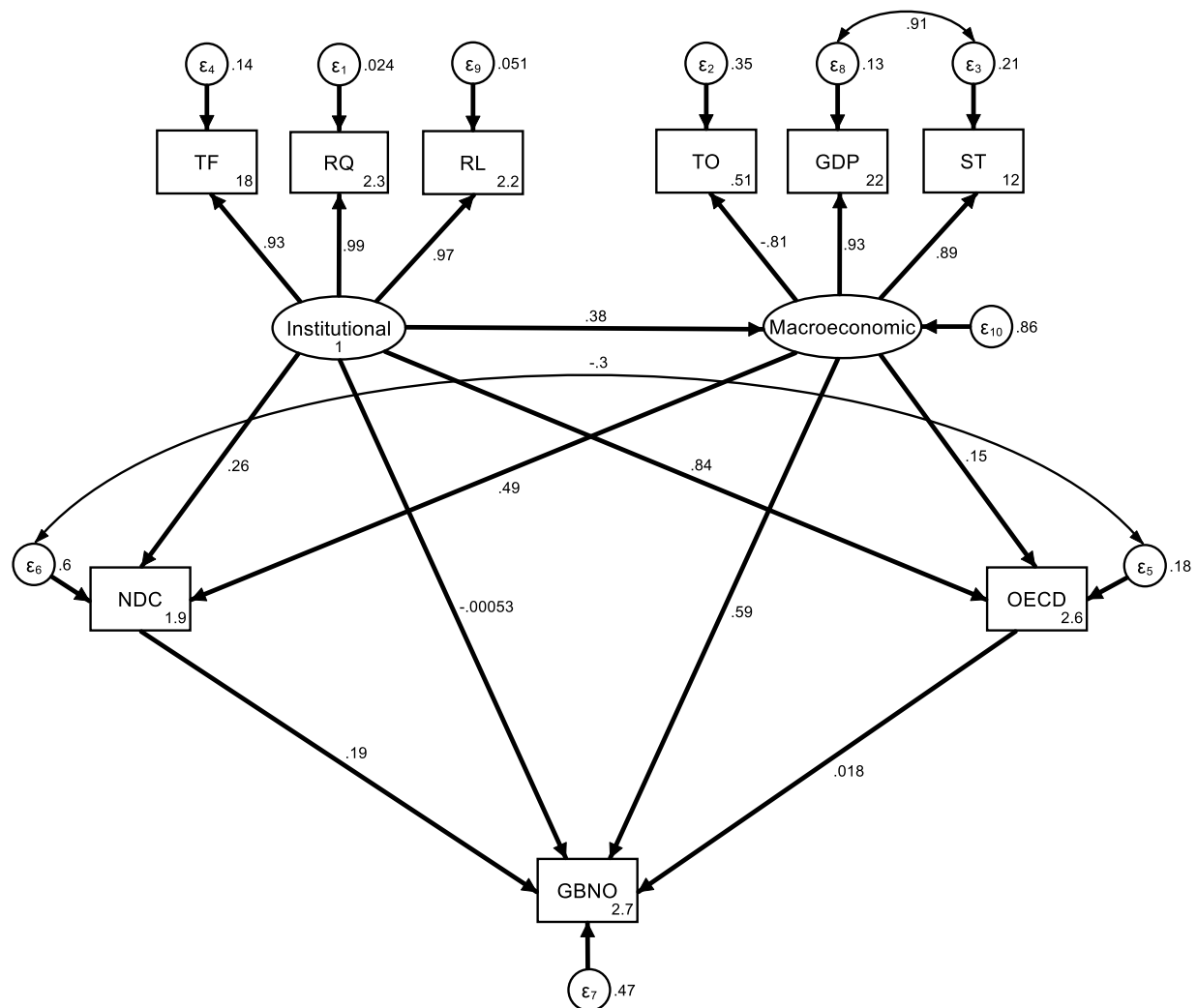
4.4.3.2. *Model 2*

Figure 4.4.3 shows the analytical results for the model with the presence of absence of green bond issuances as the dependent variable. Once again, the OECD and NDC exogenous variables were connected with a curved arrow due to their previously established covariance. The same covariance nature was assumed for GDP and ST, justifying continued use of the curved arrow to connect them.

Based on the standardized correlation coefficients, the institutional and regulatory environment latent variable once again had a considerable impact on the macroeconomic conditions latent variable. It also maintained a greater than 90% correlation with each of its manifest variables, as well as a more than 80% correlation with the OECD dummy and a more than 25% correlation with the normalized NDC index variable. The -0.0053 correlation coefficient with the GBNO dependent variable was substantially smaller than the value derived in the first model. Subsequent analyses delve into both the direct and indirect effects that the variable had on GBNO in order to further explicate, and rectify, the curious nature of this result.

The Macroeconomic variable had unique correlations with each of its underlying variables, each of which was greater than 0.8 in magnitude. These did not vary from the first model, with the largest being the GDP value of 0.93, and the -0.81 correlation with trade openness being the smallest. Moreover, the maintained a roughly 50% correlation with both

Figure 4.4.3: Structural equation model 2 – NDC scores, green bond issuance numbers



NDC and GBNO as well as a 15% correlation with OECD variable.

Finally, the coefficient for NDC and GBNO remained 0.19, once again showing that NDC impact on green bond issuances is not negligible. The value for the path from OECD to GBNO, on the other hand, decreased to 0.018. This suggests that OECD membership impacted the issuance of green bonds much less than the already small degree that it impacted the volumes of green bond issuances.

Table 4.4.20. displays the statistical significance of every intervariable path in Figure 4.4.3. 11 of the 13 paths portray 99% statistical significance, with the paths from Institutional to GBNO and OECD to GBNO showing the only paths with p-values far above the acceptable ceiling of 0.1. This implies that neither institutional quality nor OECD membership impacted green bond issuances in a statistically substantive manner in the 49 countries assessed.

Table 4.4.18. shows a matrix of total effects of each variable on every other variable, while Table 4.4.19. provides a breakdown of the indirect, direct, and total effects of each latent and exogenous variable on the green bond issuance dependent variable. The Macroeconomic latent variable had the largest, negative, highly statistically significant effect on TO, as well as substantial, positive effects on both NDC and ST. The largest, negative impact of Institutional was similarly on TO, while the variables it had the largest positive effects on are TF and NDC. Regarding the total effects on the GBNO dependent variable, Macroeconomic had the largest, statistically significant effect value of 0.689. Nevertheless, Institutional and NDC also exerted statistically significant, positive effect.

Finally, the goodness-of-fit measures depicted in Table 4.4.21. showed acceptable values in four indices, as well as a high coefficient of determination. The 0.947 CFI, 0.901 TLI, and 0.043 SRMR were once again acceptable. The coefficient of determination, remaining at 0.986, continued to reinforce the goodness of fit.

Table 4.4.18: Total effects of each variable in Model 2

	Macroeconomic	Institutional	NDC	OECD	TF	RQ	RL	TO	GDP	ST	GBNO
Macroeconomic	1.000	0.378***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Institutional	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NDC	0.492***	0.441***	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OECD	0.152	0.895***	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TF	0.000	0.926***	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
RQ	0.000	0.987	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
RL	0.000	0.974***	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
TO	-0.809***	-0.306***	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
GDP	0.931***	0.352***	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
ST	0.887***	0.336***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
GBNO	0.689***	0.324***	0.188***	0.018	0.000	0.000	0.000	0.000	0.000	0.000	1.000

***p<0.01, **p<0.05, *p<0.1

Table 4.4.19: Total effects of latent and exogenous variables in Model 2

Determinants	Indirect Effects	Direct Effects	Total Effects
NDC	0.000	0.188***	0.188***
OECD	0.000	0.018	0.018
Macroeconomic	0.095***	0.594***	0.689***
Institutional	0.324***	-0.001	0.324***

***p<0.01, **p<0.05, *p<0.1

Table 4.4.20: P-value for each path in Model 2

i	j	p-value
Macroeconomic	Institutional	0.000
OECD	Macroeconomic	0.000
OECD	Institutional	0.000
NDC	Macroeconomic	0.000
NDC	Institutional	0.000
RQ	Institutional	0.000
TF	Institutional	0.000
RL	Institutional	0.000
TO	Macroeconomic	0.000
ST	Macroeconomic	0.000
GDP	Macroeconomic	0.000
GBNO	OECD	0.802
GBNO	NDC	0.000
GBNO	Macroeconomic	0.000
GBNO	Institutional	0.994

Table 4.4.21: Goodness-of-fit measures for Model 2

CFI_SB	0.947	Satorra-Bentler comparative fit index
TLI_SB	0.900	Satorra-Bentler Tucker-Lewis index
SRMR	0.043	Standardized root mean of squared residual
CD	0.986	Coefficient of determination

4.4.3.3. Model 3

Figure 4.4.4 shows the analytical results for the model with the volume of green bond issuances as the dependent variable. While the OECD exogenous variable remains unchanged, the rank of the strength of NDCs, or NDCR, was added as the second exogenous variable (in

place of NDC). Covarying in a similar manner as the case for the OECD and NDC variables, OECD and NDCR were connected with a curved arrow. Moreover, the curved arrow between GDP and ST was retained as an indicator of their covariance.

Standardized coefficients along the model path arrows depicted an unchanged, 0.39 correlation value for the institutional and regulatory environment latent variables. The former once again maintained a greater than 90% correlation with each of its manifest variables, as well as a more than 80% correlation with the OECD dummy. Similar to the case with the NDC variable, Institutional showed a more than 25% correlation with NDCR, though in this model, it was negative. The impact on GBVOL was also negative, though to a substantially greater magnitude of -0.064.

The Macroeconomic variable had unique correlations with each of its underlying variables, each of which was greater than 0.75 in magnitude. These did not vary from the first model, with the largest being the GDP value of 0.98, and the -0.77 correlation with TO being the smallest. Moreover, it showed a 64% positive correlation with NDCR, a 13% positive correlation with OECD, and a 42% positive correlation with GBVOL.

Finally, the coefficient for NDCR and GBVOL rose slightly to 0.24, depicting a positive impact of the NDC ranking on green bond issuances that surpassed the impact of NDC strength. The value for the path from OECD to GBVOL also increased substantially to 0.14, suggesting greater positive impact in this model.

Table 4.4.24 displays the statistical significance of every intervariable path in Figure 4.4.4. 11 of the 13 paths portray 99% statistical significance. The path from OECD to GBVOL was statistically significant at the 90% level, while the path from Institutional to GBVOL remained statistically insignificant.

Figure 4.4.4: Structural equation model 3 – NDC score ranks, green bond issuance volumes

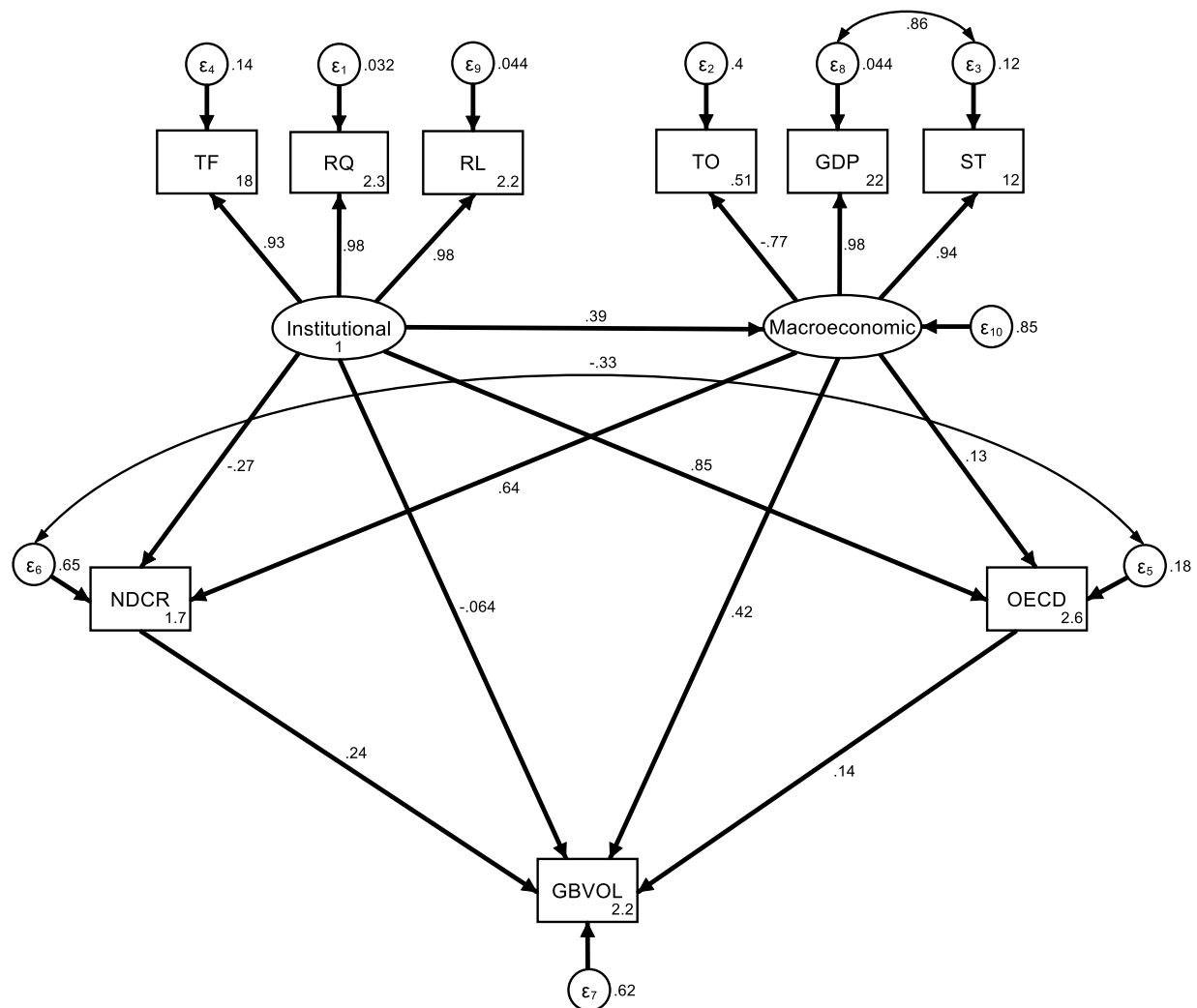


Table 4.4.22 depicts a matrix of total effects of each variable on every other variable, while Table 4.4.23 provides a breakdown of the indirect, direct, and total effects of each latent and exogenous variable on the green bond volume dependent variable. The Macroeconomic latent variable had the largest, negative, highly statistically significant impact on TO, as well as substantial, positive impacts on both NDC and ST. The largest, negative total effect of Institutional was similarly on TO, while the variable it had the largest positive total effects on are TF. Regarding the total effects on the GBVOL dependent variable, Macroeconomic had the

Table 4.4.22: Total effects of each variable in Model 3

	Macroeconomic	Institutional	NDCR	OECD	TF	RQ	RL	TO	GDP	ST	GBVOL
Macroeconomic	1.000	0.391***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Institutional	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NDCR	0.638***	-0.022	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OECD	0.134	0.899***	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TF	0.000	0.926***	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
RQ	0.000	0.984	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
RL	0.000	0.978***	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
TO	-0.772***	-0.301***	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
GDP	0.978***	0.366***	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
ST	0.978***	0.382***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
GBVOL	0.593***	0.225***	0.239***	0.145***	0.000	0.000	0.000	0.000	0.000	0.000	1.000

***p<0.01, **p<0.05, *p<0.1

Table 4.4.23: Total effects of latent and exogenous variables in Model 3

Determinants	Indirect Effects	Direct Effects	Total Effects
NDCR	0.000	0.239***	0.239***
OECD	0.000	0.145***	0.145***
Macroeconomic	0.172***	0.421***	0.593***
Institutional	0.289***	-0.064	0.225***

***p<0.01, **p<0.05, *p<0.1

Table 4.4.24: P-value for each path in Model 3

i	j	p-value
Macroeconomic	Institutional	0.000
OECD	Macroeconomic	0.000
OECD	Institutional	0.000
NDCR	Macroeconomic	0.000
NDCR	Institutional	0.000
RQ	Institutional	0.000
TF	Institutional	0.000
RL	Institutional	0.000
TO	Macroeconomic	0.000
ST	Macroeconomic	0.000
GDP	Macroeconomic	0.000
GBVOL	OECD	0.072
GBVOL	NDCR	0.000
GBVOL	Macroeconomic	0.000
GBVOL	Institutional	0.366

Table 4.4.25: Goodness-of-fit measures for Model 3

CFI_SB	0.966	Satorra-Bentler comparative fit index
TLI_SB	0.935	Satorra-Bentler Tucker-Lewis index
SRMR	0.034	Standardized root mean of squared residual
CD	0.984	Coefficient of determination

largest, statistically significant total effects value of 0.593. In this case, OECD had the second largest impact on the dependent variable, followed closely by Institutional and then by NDC.

Finally, the goodness-of-fit measures depicted in Table 4.4.25 showed acceptable values in four indices, as well as a high coefficient of determination. Indeed, the CFI and TLI values respectively increased to 0.966 and 0.935, while the SRMR dropped to 0.034. Each of these depicted better model fit compared with both of the models that employed the NDC exogenous variable. Furthermore, though it dropped slightly, the 0.984 coefficient of determination, complimented the already robust goodness of fit indices.

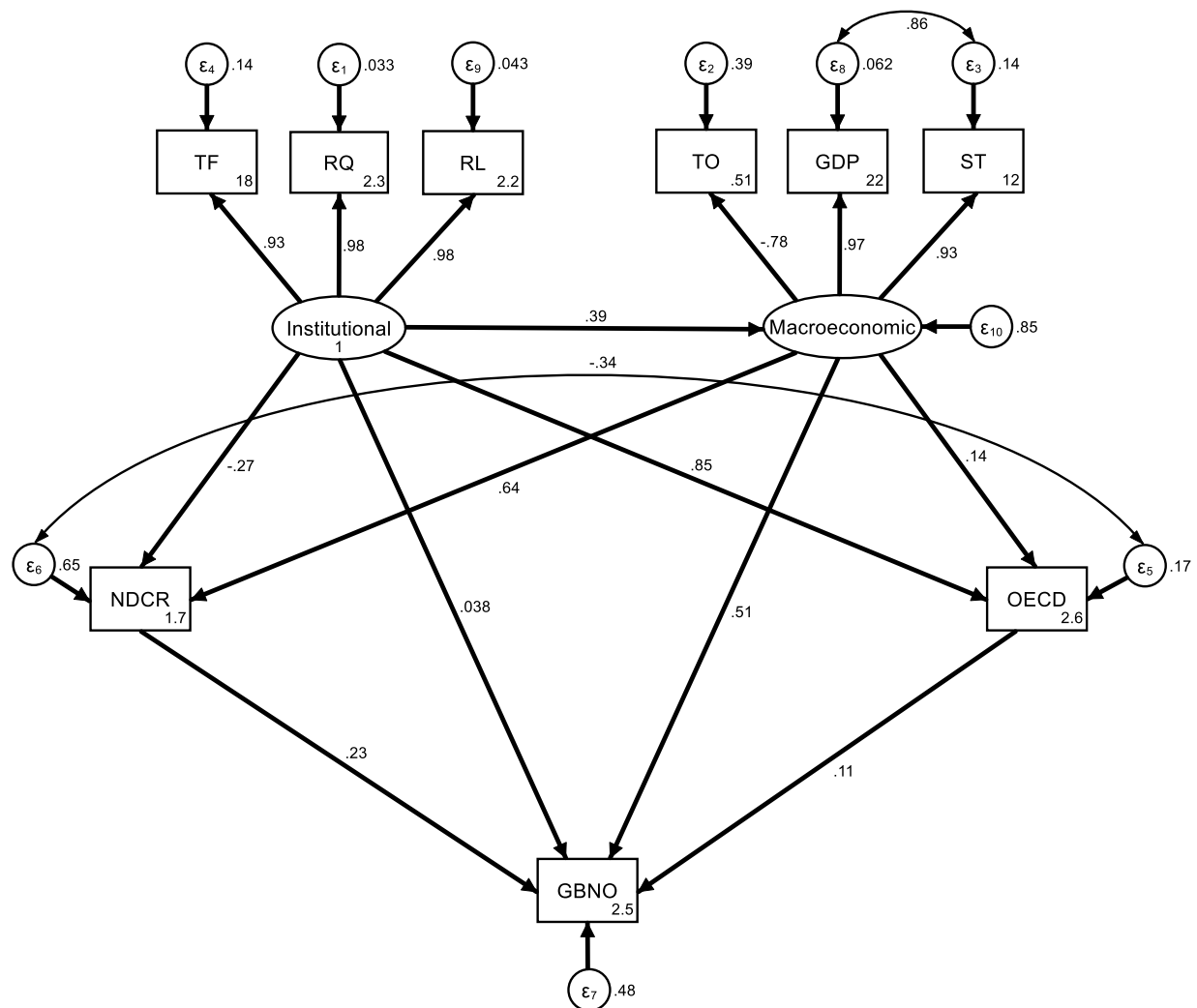
4.4.3.4. *Model 4*

Figure 4.4.5 shows the analytical results for the model with the presence of absence of green bond issuances as the dependent variable. Once again, the OECD and NDCR exogenous variables, as well as the GDP and ST manifest variables of the Macroeconomic latent variable, were connected with a curved arrow due to their previously established covariance.

The correlation coefficient of the Institutional and Macroeconomic latent variables the institutional and regulatory environment latent variable remained 0.39 (as in the previous model), indicating consistent, considerable correlation. Coefficients between Institutional and its manifest variables also remained over 0.90, while those with the OECD and NDCR variable remained over 0.80 and 0.25, respectively. The correlation coefficient with the GBNO dependent variable was substantially larger than the value derived the previous model, reaching .038. Subsequent analyses reveal both the direct and indirect effects that the variable had on GBNO.

The Macroeconomic variable had unique correlations with each of its underlying variables, each of which was greater than 0.8 in magnitude. These did not vary from the first model, with the largest being the GDP value of 0.93, and the -0.81 correlation with trade openness being the smallest. Moreover, the maintained a roughly 50% correlation with both

Figure 4.4.5: Structural equation model 4 – NDC score ranks, green bond issuance numbers



NDC and GBNO as well as a 15% correlation with OECD variable.

Finally, the coefficient for NDCR and GBNO dropped slightly (by 0.01) to 0.23, reinforcing the notion that NDC impact on green bond issuances is not negligible. The value for the path from OECD to GBNO also dropped slightly (by 0.03) from the previous model to 0.11. As depicted in the second model, this suggests that OECD membership impacts green bonds issuance less than the already small degree that it impacts the volumes of green bond issuances.

Table 4.4.28. displays the statistical significance of every intervariable path in Figure 4.4.5. 11 of the 13 paths portray 99% statistical significance, with the paths from Institutional to GBNO and OECD to GBNO showing the only paths with p-values above the acceptable ceiling of 0.1. This implies that the impact of neither institutional quality nor OECD membership on green bond issuances was statistically significant in the 49 countries assessed.

Table 4.4.26 provides a matrix of total effects of each variable on every other variable, while Table 4.4.27 outlines the indirect, direct, and total effects of each latent and exogenous variable on the green bond issuance dependent variable. The Macroeconomic latent variable had the largest, negative, highly statistically significant effects on TO, as well as substantial, positive effects on both NDCR and ST. The largest, negative effect of the Institutional latent was similarly on TO, while the variables it had the largest positive effects on were TF and ST. Uniquely, the Institutional total effects on NDCR were neither large in magnitude nor statistically significant. Regarding the total effects on the GBNO dependent variable, Macroeconomic had the largest, statistically significant impact value of 0.673. Nevertheless, Institutional and NDCR also exerted statistically significant, positive impact.

Finally, the goodness-of-fit measures depicted in Table 4.4.29 showed acceptable values in four indices, as well as a high coefficient of determination. The 0.947 CFI, 0.901 TLI, and 0.043 SRMR were once again acceptable. The coefficient of determination, remaining at the 0.984-level of the previous model, continued to reinforce the goodness of fit.

Table 4.4.26: Total effects of each variable in Model 4

	Macroeconomic	Institutional	NDCR	OECD	TF	RQ	RL	TO	GDP	ST	GBNO
Macroeconomic	1.000	0.391***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Institutional	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NDCR	0.645***	-0.022	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OECD	0.136	0.899***	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TF	0.000	0.926***	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
RQ	0.000	0.984	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
RL	0.000	0.978***	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
TO	-0.779***	-0.305***	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
GDP	0.969***	0.379***	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
ST	0.929***	0.363***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
GBNO	0.673***	0.327***	0.229***	0.105**	0.000	0.000	0.000	0.000	0.000	0.000	1.000

***p<0.01, **p<0.05, *p<0.1

Table 4.4.27: Total effects of latent and exogenous variables in Model 4

Determinants	Indirect Effects	Direct Effects	Total Effects
NDCR	0.000	0.229***	0.229***
OECD	0.000	0.105**	0.105**
Macroeconomic	0.162***	0.512***	0.673***
Institutional	0.290***	0.038	0.327***

***p<0.01, **p<0.05, *p<0.1

Table 2.2.28: P-value for each path Model 4

i	j	p-value
Macroeconomic	Institutional	0.000
OECD	Macroeconomic	0.000
OECD	Institutional	0.000
NDCR	Macroeconomic	0.000
NDCR	Institutional	0.000
RQ	Institutional	0.000
TF	Institutional	0.000
RL	Institutional	0.000
TO	Macroeconomic	0.000
ST	Macroeconomic	0.000
GDP	Macroeconomic	0.000
GBNO	OECD	0.164
GBNO	NDCR	0.000
GBNO	Macroeconomic	0.000
GBNO	Institutional	0.563

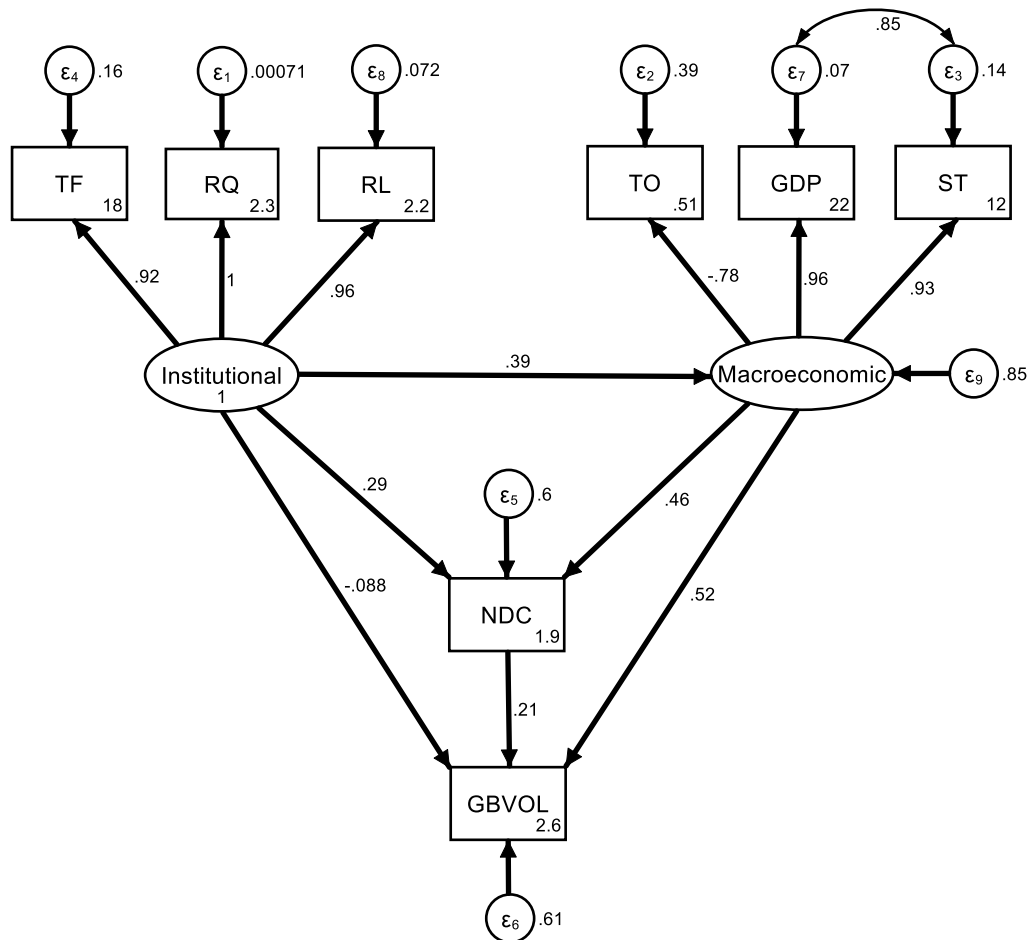
Table 4.4.29: Goodness-of-fit measures for Model 4

CFI_SB	0.965	Satorra-Bentler comparative fit index
TLI_SB	0.934	Satorra-Bentler Tucker-Lewis index
SRMR	0.035	Standardized root mean of squared residual
CD	0.984	Coefficient of determination

4.4.3.5. Model 5

Figure 4.4.6 shows the analytical results for the model with the volume of green bond issuances as the dependent variable. The main difference between this and the previous figures is that the OECD exogenous variable is excluded from the analysis. This is justified by 1) the

Figure 4.4.6: Structural equation model 5 – NDC scores, green bond issuance volumes, no OECD



frequent lack of statistical significance of the OECD path to the dependent variables GBVOL and GBNO and 2) to isolate and further examine the effects of the NDC exogenous variable that was originally constructed in this study. As was the case in all previous models, GDP and ST were assumed to covary and thus were connected with an arched line.

Standardized coefficients along the model path arrows depicted an unchanged, 0.39 correlation value for the institutional and regulatory environment latent variables. The former once again maintained a greater than 90% correlation with each of its manifest variables, while the correlation with the NDC variable increased to nearly 30% (at a value of 0.29). As consistently demonstrated in previous models, the correlation with GBVOL was negative and small in magnitude (-0.088).

The Macroeconomic variable had high correlations with each of its underlying variables, each of which was greater than 0.75 in magnitude. The largest was the GDP value of 0.98, and the smallest was with the TO value of -0.78 correlation with TO being the smallest. Moreover, the 46% positive correlation with NDC, as well as the 52% correlation GBVOL, are in the ballpark range of values estimated in previous models. Finally, the coefficient for NDC and GBVOL was 0.21, depicting a positive value that is relatively uniform with previous model estimates.

Table 4.4.32 displays the statistical significance of every intervariable path in Figure 4.4.6 All 12 paths portray 99% statistical significance, which is an improvement over the few statistically insignificant pathways revealed in the previous four models. Additionally, Table 4.4.30 depicts a matrix of total effects of each variable on every other variable, while Table 4.4.31 provides summarizes the indirect, direct, and total effects of each latent and exogenous variable on the green bond volume dependent variable.

The Macroeconomic latent variable had the largest, negative, highly statistically significant effect on TO, though to magnitudes of scale smaller than in previous models. It also portrayed a similar magnitude (~1.0 to ~2.0) of positive effects on NDC, GDP, and ST. Consistent with models 1 through 4, the largest, negative total effect of the Institutional latent

Table 4.4.30: Total effects of each variable in Model 5

	Macroeconomic	Institutional	NDC	TF	RQ	RL	TO	GDP	ST	GBVOL
Macroeconomic	1.000	0.388***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Institutional	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NDC	0.459	0.470***	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TF	0.000	0.917***	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
RQ	0.000	0.999	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
RL	0.000	0.963***	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
TO	-0.783***	-0.304***	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
GDP	0.964***	0.374***	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
ST	0.929***	0.360***	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
GBVOL	0.612***	0.209***	0.208***	0.000	0.000	0.000	0.000	0.000	0.000	1.000

***p<0.01, **p<0.05, *p<0.1

Table 4.4.31: Total effects of latent and exogenous variables in Model 5

Determinants	Indirect Effects	Direct Effects	Total Effects
NDC	0.000	0.208***	0.208***
Macroeconomic	0.095***	0.517***	0.612***
Institutional	0.298***	-0.088***	0.209***

***p<0.01, **p<0.05, *p<0.1

Table 4.4.32: P-value for each path in Model 5

i	j	p-value
Macroeconomic	Institutional	0.000
NDC	Macroeconomic	0.000
NDC	Institutional	0.000
RQ	Institutional	0.000
TF	Institutional	0.000
RL	Institutional	0.000
TO	Macroeconomic	0.000
ST	Macroeconomic	0.000
GDP	Macroeconomic	0.000
GBVOL	NDC	0.000
GBVOL	Macroeconomic	0.000
GBVOL	Institutional	0.004

Table 4.4.33: Goodness-of-fit measures for Model 5

CFI_SB	0.953	Satorra-Bentler comparative fit index
TLI_SB	0.912	Satorra-Bentler Tucker-Lewis index
SRMR	0.042	Standardized root mean of squared residual
CD	0.999	Coefficient of determination

variable was on TO, while the variable it had the largest positive total effects on was TF.

Regarding the total effects on the GBVOL dependent variable, Macroeconomic had the largest, statistically significant total effects value of 0.612. The Institutional variable total effects followed with a 99% statistically significant value of 0.209. Total effects of the NDC exogenous variable was also positive and statistically significant with a value of 0.208

Finally, the goodness-of-fit measures depicted in Table 4.4.33 showed acceptable values in four indices, as well as a high coefficient of determination. Specifically, the respective CFI and TLI values of 0.953 and 0.912, as well as the SRMR of 0.042, each indicated goodness of model fit. Measuring 0.999 and the highest value of depicted out of all five model analyses thus far, the coefficient of determination bolstered the robustness of the goodness of fit indices.

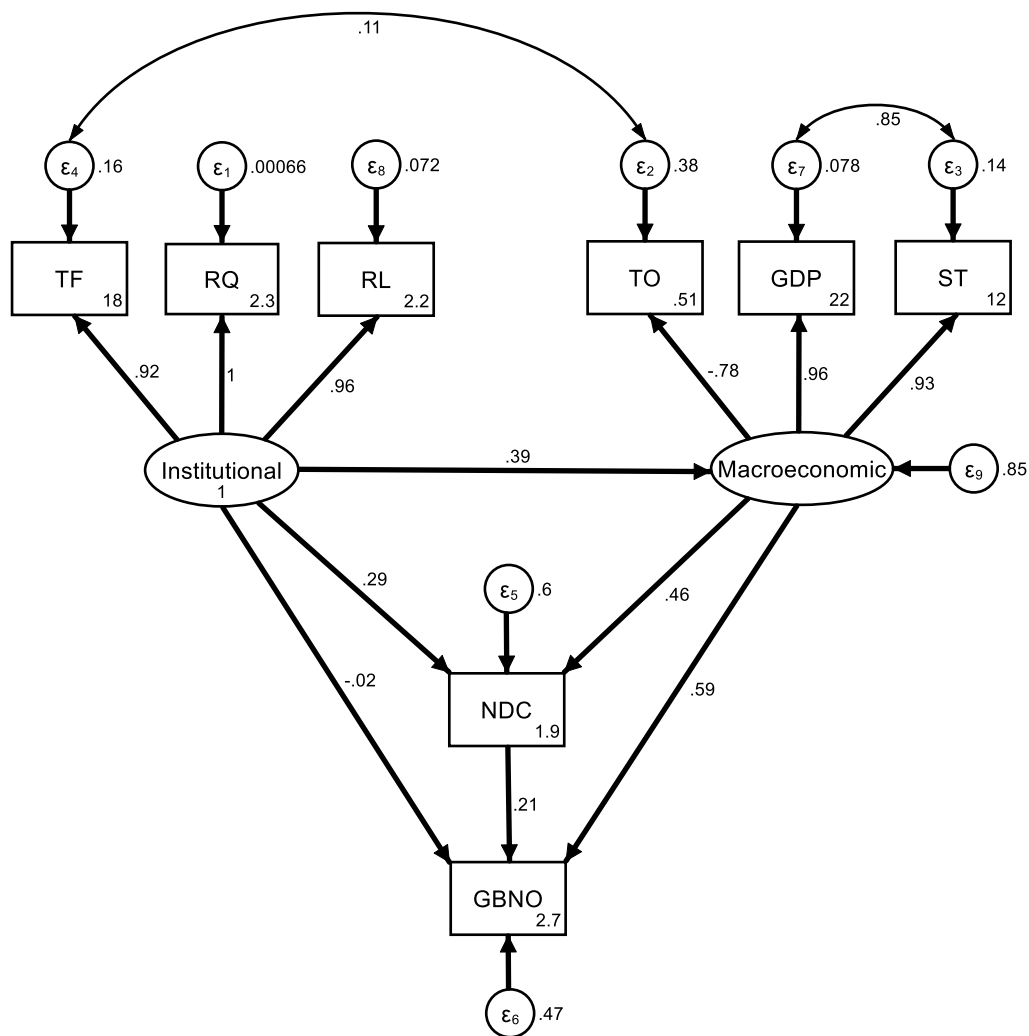
4.4.3.6. *Model 6*

Figure 4.4.7 shows the analytical results for the model with the presence or absence of green bond issuances as the dependent variable. Once again, the NDC variable is isolated as the solitary observed endogenous variable to perform a closer analysis of its total effects and statistical significance. While covariance was once again assumed for GDP and ST, this model also assumed covariance between TF and TO. This is reasonable as, the freer a country and its citizens are to trade (e.g. the higher the TF), the more their exports and trade openness (e.g. the higher the TO) would be.

Standardized coefficients along the model path arrows depicted an unchanged, 0.39 correlation value for the institutional and regulatory environment latent variables. The former once again maintained a greater than 90% correlation with each of its manifest variables, while the correlation with the NDC variable increased to nearly 30% (at a value of 0.29). As consistently demonstrated in previous models, the correlation with GBVOL was negative and small in magnitude (-0.02).

The Macroeconomic variable had high correlations with each of its underlying variables, each of which was greater than 0.75 in magnitude. The largest was the GDP value of 0.96, and the smallest was with the TO value of -0.78 correlation with TO being the smallest. Moreover,

Figure 4.4.7: Structural equation model 6 – NDC scores, green bond issuance numbers, no OECD



the 46% positive correlation with NDC, as well as the 59% correlation GBNO, were in the ballpark range of values estimated in previous models. Finally, the coefficient for NDC and GBNO was 0.21, depicting a positive value that was relatively uniform with previous model estimates.

Table 4.4.36 displays the statistical significance of every intervariable path in Figure 4.4.7. 11 of 12 paths portray 99% statistical significance, while the path from the Institutional

Table 4.4.34: Total effects of each variable in Model 6

	Macroeconomic	Institutional	NDC	TF	RQ	RL	TO	GDP	ST	GBNO
Macroeconomic	1.000	0.389***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Institutional	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NDC	0.461	0.470***	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TF	0.000	0.916***	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
RQ	0.000	0.999	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
RL	0.000	0.963***	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
TO	-0.784***	-0.305***	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
GDP	0.960***	0.373***	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
ST	1.806***	1.551***	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
GBNO	0.691***	0.310***	0.213***	0.000	0.000	0.000	0.000	0.000	0.000	1.000

***p<0.01, **p<0.05, *p<0.1

Table 4.4.35: Total effects of latent and exogenous variables in Model 6

Determinants	Indirect Effects	Direct Effects	Total Effects
NDC	0.000	0.213***	0.213***
Macroeconomic	0.098***	0.593***	0.691***
Institutional	0.331***	-0.020	0.310***

***p<0.01, **p<0.05, *p<0.1

Table 4.4.36: P-value for each path in Model 6

i	j	p-value
Macroeconomic	Institutional	0.000
NDC	Macroeconomic	0.000
NDC	Institutional	0.000
RQ	Institutional	0.000
TF	Institutional	0.000
RL	Institutional	0.000
TO	Macroeconomic	0.000
ST	Macroeconomic	0.000
GDP	Macroeconomic	0.000
GBNO	NDC	0.000
GBNO	Macroeconomic	0.000
GBNO	Institutional	0.470

Table 4.4.37: Goodness-of-fit measures for Model 6

CFI_SB	0.954	Satorra-Bentler comparative fit index
TLI_SB	0.909	Satorra-Bentler Tucker-Lewis index
SRMR	0.040	Standardized root mean of squared residual
CD	0.999	Coefficient of determination

latent variable exceeds the maximum p-value of 0.1 that deems acceptable statistical significance. Next, Table 4.4.34 provides a matrix of total effects of each variable on every other variable, while Table 4.4.35 summarizes the indirect, direct, and total effects of each latent and exogenous variable on the green bond issuance dependent variable.

The Macroeconomic latent variable had the largest, negative, highly statistically significant effect on TO, though to magnitudes of scale smaller than in previous models. It also portrayed a similar magnitude (~ 1.0 to ~ 2.0) of positive effects on NDC, GDP, and ST. Consistent with models 1 through 4, the largest, negative total effect of the Institutional latent variable was on TO, while the variable it had the largest positive total effects on was TF. Regarding the total effects on the GBNO dependent variable, Macroeconomic had the largest, statistically significant total effects value of 0.691. The Institutional variable total effects followed closely with a 99% statistically significant value of 0.310. Total effects of the NDC exogenous variable was also positive and statistically significant, measuring 0.213.

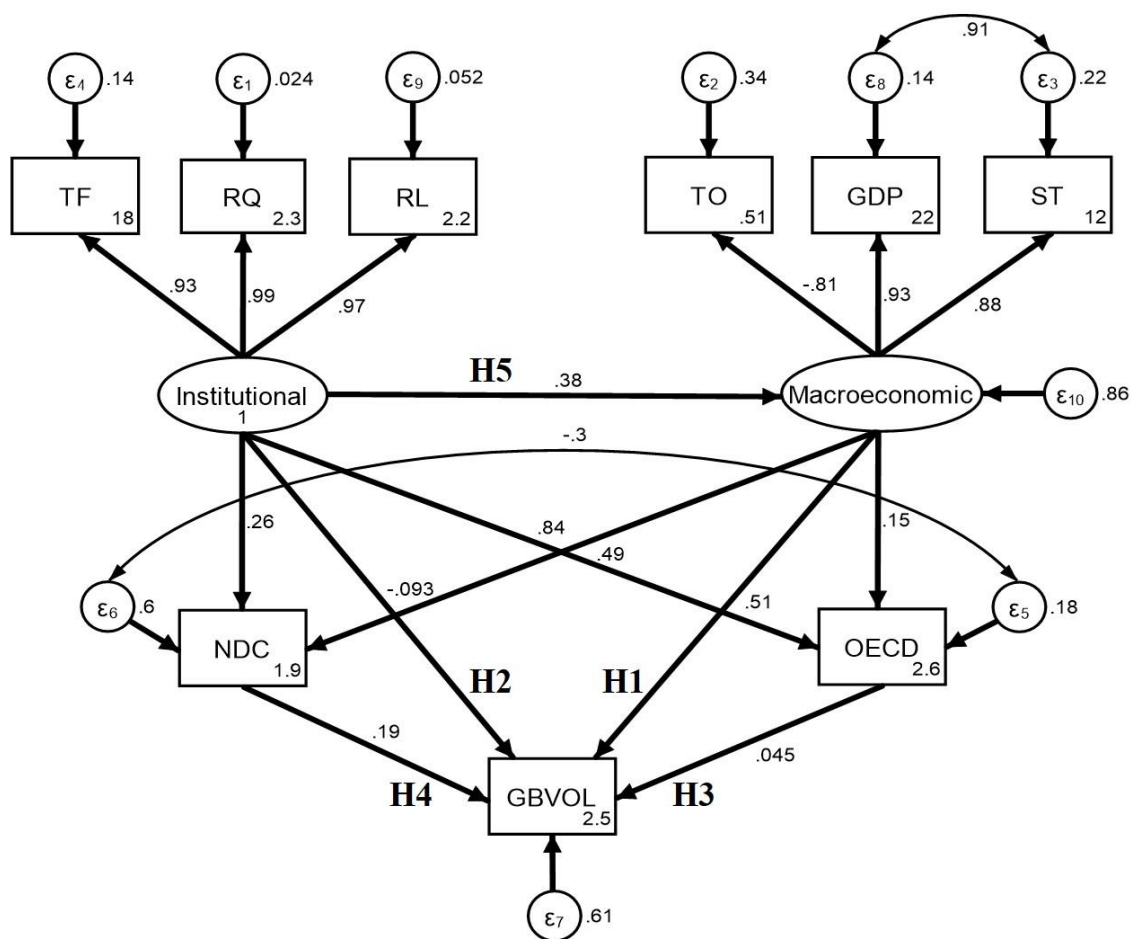
Finally, the goodness-of-fit measures depicted in Table 4.4.37 showed acceptable values in four indices, as well as a high coefficient of determination. Specifically, the respective CFI and TLI values of 0.954 and 0.909, as well as the SRMR of 0.04, each indicated goodness of model fit. Once again measuring 0.999, the high coefficient of determination bolstered the robustness of the goodness of fit indices.

4.4.3.7. *Master Model*

Pre-estimation correlation measurements showed substantial coefficients for certain variables, including 0.3621 for the OECD and NDC variables and 0.979 for ST and GDP variables. These correlations were appropriately represented by the curved, double-headed arrows connecting the variables mentioned. The theoretical underpinning for the former is that the development level of OECD countries provides the wherewithal to implement more robust NDCs. The latter correlation is also reasonable, as the size of the stock market varies positively with the size of the economy, regardless of its income group (Beck et al., 2009).

Based on these considerations and the aforementioned hypotheses, the SEM depicted in Figure 4.4.8 was constructed. The values beside the path arrows depict the mean standardized correlation coefficients of the variables. H1-H5 are labelled along the arrows that measure the path coefficients of the variable relationships predicted in their respective hypotheses. Table 4.4.38 provides the statistical significance for each path. 13 of the 15 paths portrayed 99% statistical significance. The path from OECD to GBVOL, as well as the path from Institutional to GBVOL, were the two statistically insignificant exceptions. Their respective 0.569 and 0.225 p-values were far above the maximally acceptable value of 0.1.

Figure 4.4.8: Structural equation model 7 – Master Model with hypotheses



Regarding the goodness of model fit, Satorra-Bentler CLI and TLI values were tested versus the saturated model because the Satorra-Bentler adjustments are robust to nonnormality. This was an important consideration due to the large sample size and diversity of data included in the analysis. Table 4.4.39 displays the goodness-of-fit indices for the model, and each measure shows acceptable values. Specifically, the 0.947 CFI and 0.901 TLI were both above the 0.9 minimally acceptable values and the SRMR was less than the 0.05 maximally acceptable value (Hu and Bentler, 1999). Furthermore, the high 0.986 coefficient of determination (CD) for the model reinforced the goodness of fit.

Table 4.4.38: P-values for each path in Master Model

i	j	p-value
Macroeconomic	Institutional	0.000
OECD	Macroeconomic	0.000
OECD	Institutional	0.000
NDC	Macroeconomic	0.000
NDC	Institutional	0.000
RQ	Institutional	0.000
TF	Institutional	0.000
RL	Institutional	0.000
TO	Macroeconomic	0.000
ST	Macroeconomic	0.000
GDP	Macroeconomic	0.000
GBVOL	OECD	0.569
GBVOL	NDC	0.000
GBVOL	Macroeconomic	0.000
GBVOL	Institutional	0.225

Table 4.4.39: Goodness-of-fit measures for Master Model

CFI_SB	0.947	Satorra-Bentler comparative fit index
TLI_SB	0.901	Satorra-Bentler Tucker-Lewis index
SRMR	0.043	Standardized root mean of squared residual
CD	0.986	Coefficient of determination

4.4.3.7.1. *Direct effects*

The coefficients for paths from Institutional to TF, RQ, and RL, as well as the path from Macroeconomic to GDP, were each positive and above 0.90. Though the path from Macroeconomic to TO showed a negative coefficient, it was similarly high in magnitude with a value of -0.81. The path from Macroeconomic to ST showed a similarly high 0.88 coefficient. Overall, each latent variable directly impacted its observed variables substantially, thus validating the variable groupings derived from the EFA.

The Macroeconomic latent variable displayed a 0.51 path coefficient with GBVOL, portraying it as the latent variable with the largest magnitude of direct effects on green bond issuance volumes in this model. This positive and statistically significant correlation validates H1. Macroeconomic also showed a 0.49 coefficient with NDC, and a 0.15 correlation with OECD in this model. This suggests that Macroeconomic factors greatly affect NDCs, though they are not strongly, directly determinative of OECD membership. Moreover, its coefficients with both NDC and GBVOL were more double those between Institutional and the same variables alluding to the comparative importance of Macroeconomic factors to each.

The Institutional latent variable had a -0.093 path coefficient for GBVOL. Though this direct measurement was small and negative, it is unlike each of the other coefficients with Institutional in that it is statistically insignificant. As discussed in the following subsection, it still

exerts considerable indirect effects that amount to a net positive impact on GBVOL that validates H2. Additionally, the respective 0.25 and 0.84 path coefficients from Institutional to NDC and OECD highlight the large magnitude of its direct effects on each.

The statistically insignificant (as portrayed in Table 4.4.38) 0.045 path coefficient for OECD and GBVOL reveals that in this model, OECD membership was not a coercive determinant of green bond issuances. This invalidates H3 which predicted OECD membership would positively influence green bond issuance volumes. By contrast, NDC showed a 0.19 correlation coefficient with GBVOL, depicting the largest positive exogenous variable impact on green bond issuance volumes that validates H4. This is also the second largest direct impact on GBVOL out of the four direct impacts assessed in this model, indicating the comparatively high degree to which NDCs directly influence green bond issuance volumes. Finally, the 0.38 coefficient for the path from Institutional to Macroeconomic reveals a considerable, positive impact of the former on the latter that validates H5.

4.4.3.7.2. Indirect and total effects

Table 4.4.40 provides an outline of the indirect, direct, and total effects of each latent and exogenous variable on the GBVOL dependent variable, while Table 4.4.41 shows a matrix of total effects of each variable on every other variable. While neither NDC nor OECD exerted any indirect effects on GBVOL, both Macroeconomic and Institutional showed positive, statistically significant indirect impacts. The 0.314 coefficient for Institutional indirect effects deserves attention for two reasons. First, it is nearly half the magnitude of the direct effects exerted by Macroeconomic on GBVOL, suggesting the broad range of impacts that Institutional must exert on other variables to ultimately influence GBVOL. Next, when combined with negligible direct

Table 4.4.40: Total effects of latent and exogenous variables in Master Model

Determinants	Indirect Effects	Direct Effects	Total Effects
NDC	0.000	0.187***	0.187***
OECD	0.000	0.045	0.045
Macroeconomic	0.099***	0.510***	0.609***
Institutional	0.314***	-0.093	0.221***

***p<0.01, **p<0.05, *p<0.1

Table 4.4.41: Total effects of each variable in Master Model

	Macroeconomic	Institutional	NDC	OECD	TF	RQ	RL	TO	GDP	ST	GBVOL
Macroeconomic	1.000	0.376***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Institutional	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NDC	0.492***	0.442***	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OECD	0.154	0.513***	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TF	0.000	0.926***	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
RQ	0.000	0.988	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
RL	0.000	0.974***	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
TO	-0.810***	-0.305***	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
GDP	0.928***	0.349***	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
ST	0.882***	0.332***	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
GBVOL	0.609***	0.221***	0.187***	0.045	0.000	0.000	0.000	0.000	0.000	0.000	1.000

***p<0.01, **p<0.05, *p<0.1

effects, it renders a statistically significant 0.224 coefficient of total effects on GBVOL that are roughly one third of total Macroeconomic effects and validate H2.

Total effects exerted on GBVOL by both Macroeconomic and Institutional point to their indirect effects through pathways with intervening variables. For Institutional, Table 4.4.41 reveals the substantial 0.376, 0.442, and 0.513 respective coefficients for total effects on Macroeconomic, NDC, and OECD that resulted in the aforementioned 0.314 indirect impact on GBVOL. Macroeconomic similarly exerted 0.492 total effects on NDC that led to the 0.099 indirect impacts on GBVOL. Both of these results are reasonable given that latent variables are the unmeasured constructs that affect many other variables both directly and indirectly.

Regarding the magnitude of total effects on GBVOL, the Macroeconomic latent variable had largest, statistically significant coefficient of 0.609. The Institutional variable followed with a 0.221 coefficient, while the NDC exogenous exerted the same 0.187 magnitude of its direct effects. Similar to NDC, OECD exerted zero indirect effects, so its total effects were analogous to the negligible, statistically insignificant 0.045 coefficient of its direct effects.

4.5. Discussion and policy implications

4.5.1. Discussion

The empirical results obtained through the SEM analysis validate four of the five SEM hypotheses H1-H5. H1 was validated as macroeconomic factors did in fact have substantial impacts on green bond issuance volumes. This echoes recent finance literature that notes influence of systemic macroeconomic determinants on green bond demand (Broadstock & Cheng, 2019) as well as the significant role of macroeconomic fundamentals in financial market performance more generally (Engle, 2013). Indeed, just as economic factors can mobilize green

venture capital into sustainable finance for cleaner production (Cheng et al., 2019), it is reasonable that they could similarly affect green bond issuances for similar purposes.

H2 was validated by the positive net effects that institutional factors mostly indirectly) on green bond issuance volumes. This positive result aligns with Ng (2018), which showed institutional factors to promote the issuance of green bonds and the overall integrity of green finance. They also compliment Staniskis and Stasiskiene (2003), which emphasized the importance of institutional capacities in financing cleaner production projects. Finally, they resonate with previous literature on the ramifications of underdeveloped institutional supports. For example, Pickering et al. (2015) noted that inadequate preparations from environmental and financial institutions undermine adaptation and mitigation investments, while Banga (2019) added that institutional barriers hinder green bond issuances and market growth.

H3, which predicted that OECD membership would promote green bond issuance volumes, was invalid. This may seem paradoxical given the higher tendency for OECD countries to issue bonds (as described in Section 4.3). However, this is reasonable given the growing number of high volume green bonds being issued in developing, non-OECD countries (especially China). For example, Barua and Chiesa (2019) found that the volumes of higher grade bonds issued in emerging markets are likely larger than those issued in non-emerging markets. Nevertheless, trends like the massive upscaling of the U.S. municipal green bond market issuances from roughly \$3 billion in 2014 to roughly \$10 billion in 2017 (Chiang, 2017) and the French government issuance of the record-setting €9.7 billion green bond in 2017 suggest that OECD members will continually increase their issuance volumes over time.

Confirmation of H4 that predicted the robustness of NDCs to have positive impacts on green bond issuance volumes is perhaps the most substantive finding of this study. Indeed, this

represented the largest impact of any single exogenous variable, accounting for nearly half of the direct impacts exerted by latent macroeconomic factors. This finding implies that the degree to which countries adopt robust, far-reaching NDCs affects the volume of their green bond issuances to meet climate and sustainability investment pursuits. This builds upon Flaherty et al., (2017), which found that “the issuance of green bonds could fund immediate investment in climate mitigation [policies] such that the debt might be repaid by future generations, those who benefit most from reduced environmental damages.”

Finally, H5 was validated as institutional factors exerted a nearly 40% direct influence on macroeconomic factors. This aligns with the findings of Keely and Ikeda (2017), where institutional variables showed a considerable impact on economic variables in a SEM analysis of foreign direct investments (FDI) in wind energy in developing economies. Furthermore, this alludes to the indirect impacts that institutional factors have on green bond issuance volumes through their ability to bolster the macroeconomic factors that the findings also show to be substantial green bond market drivers.

4.5.2. Implications for theory and practice of sustainability

The results of this study provide a number of theoretical and practical implications for sustainability. Regarding theory, (1) institutional and macroeconomic capital market factors that have been noted in preceding theoretical studies to drive conventional market growth also drive green bond market growth, and (2) these conventional market drivers promote sustainability by accelerating green bond market growth. Ultimately, these factors provide the investment context for governments and other issuers that find (green) bonds to be effective avenues for “tapping investors’ resources and shift[ing] them into non-conventional capital assets, which will become

increasingly important for long-term sustainability” (Yamaguchi and Managi, 2017). As the forces behind the increasing volumes of green bond proceeds allocations to renewable energy, low-carbon transportation, and other green investments around the globe, institutional and macroeconomic factors indirectly affect sustainability outcomes at both domestic and international levels.

The results also imply that in theory, (1) green bond markets have unique drivers in addition to conventional bond market drivers identified in theoretical literature, and (2) these drivers promote sustainability by inducing green bond market growth. In this study, NDCs were identified as one of the unique drivers, and their considerable influence on green bond markets resonates with historical evidence that global environmental initiatives provide the impetus for innovative sustainability financing. For example, the Clean Development Mechanism (CDM) under the Kyoto Protocol leveraged a certified emission reduction (CER) credit trading scheme to mobilize more than \$300 billion for 7,800 projects. This resulted in over 2 billion tonnes of carbon dioxide (CO₂) emissions reductions, 100,000 gigawatt hours (GWh) of annual renewable electricity generation, and 1 million efficient cook stove installations (UNFCCC, 2018).

As a policy successor to the Kyoto Protocol, the Paris Agreement similarly stands to apply financial resources from an ever-expanding set of climate and sustainability investment vehicles. One is the Green Climate Fund (GCF), which funneled \$5.6 billion in loans and grants into the 111 climate-resilient and low-emission projects behind 1.5 billion tonnes of avoided CO₂ emissions (Green Climate Fund, 2019). Others are Paris-aligned, labelled green bonds. A mere 4% of all global issuances (\$58 billion) funded 1,851 assets responsible for over 108 million tCO_{2e} in emissions reductions, 1,500 gigawatts (GW) of renewable energy capacity, 57,000 gigawatt hours (GWh) of renewable energy generation, and 737 GWh in energy savings from

2008 to 2017 alone (Tolliver et al., 2019). The findings of this study therefore suggest green bonds to be links that connect NDC targets with the sustainability outcomes urged by the overarching Paris framework.

Regarding practical implications, institutional aspects that underlie capital account openness, regulatory quality, and rule of law are less determinative of green bond market growth than macroeconomic aspects that underlie the size of the economy, the percentage of trade within the economy, and amount of stock market capitalization. As such, countries pursuing sustainability agendas using green bonds should prioritize bolstering macroeconomic factors conducive to conventional capital market formation. An additional theoretical implication of this is that although environmental concerns integral to sustainable development “in almost every case...have not been sufficiently integrated with economic sectors and decision-making...” (Sneddon et al., 2006), green bond markets driven by macroeconomic factors stand to link the economy with sustainable development.

One final practical implication involves the potential for NDCs to lower sustainability investment costs by accelerating green bond market growth. At the corporate level, the cost of bond financing is likely lower than equity investments, and lower monitoring costs and dispersed ownership can make fixed income products (e.g. bonds) lower cost alternatives to bank loans (Ng et al., 2016). The degree to which countries enhance their NDCs will affect green bond market growth and thus affect the cost and feasibility of sustainable development.

4.6. Conclusions

There are wide gaps between commitments to the Paris Agreement and actual investments at the country level, and major shifts in financial flows toward low-carbon

infrastructure will be required to bridge these gaps (Peake and Ekins, 2016). Green bond markets are growing precipitously to meet this demand for climate and sustainability investments. The bonds themselves offer issuing firms the opportunity to expand their green investment capacity by attracting both institutional and socially responsible investor (SRI) funding to environmentally-friendly projects. Considering the expanding role of green bonds as investment vehicles for cleaner production and sustainable outcomes, this study used a sample of \$319 billion outstanding in green bond issuances across 49 countries from 2007 to 2017 in an exploratory factor analysis (EFA) and structural equation modelling (SEM) to examine the drivers behind green bond issuance volumes.

Following a literature review of green bond market barriers, pricing comparisons of green and conventional bonds, and theoretical and empirically tested capital market drivers, exploratory factor analysis was performed to create Institutional and Macroeconomic latent factors that underlie manifest variable groupings. Thereafter, this study set literature precedent by constructing an original normalized index to calculate robustness scores for country-specific NDCs. NDC index scores and an OECD membership dummy variable were then added as exogenous variables alongside the latent factors to perform a structural equation model analysis.

This study provides the first SEM-based quantitative assessment of green bond market drivers. The results shed light on how factors that are known to impact conventional corporate and sovereign bond market growth affect green bond markets expansion as well. The results are also the first to show NDC impacts on green bond market capitalization. Specifically, the findings reveal that:

1. Macroeconomic drivers behind conventional capital market growth that underlie the size of the economy, stock market capitalization, and trade openness also drive green bond market growth;
2. Institutional drivers behind conventional bond growth that underlie capital account openness, rule of law, and regulatory quality also drive green bond market growth, but indirectly;
3. OECD membership has a negligible impact on green bond market growth;
4. NDCs have the largest direct impacts (path coefficient: 0.19) of any exogenous variable on green bond market growth; and
5. Institutional factors exert considerable influence on macroeconomic factors, which indirectly affects green bond issuance volumes.

These findings also provide a number of theoretical and practical implications for sustainability, including:

1. Macroeconomic and institutional drivers of conventional capital market growth promote sustainability by accelerating green bond market capitalization;
2. Beyond conventional capital market determinants, NDCs are among the unique drivers of green bond market growth that promote sustainability as a result;
3. Institutional improvements should follow macroeconomic improvements in the pursuit of sustainability via green bond finance;
4. Green bond market growth stands to bridge the gap between economic factors and sustainability, and
5. NDCs are key to bringing down the firm costs of pursuing sustainability investments by promoting green bonds as lower cost finance alternatives.

A few remaining considerations could be addressed in subsequent research. First, as the earliest green bonds were issued before the NDCs were officially submitted, it is likely that a number of additional environmental policies that align with the intended uses of green bond proceeds drove green bond issuances at various points in time. The climate, energy, and natural resource use mandates of the EU 20-20-20 Plan, China's 11th and 12th Five-Year Plans, and the U.S. Clean Air and Clean Water Acts all represent macro-level directives that may have yet unmeasured impacts on green bond finance for infrastructure that enhances sustainability. Similarly, the impact that particular targets within NDCs have on green bond issuances deserves attention. In this study, renewable energy capacity additions, forest management, and all other specific actions were broadly incorporated into NDC score calculations. Analyzing the stringency of individual NDC target actions may reveal key insights into how each affects green bond finance for climate, sustainable development, and cleaner production investments.

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Appendix 4A

Table 4A: Metrics and calculation rubric for normalized index of Paris Agreement Nationally Determined Contributions robustness

1. Mitigation contribution type	Score
Not specified	0
Actions only	1
Non-GHG reduction target ¹ only	2
Non-GHG reduction target and actions	3
GHG reduction target ²	4
GHG reduction and non-GHG reduction targets	5
2. Single or multi-year mitigation target³	Score
Not specified	0
Single-year target	1
Multi-year target	2
3. Long-term mitigation target⁴	Score
No long-term target	0
Long-term target	1
4. GHG scope	Score
Not specified	0
Fewer than six Kyoto Gases ⁵	1
Six Kyoto Gases	2
Six Kyoto Gases and Black Carbon	3
Seven Kyoto Gases or equivalent	4
5. Non-GHG scope	Score
Not applicable	0
Single non-GHG target	1
Multiple non-GHG targets	2
6. Percentage of national emissions covered	Score
Not specified	0
1% - 50%	1
50% - 99%	2
100%	3
7. GHG reduction target type	Score
None or not specified	0
Trajectory target	1
Baseline scenario target	2
Base year intensity target	3
Base year intensity and trajectory targets	4
Base year emissions or fixed-level target	5

8. Breadth of covered economic sectors	Score
Not specified	0
Partial sectors	1
All sectors excluding LULUCF ⁶	2
All sectors including LULUCF	3
9. Conditionality	Score
Not specified	0
Conditional	1
Partially conditional	2
Unconditional	3
10. Transparency and progress traceability	Score
Not specified	0
Host country methodology	1
Pre-2006 IPCC guidelines	2
2006 IPCC guidelines	3
Multiple guidelines (including 2006 IPCC)	4
11. Use of international market mechanisms⁷	Score
Not specified	0
Unintended	1
Potential	2
Intended	3
Total Score	35

¹Non-greenhouse gas (GHG) emission reduction targets conventionally include renewable energy implementation and forestry preservation or development targets.

²The United Nations International Panel on Climate Change (IPCC) defines six measures for achieving greenhouse gas emission reduction targets, each included in subsection 3 of this index.

³Single-year targets require emissions reductions to reach a certain threshold by a single pre-determined year, while multi-year targets require yearly emissions reductions towards a final threshold level. The latter promotes greater cumulative emissions reductions.

⁴Most NDCs outline targets that fall between the years 2021 and 2030, including penultimate targets for 2030. Long-term targets build upon 2030 and pre-2030 targets, usually extending to 2050.

⁵Kyoto Gases include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF₆), and nitrous trifluoride (NF₃).

⁶Land use, Land use change, and Forestry is denoted LULUCF by the IPCC.

⁷International market mechanisms mentioned in the literature include the European Union Emissions Trading System, Clean Development Mechanisms, and other bilateral, regional, and international procedures that may be established in accordance with the Paris Agreement.

Chapter 5: Policies supporting green bonds for sustainable energy

The International Energy Agency (IEA) New Policies Scenario projects global energy demand to grow by a quarter as the global population increases by 1.7 billion people through 2040 (IEA 2018). Simultaneously the IEA Sustainable Development Scenario (SDS) instructs to reduce the fossil fuel share of energy supply investment by 40% through 2030 and to increase the share of renewable power in total energy supply to 60% by 2040 to achieve the three energy-related United Nations Sustainable Development Goals (UN SDGs). It also supports the Paris Agreement mandate to restrict global average temperature rises over the 21st century to well below 2 °C (IEA, 2018). Each framework implies a substantial scaling-up of the \$1.8 trillion (USD) in global energy investments (IEA, 2018) observed in 2018.

A number of policy supports are behind the growing trend in clean energy investments. The International Energy Agency and International Renewable Energy Agency (IEA/IRENA) Joint Policies and Measures Database (2019) classifies policy supports into six categories: (1) Economic Instruments, (2) Information and Education, (3) Policy Support, (4) Regulatory Instruments, (5) Research, Development and Deployment (RD&D), and (6) Voluntary Approaches. Within these, feed-in-tariffs (FiT), renewable portfolio standards (RPS), tradeable renewable energy certificates (REC), and tax incentives are among the most widely applied policy supports with empirically tested significant impacts on renewable energy deployment.

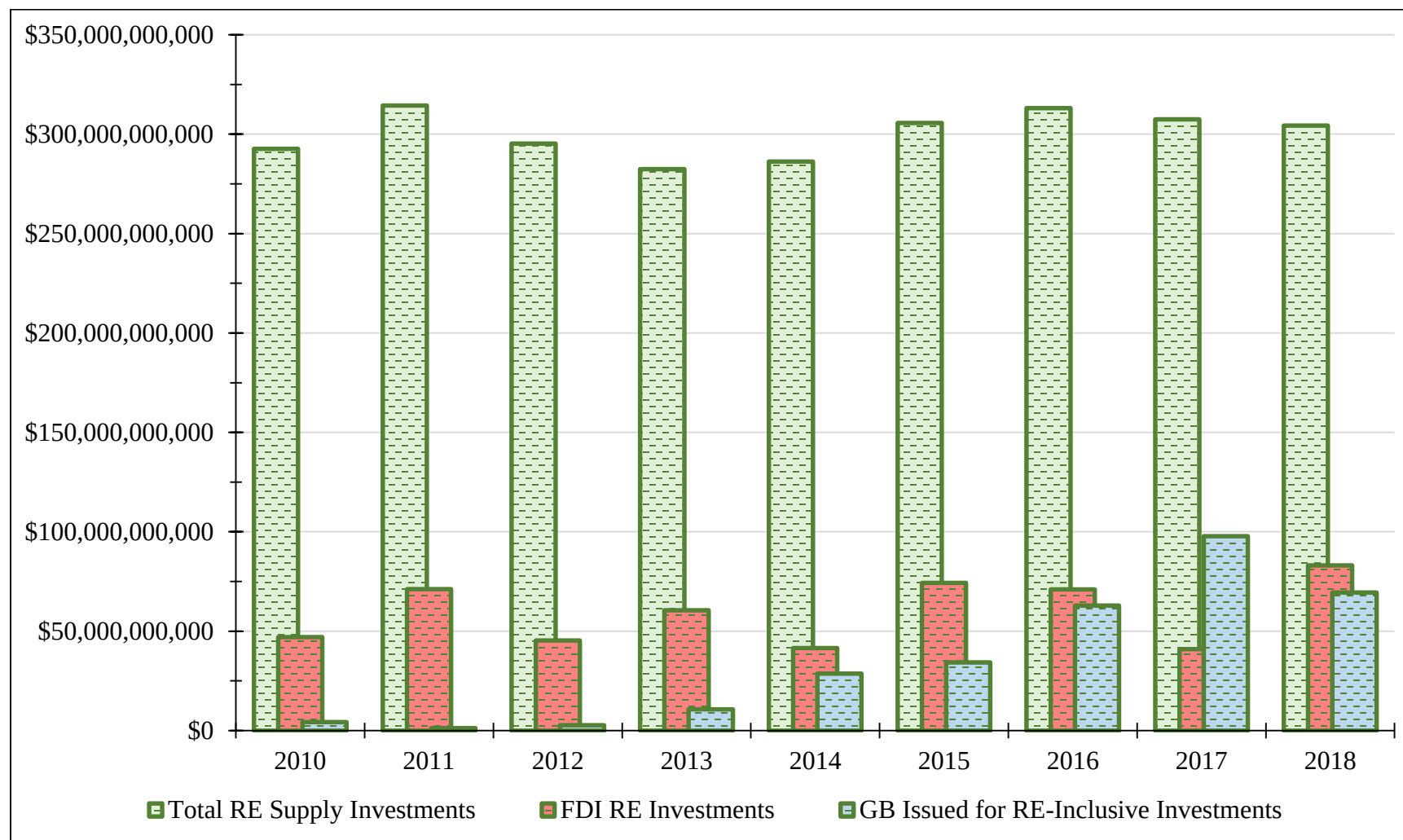
Nationally Determined Contributions (NDCs) country-specific pledges to demonstrate progress towards the greenhouse gas (GHG) emissions reductions, sustainable development, and poverty eradication objectives of the Paris Agreement from 2020 onward. In addition to specific GHG emissions reduction targets, NDCs outline actions for increasing renewable energy (RE) capacity and RE share of total power generation, using land and managing forests sustainably,

and other targets relevant to the host country's circumstances and local development level. With three quarters of all NDCs aiming to employ renewable energy to mitigate climate change, and over half of all NDCs providing specific renewable energy targets (IRENA, 2017), NDCs are likely to impact renewable energy investments in both developed and developing countries.

Defined by the International Capital Market Association (ICMA) Green Bond Principles (GBP) (2018) as “any type of bond instrument where the proceeds will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible Green Projects,” green bonds are increasingly employed as renewable energy investment vehicles. From 2010 to 2017, green bond issuances in which at least some of the proceeds were earmarked for renewable energy or energy efficiency investments rose from roughly \$4.3 billion to around \$97.8 billion (Climate Bonds Initiative, 2018). Figure 6.1 depicts annual growth trends among green bonds issued for at least partially for renewable energy investments, foreign direct investment (FDI) in renewable energy projects, and total global renewable energy supply investments between 2010 and 2018. Note that the slight decline in 2018-year green bond issuances reflects a lack of data availability at the time of data sampling of this study. Regardless, although the three sources may overlap in some cases, green bonds issuances for renewable energy are increasing relative to total supply investments and FDI. This suggests green bonds will continue to be important tools for renewable energy investments through the future.

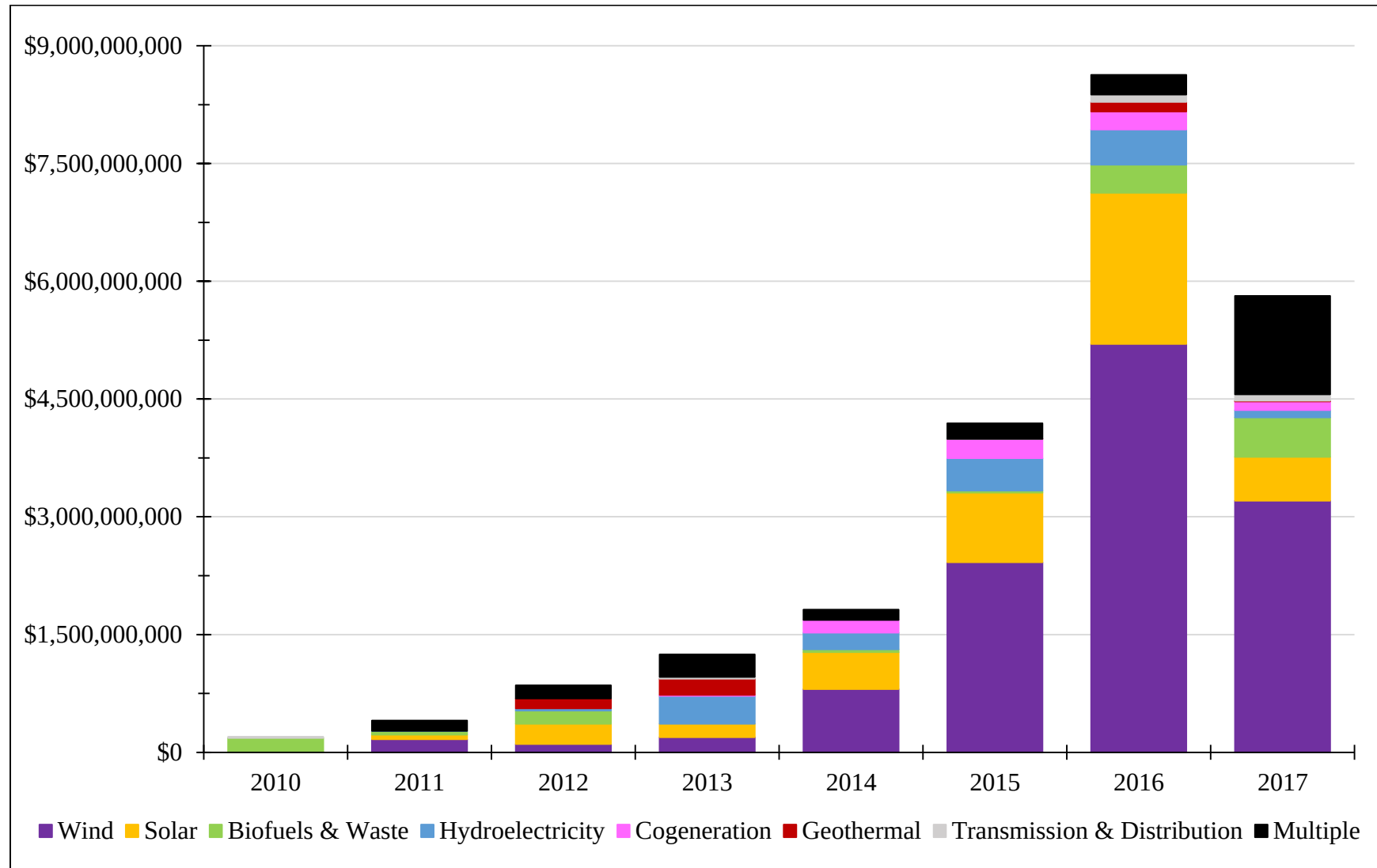
For a closer look at how green bond finance has been applied over a similar time span, Figure 6.2 displays green bond proceeds allocations from 53 major issuers to eight renewable energy categories. Though the drop in 2017-year allocations is explained by sparseness of data

Figure 5.1: Green bond and foreign direct investment as a share of global renewable energy supply investments, 2010 - 2018



Source: Created by author using IEA World Energy Investment 2019 (Total RE Supply Investments), Climate Bonds Initiative Q3 2018 Database (2018) (GB Issued for RE-Inclusive Investments, Financial Times Ltd. fDi Intelligence fDiMarkets Data (2019) (FDI RE Investments)

Figure 5.2: Annual green bond proceeds allocations by renewable energy category, 2008 - 2016



Source: Original green bond proceeds allocations data created by author

during the data collection period of this study, the overall growth trends from just under \$200 million in 2010 to over \$8.6 billion by 2016 suggest greater volumes of green bond funding will finance renewable energy investments in years to come. Moreover, with the 75%, 20%, and 50% respective capital cost decreases for solar photovoltaic (PV), onshore wind, and battery storage technologies driving the 55% increase in renewable power investments since 2010 (IEA, 2019), rising green bond allocations to the first two of these three technologies are in stride with global developments. Due to their links to investments that yield positive environmental outcomes, understanding the climate agendas and renewable energy policy supports that promote green bond proceeds allocations to renewable energy projects and assets is crucial to advancing climate and sustainable development agendas.

5.1. Empirical assessments of renewable energy policy supports

An extensive literature base is dedicated to measuring the impacts that various policy supports exert on renewable energy proliferation. Carley (2009) used a fixed effects vector decomposition with U.S. state government data from 1998 to 2006 to empirically evaluate the link between renewable portfolio standard (RPS) policy implementation and the percentage of renewable energy electricity generated. Their results showed that the influence of RPS policies on renewable energy generation increases is a function of the number of years that the policies are in place. Delmas and Montes-Sancho (2011) used two stages of regressions to assess the impact of state-level RPS and mandatory green power options (MGPO) on renewable energy capacity investments among 650 electric utilities throughout 48 states from 1998 to 2007. They found that investor-owned utilities invest more than publicly owned utilities in response to RPS, and MGPO leads to greater amounts of green electricity and installed renewable capacity.

Pfeiffer and Mulder (2013) use two-stage estimation methods to assess non-hydro renewable energy adoption drivers in 108 countries from 1980 to 2010. Their results show that economic (e.g. direct infrastructure investments) and regulatory (e.g. auditing, codes, standards) instruments, per capita income, schooling levels, and democratic regimes positively affect renewable energy diffusion while foreign aid, fossil fuel production, growth in electricity consumption, and policy support programs hinder diffusion. Finally, Polzin et al. (2015) conducted panel data regression for the 2000 to 2011 time period to examine the effect that economic, fiscal, and other incentives and supports had on private institutional investments in renewable energy throughout OECD countries. Their results showed that for monetary, fiscal, and economic incentives such as feed-in-tariff and direct investments were the most relevant policy measures for investors in the wind, solar, and biomass sectors.

Additionally, many studies employ difference-in-differences estimations to measure the impact of renewable energy policies on renewable energy generation, consumption, prices, demand, and other variables of interest. Assessing the impacts of state-level RPS implementation on renewable generation investments from 1990 – 2010, Fabrizio (2012) showed that while states with prior regulatory policy instability did not experience greater renewable generation investment, firms did still positively respond to RPS policy initiatives to invest in location-specific, long-lived assets. At the California state level, Kirkpatrick and Benneer (2014) demonstrated Property-Assessed Clean Energy (PACE) programs established between 2008 and 2010 led to a 108% increase in mean solar watt installations per household. Shrimali et al. (2015) used a 50-state panel dataset for the years 1990 to 2011 to examine national and state policy impacts on U.S. wind energy deployment. They show that among the available policy measures, the national production tax credit is effective and also influences state-level policies that promote

wind development. Finally, Upton Jr. and Snyder (2017) estimate the impact of RPS on renewable energy generation, electricity prices, associated emissions, and electricity demand in 49 states from 1990 to 2013 to find that RPS states experiences less renewable energy growth, greater electricity prices, and no substantial difference in renewable energy generation compared with non-RPS states.

With the European Investment Bank €600 million (roughly \$848 million) issuance of its Climate Awareness bond in 2007 marking the inauguration of the green bond market, there is a gap in existing literature on the policy factors driving green bond investments. In particular, as labelled green bonds are issued under certification schemes that guarantee their proceeds are earmarked to renewable energy and other investments conducive to Paris Agreement, UN SDGs, and IEA SDS outcomes, there is a need for empirical assessments of the policy drivers behind growing proceeds flows to low-carbon, sustainable energy projects and assets. Furthermore, from the trends visible in Figures 6.1 and 6.2, the majority of growth in both green bond issuances and proceeds allocations for renewable energy investments coincided with the formation of the Intended Nationally Determined contributions (INDCs) in 2015 through the submission of official NDCs at the end of 2016. The primary objective of this study, therefore, is to measure the impact that NDCs have on the growing volumes of green bond proceeds allocations to renewable energy investments. An additional aim is to assess the degree to which economic, regulatory, and fiscal policy supports for renewable energy investments also influence green bond proceeds allocations to renewable energy projects and assets. In doing so, this is the first study to examine the degree to which both NDCs and other policy measures affect green bond funding for renewable energy assets.

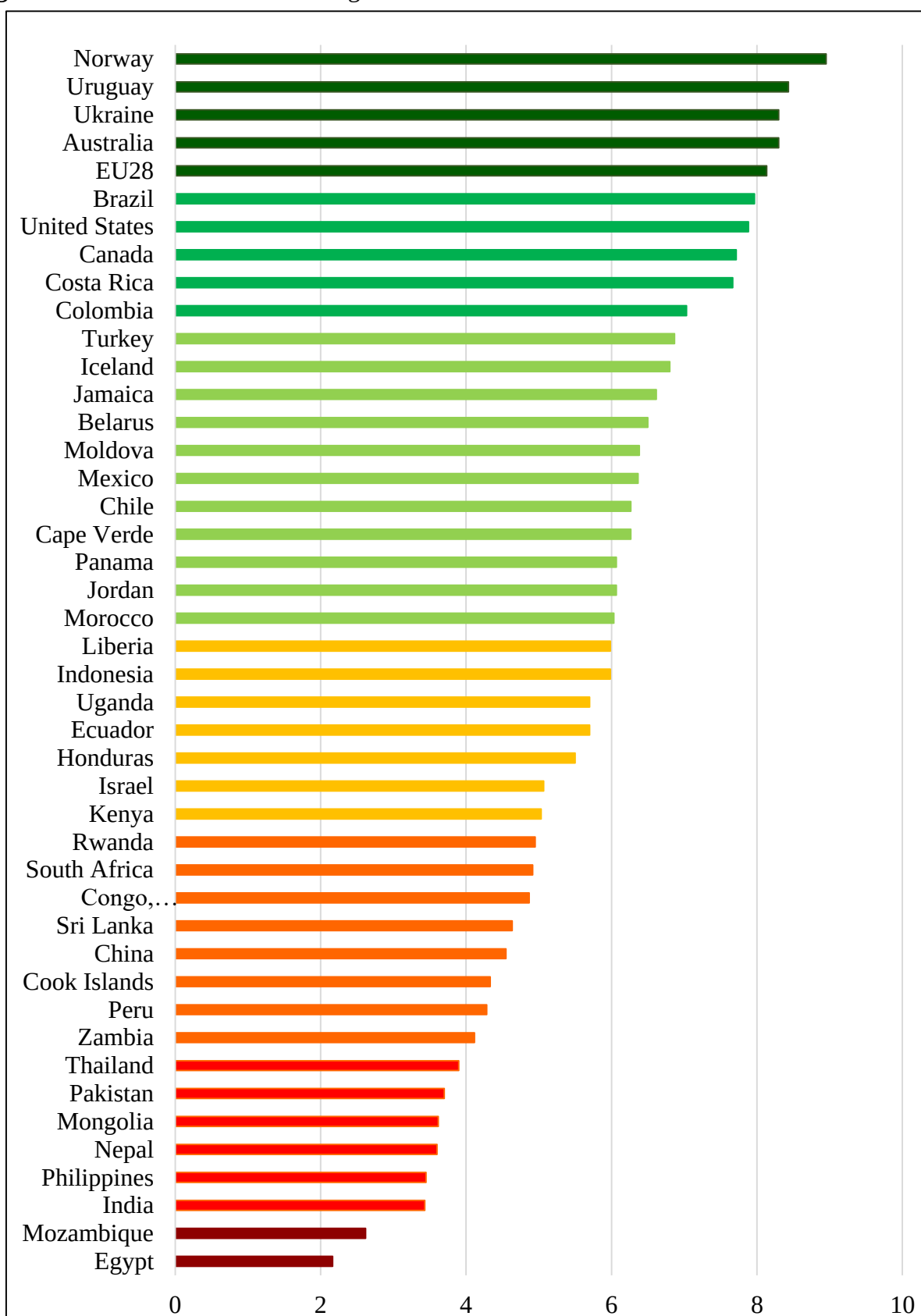
5.2. Data

A panel dataset including nearly \$20 billion in green bond proceeds allocations to renewable energy assets in 43 countries and 20 European Union (EU) countries during the years 2008 through 2016 was created by the authors using post-issuance reports published by 53 green bond issuing organizations. These organizations were among the 103 listed in an overview of publicly-available post-issuance reporting published by the Climate Bonds Initiative (2017). Data was selected based upon the availability of 1) the names, domiciles, and institutional structure of issuing organizations; 2) the location, green investment category (e.g. renewable energy.), of projects or assets financed (at least partially) with the proceeds; and 3) the year, frequency, and volume of allocated proceeds.

To measure the correlation between NDCs and green bond issuances, an NDC robustness index was constructed based upon the original methodology employed by Tolliver et al. (2019b). The index comprises 11 categories, each with scores assigned based upon the strength of the underlying NDC commitments. To calculate final index scores for each country assessed in this study, the scores for each index category were normalized and summed. The index categories and scoring rubric are listed in Table 4A in the Appendix of Chapter 4. These scores were employed as the dependent variable in the subsequent DiD analysis. NDC robustness index scores for each country of this study are displayed in descending order in Figure 6.3.

Three original dummy variables were also constructed using data from the International Energy Agency/International Renewable Energy Agency (IEA/IRENA) Joint Policies and Measures database to control for country-specific renewable energy policy supports. In a given year, countries that implemented or adhered to existing renewable portfolio standards (RPS) or obligation schemes, feed-in-tariffs (FiT), or tradeable renewable energy certificates (REC) were assigned a value of “1” to the RE ECONOMIC binary variable. Countries that implemented or

Figure 5.3: NDC scores in descending order



adhered to existing building codes, monitoring requirements, strategic planning for renewable implementation, or other top-down mandates were assigned a value of “1” to the RE REGULATORY binary variable. Finally, countries that implemented or adhered to existing tax credit or exemption schemes, direct public infrastructure investments, or public loans, grants, or subsidies were assigned a value of “1” to the RE FISCAL binary variable.

5.3. Methods

Difference-in-difference (DiD) estimation uses longitudinal data separated into treatment and control groups to estimate causal effects. As it is useful in comparing outcome changes in data populations that undergo a treatment and populations that remain untreated, it is often used in economic studies to estimate the effects of policy enactments, legal code ratifications, economic environments or other new implementations.

Specifically, once treatment and control groups are created, outcomes are observed for two time periods for each group. Then, the former group is exposed to treatment only in the second period, while the latter group is not exposed to treatment in any period. Since biases could result from permanent differences between the groups as well as from trends that affect comparisons in the treatment group over time, the average gains in the control group are subtracted from average gains in the treatment group.

The DiD regression model for this study can be written as follows:

$$REGB_{it} = \beta_0 + \beta_1 TIME_t + \beta_2 NDC_i + \beta_3 NDC_i * TIME_t + \beta_4 ECONOMIC_{it} + \beta_5 REGULATORY_{it} + \beta_6 FINANCIAL_{it} + \varepsilon_{it} \quad (5.1)$$

where:

$REGB_{it}$ is the dependent variable that indicates the volume of green bond proceeds allocations to renewable energy;

$TIME$ is the dummy variable that indicates the start of the treatment period;

NDC_i is the group exposed to the treatment;

$NDC_i * TIME_t$ is the interaction between the treatment period and treatment group;

$ECONOMIC_{it}$ is a binary control variable for economic policy supports;

$REGULATORY_{it}$ is a binary control variable for regulatory policy supports; and

$FINANCIAL_{it}$ is a binary control variable for financial policy supports.

Table 5.3 shows the summary statistics for the variables included in the model.

Table 5.3: Summary statistics for the Difference-in-differences analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
REGB	567	3.42E+07	1.73E+08	0	2.62E+09
Time	567	0.1111111	0.3145472	0	1
NDC	567	0.713026	2.109969	0	8.571429
NDCTime	567	0.0546737	0.227543	0	1
REGULATORY	567	0.5820106	0.4936639	0	1
FINANCIAL	567	0.1410935	0.3484253	0	1
ECONOMIC	567	0.021164	0.144058	0	1

5.4. Results and discussion

5.4.1. Difference-in-differences (DiD) results

Table 6.4 shows the difference in difference estimation results. The NDC treatment group $NDC*TIME$ showed positive, statistically significant impact on the Total RE Allocation Volumes dependent variable. Indeed, this relationship showed the largest impact on the RE allocations as demonstrated by the 9.99 E+07 magnitude of its correlation coefficient. In order of

magnitude, binary variable policy support controls FINANCIAL, ECONOMIC, and REGULATORY also showed positive, statistically significant results. Overall, these results reveal NDCs as unique factors that promote green bond finance for renewable energy and also that conventional policy drivers of renewable energy investments similarly affect green bond allocations.

Table 5.4: Difference-in-differences results

Total RE Allocation Volumes	Coef.	Robust Std. Err.	t	P>t	[95% Conf. Interval]
Time	1876369	6353165	0.3	0.768	-1.06E+07 1.44E+07
NDCDiD	2.21E+08	9.99E+07	2.21	0.028	2.45E+07 4.17E+08
ECONOMIC	6.64E+07	3.73E+07	1.78	0.076	-6866203 1.40E+08
REGULATORY	1.29E+07	7504554	1.72	0.085	-1798053 2.77E+07
FINANCIAL	6.81E+07	3.95E+07	1.72	0.085	-9518301 1.46E+08
_cons	3335188	7136249	0.47	0.64	-1.07E+07 1.74E+07

5.4.2. Discussion and policy implications

Ever since its implementation, the Paris Agreement has been credited with progressively altering global energy investment patterns. Kern and Rogge (2016) note that as of 2015, Paris-led “global capacity additions in renewable electricity (53.6%) have surpassed those in conventional technologies, and global investment in renewables was more than double the amount allocated to new coal and gas generation.” The highly significant correlation coefficient between Paris NDCs and RE allocations empirically reinforces this notion and alludes to the substantive impact that country-level Paris pledges have on renewable energy investments. Indeed, renewable energy investments are conducive to national pledges to the Paris Agreement that reflect a number of

varying incentives, including (1) creating local, national, and public goods of reduced climate change, (2) generating competitive economic benefits such as new industries (e.g. solar and wind power, energy storage technologies), (3) bargaining for side-payments, and (4) creating reputational benefits (Keohane and Victor, 2016). Moreover, the national government-drafted NDCs would naturally promote greater renewable energy investments, as “nation states have the most obvious mandate to govern energy systems” and “it is at the national level where some of the most significant decisions to steer energy systems to avoided dangerous climate change are and will be made” (Cherp et al., 2018). Green bond allocations to renewable energy thus reflect NDCs stringency and the demand for renewable energy as a key component of achieving GHG emissions reductions. Moreover, countries that wish to enhance their investments in renewable energy capacity should ensure they have contributed robust, progressive, green bond allocation-inducing NDCs to the Paris Agreement.

The positive impact of economic policy supports on renewable energy demonstrated by the results of this study echo an extensive line of related research. Couture and Gagnon (2010) stated that fixed price FiTs enhance investment security and encourage greater, lower-cost renewable energy deployment by offering “remuneration that is independent from prevailing electricity prices that can help lower investment risks” and creating “greater predictability of future cash flows.” Mahone et al. (2009) noted that increasing RPS targets effectively “raises the cost-effective level of energy-efficiency investment” that aids the expansion of clean, sustainable, renewable energy. Tradeable renewable energy certificates are also notable economic policy measures, lauded as “one instrument having the potential to induce sufficient investment in RE in a cost-efficient way and compatible with a liberalized energy market” (Nielsen and Jeppesen, 2003). With 62% (roughly \$327 billion) of all green bonds being issued

in the North American and European regions in which many renewable energy economic policy measures were pioneered, it's reasonable to expect such policies have and will continue to incentivize green bond allocations through the decades to come.

The results that showed regulatory policy supports to exert positive effects on green bond proceeds allocations to renewable energy investments is also supported by previous studies. Technical standards such as grid codes support renewable energy investments, while those that “are not aligned with international standards could drive up costs and act as a de facto market-access barrier” (Keeley and Matsumoto, 2018). Codes and standards can also promote rapidly growing renewable energy sectors such as solar PV by offsetting the comparatively high costs of renewable energy by enhancing energy efficiency (Wei et al. 2010). Moreover, strategic planning aids in creating effective renewable energy investment frameworks by influencing public research funding allocations that lead to often irreversible path dependencies and may affect investment decisions among financial, corporate and retail investors (Wüstenhagen and Menichetti, 2012). More generally, Pfeiffer and Mulder (2013) found regulatory support measures to have strong effects on renewable energy technology diffusion. The results of this study align with these and similar findings throughout the literature.

Finally, the strong, statistically significant correlation coefficients between financial policy supports and green bond allocation volumes is consistent with the findings throughout relevant literature. Tax credits can aid in alleviating private sector financial constraints of renewable energy project investments by reducing uncertainty and making market entry more profitable (Nesta et al., 2014). Direct public infrastructure investments spur renewable energy deployment (Polzin et al., 2015), while such public and private financial supports as grants and loans towards capital or operational costs are notably influential in renewable energy integration

(Abdmouleh et al., 2015). As debt securities, green bonds complement each of the aforementioned financial policy supports, and it is thus reasonable that the latter would affect the former's renewable energy investments. Thus, financial policies are an ideal option for countries aiming to drive renewable energy investments using green bonds.

5.5. Conclusions

Green bonds, as yet another form of debt security, are distinguishing themselves among conventional bonds that are “time-tested financial tool[s] that financed the sewers of London and two world wars” (Bromley 2016). In addition to a growing trend of green bonds issued with proceeds earmarked for renewable energy projects and assets, reported proceeds allocations to renewable energy infrastructure have risen precipitously to surpass \$26.7 billion by 2017 (Tolliver et al., 2019a). An extensive line of literature precedent measures the positive, statistically significant impacts that various policy support measures have on investments in renewable energy deployment. This study complements existing literature with the first difference-in-differences (DiD) assessment of the impact exerted by Paris Agreement Nationally Determined Contributions (NDCs) as well as other economic, regulatory, and fiscal policy supports on global green bond proceeds allocations to renewable energy projects and assets between 2008 and 2016.

Following a review of the empirical literature on policy support impacts on renewable energy deployment, this study employed an original NDC regulatory index to calculate robustness scores for the NDCs of the 43 countries and 20 EU-bloc countries included in the analysis. NDC index scores and binary variables for economic, regulatory, and financial policy

supports were employed in an empirical assessment of global green bond allocations to renewable energy infrastructure.

The results shed light on how factors that are known to impact renewable energy deployment affect renewable energy investment via green bond finance as well. The results are also the first to show NDC impact on green bond allocations to renewable energy. Specifically, the findings reveal that: (1) NDCs positively impacted green bond allocations to renewable energy with the highest statistical significance out of all assessed policy supports; (2) feed-in-tariffs (FiTs), renewable portfolio standards (RPS), and tradeable renewable energy certificate (REC) economic policy supports exerted the second largest magnitude of positive, statistically significant impact on green bond finance for renewable energy; (3) building codes, monitoring requirements, strategic planning, or other top-down regulatory policy supports exerted positive, statistically significant impacts on green bond allocations to renewable energy that were the smallest in magnitude out of all of the policy supports assessed; and (4) financial policy supports, including tax credit or exemption schemes, direct public infrastructure investments, and public loans, grants, or subsidies, exerted the largest magnitude of positive, statistically significant impacts on green bond proceeds distributions to renewable energy projects and assets out of all policy supports included in this study.

These results also reveal a number of useful policy implications. First, countries aiming to support the expansion of renewable energy systems should bolster their NDCs that incite green bond allocations to renewable energy projects and assets. Second, as the economic, regulatory, and financial policy supports that have bolstered renewable energy growth also positively impact green bond finance for renewable energy, countries should employ them to promote greater green bond proceeds flows into renewable energy investments. Finally, due to

their impact on green bond allocations to environmentally-friendly renewable energy infrastructure, the extent to which countries bolster NDCs and implement renewable energy policy supports stands to have a marked impact on climate-friendly, sustainable outcomes.

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Chapter 6: Energy security and sustainability through energy consumption

Energy consumption remains a key component of sustainability, underpinning the continued prosperity of developed nations and fueling the rapid economic growth among developing nations. Bierbaum and Matson (2016) stress the importance of energy from an anthropological, humanitarian standpoint, stating that “No resource is more fundamental to human development and well-being than energy. Energy is a key ingredient of almost all aspects of human existence, from producing food, to accessing and purifying water, to heating and lighting homes. Therefore, human well-being depends on sustainable, reliable, and enduring forms of energy.” These views compliment the preceding, more economy-centric work by Brown (2014), which notes that “energy is essential for any form of economic activities; increasing energy consumption has characterized industrialization and economic development over the past century.” These notions are supported by the fact that total global energy consumption nearly doubled from 4,667 million tonnes of oil equivalent (Mtoe) in 1973 to 9,301 Mtoe by 2013 (International Energy Agency [IEA], 2016)

Though the importance of energy to modern nation states is widely recognized, an abundance of context-specific conditions renders it difficult to formulate universally applicable measures for maintaining uninterrupted energy supplies that meet perpetual demands. It is this vexing yet inescapable context that embodies the concept of energy security, a topic of political and economic preeminence among increasingly energized countries around the world. The IEA (2010) and Hughes (2012) define energy security as “the uninterrupted physical availability [of energy] at a price which is affordable, while respecting environmental concerns.” Brown et al. (2014) and Sovacool (2016) describe it as “equitably providing available, affordable, reliable,

efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users.” Despite a lack of consensus surrounding energy security conceptualizations, an extensive literature base of theoretical frameworks and evaluation methodologies truly demonstrates how energy security definitions, measurements, and policy applications are adapted to suit time and location-dependent scenarios. Moreover, they shed light on the broad spectrum of interrelated factors that serve to bolster or undermine the stability and longevity of diverse energy systems throughout the world.

One of the areas that requires further investigation is the relationship between energy security and energy consumption. That is, how does greater or lesser energy security or energy security risk affect the types and amounts of energy consumed. This aim of this Chapter is to assess the impact energy security risk on the consumption of available energy supply sources throughout a diverse basket of developed and developing countries. Specifically, this study adds to the sustainability discourse by including empirical measurements of energy security risk, per capita gross domestic product (GDP), and population variables in regression analyses of their impacts on the consumption of nine energy supply sources with varying impacts on sustainability.

6.1. The evolution of energy security concepts and emphases

As mentioned, the concept of energy security is amorphous and context based. However, an understanding of the evolution of energy security, how it is perceived, and how it is measured are the building blocks for assessing the relationship between energy security and sustainable consumption. In addition to previously provided definitions, some of the other well-known conceptualizations arise from the notion of energy insecurity. Bohi and Toman (1997) note that it

“refers to the loss of economic welfare that may occur as a result of a change in the price or availability of energy,” while the IEA (2007) adds that it “stems from the welfare impact of either the physical unavailability of energy or prices that are not competitive or overly volatile.”

Though there are numerous energy security definitions provided by an ever-abundant literature base, Winzer (2011) provides a useful distinction among prominent authors in the field by categorizing their contributions along the lines of 3 distinct analytical objectives.

Accordingly, the first group of authors, “defines security as the continuity of energy commodity supplies,” as depicted by Billinton and Allan (1996) and Hoogeveen and Perlot (2007). The second group “introduce subjective severity filters to distinguish between secure and insecure levels of continuity,” as demonstrated by Yergin (1988), Luciani (2004), Andrews (2005), and Mabro (2008). The third group “extends the impact measure to the price and continuity of services, the impacts on the economy and in some cases the environment,” as demonstrated by Bohi et al. (1996), Joode et al. (2004), Grubb et al. (2006), and Verrastro and Laidlaw (2007). Importantly, it is this latter definition that harnesses considerations of sustainability that best represents the analytical scope of this Chapter.

Beyond defining energy security, many studies shed light on its components and dimensions. The “four A’s of energy security” (availability, affordability, accessibility, and acceptability) presented by the Asia Pacific Energy Research Centre (APERC 2007) are widely cited in contemporary literature as primary dimensions. Von Hippel et al. (2011) indicate the environment, technology, demand-side management, social and cultural factors, and post-Cold War international relations as the modern energy security factors which compliment traditional supply-side considerations.

Cherp and Jewell (2011) group energy security conceptualizations into three eras, each hailing from distinct academic fields and emphasizing unique, time-relevant perspectives on the risks and primary protection mechanisms (e.g. security) of energy systems. The “sovereignty” perspective predominant throughout the 20th century highlights the imperative for developed nations to control oil and gas supplies for military campaigns from World War I through the Cold War. It subsequently cites the imperative for those same nations to later establish international regimes to counter Organization of Oil Exporting Countries (OPEC) monopoly power and secure sufficient supplies of fuels that are indispensable to economic activity.

The “robustness” perspective covers the latter half of the 20th century and points to the durability of energy supply systems. Particularly, it points to the resource scarcity outlined in such works as the Club of Rome’s *The Limits to Growth* brought to life by the 1970s oil crises and to technological vulnerabilities made apparent by the 1979 Three Mile Island and 1986 Chernobyl nuclear power plant accidents and other terrorist, natural disaster, or technical failure-induced energy supply disruptions. In this manner, emphasizes energy considerations beyond oil and gas supply security and calls for the technological improvements and energy diversification.

Finally, the “resilience” perspective emerged in the 1980s and 1990s alongside deregulations of national energy systems in countries around the world. It treats energy as a market commodity instead of as a public good. As such, this perspective proposes that the risk of energy supply disruptions should be distributed across multiple energy technologies and systems.

Due to the time, location, and disparities among energy security that arise from varying time and location dependent circumstances, it is widely noted that there exists no standardized, widely accepted definition. Note, however, that an inclusive consideration of each of these perspectives promotes the priority of reliable access to efficient, secure, renewable, disaster-

resilient energy technologies and delivery services at the core of modern sustainable energy concepts (Angelou et al., 2013).

6.2. Energy security risks

Many energy security factors are rooted exclusively in preexisting natural conditions, allowing inhabitants of a given area to leverage their environs to their advantage or, conversely, forcing them to adapt to and overcome harsher circumstances. The availability and accessibility of natural energy resource endowments, particularly crude oil and other fossil fuel reserves, serve to illustrate just how substantially the environment and the supplies it makes available can greatly impact the economy and energy security of a given area. For example, Saudi Arabia, with over 366 quadrillion proven conventional oil reserves (15.7% of the global total) (British Petroleum, 2016), maintained a high degree of energy independence and security (World Energy Council, 2015), considerable global oil market influence within the OPEC collective, and \$130 billion in fossil fuel revenues in 2015 (OECD, 2016).

By contrast, Japan, which boasted the world's third largest single-country economy in the same year (World Bank, 2016), was nevertheless challenged by its lack of domestic fossil and nuclear fuel reserves, reflected in the fact that it imported 94% of its primary energy resources including 80% of its oil that was supplied by politically volatile Middle Eastern countries. While the case of Saudi Arabia illustrates the economic gains associated with abundant domestic energy resources and the potential economic gains associated with abundant energy resources and inherent energy security, the latter draws attention to an opposite effect. Namely, it demonstrates the energy quandary faced by resource poor nations and the dire situations they

could face in instances of geopolitical conflict, war, or terrorism that tend to disrupt supplies from the major Middle Eastern fossil fuel exporters.

It is also worth noting that beyond nonrenewable resource endowments, other natural conditions, including geography, seasonal weather patterns, and terrain also determine the availability and accessibility of renewable energy. For instance, many regions around the world are home to weather patterns conducive to substantial, economically viable wind and solar power generation. Jacobson and Delucchi (2011a) noted that “...the wind power in locations over land and near shore where the wind speed is 7 m/s [meters/second] is around 72-170 TW [terawatts]...Over half of its power is in regions that could be practically developed. Large regions of fast winds worldwide include the Great Plains of the U.S. and Canada, Northern Europe, the Gobi and Sahara Deserts, much of the Australian desert areas, and parts of South Africa and Southern South America.” Köberle et al. (2015) revealed the technical potential as of 2010 to implement concentrated solar power (CSP) below \$0.35/kilowatt hour (kWh) and yield roughly 25,000 or more terawatt hours per year (TWh/year) in Northern and Western Africa and Oceania. They also cite the possibility to generate roughly 15,000 TWh/year in Eastern Africa, the Middle East, and China.

Regarding solar power, Köberle et al. (2015) add that there exists similar technical potential to implement solar photovoltaic (PV) power at the same \$0.35/kWh price and yield roughly 14,000 TWh/year in power generation in Northern Africa, Western Africa, and Oceania. Moreover, implementing solar PV with the same pricing schemes in Eastern Africa, the Middle East, China, and the rest of Southern Africa would each yield approximately 8,000 TWh/year. In both cases, should these energy sources be fully harnessed to their maximum potential, they

would produce enough power to exceed the 12.5 TW global end-use energy demand (Jacobson and Delucchi, 2011a) and bolster energy independence and thus security of host nations.

However, much the literature precedents aim to derive measures for coping with energy security risks, including those risks that arise from human action, environmental phenomena, and technological failures. Regarding human action, the Organization of Arab Petroleum Exporting Countries (OAPEC) oil embargo of 1973-1974 that came as a response to the U.S. backing of Israel in the Yom Kippur War and the 1990 oil price shock following the Iraqi invasion of Kuwait both exhibit the remarkable risks that military campaigns in the Middle East pose to global markets and energy security. Another example of risk that arose as a result of human action was Al-Qaeda terrorist attack on Abqaiq, Saudi Arabia's largest oil production facility that accounted for 5.7 million barrels per day (or 60% of the total production in Riyadh). Though it was eventually deemed to be a failure, the attack itself pushed oil futures prices to 64.14 per barrel and ran the risk of precipitating an economic crisis (Abir, 2006). One final example of this category was the decision by Russian state-run natural gas utility giant Gazprom to substantially raise prices while cutting Ukraine-bound natural gas supplies in the wake of pricing, payment, and allocation disputes in winter of 2005 to 2006 (Nichol & Woehrel, 2006). This showed how geopolitical maneuvering and economic leveraging of one entity or group could severely undermine the energy security of a contracting country or region.

On environmental disaster-induced energy security risks, successive Hurricanes Katrina and Rita in August and September of 2005 respectively severed 25% and 20% of total U.S. oil and natural gas production in the Outer Continental Shelf of the Gulf of Mexico (Kumins & Bamberger, 2005). On technological failure-induced energy security risks, the thermal reactor destruction, steam explosions, and graphite moderator ignitions of the 1986 Chernobyl incident

led to the accidental release of 5,300 petabecquerels (PBq) of volatile radionuclides iodine, cesium, and tellurium and exposed local residents to life-threatening xenon poisoning. The eventual evacuation of 116,000 residents from a 4,300 km² exclusion zone represents one of the most severe, yet unresolved radiation crises to date. (Steinhauser et al, 2014). Finally, the 9.0 magnitude Great East Japan Earthquake and ensuing tsunami depict unique, multidimensional energy security risks (e.g. both environmental and technological). The sequence of natural disasters eliminated 27 gigawatts (GW) of electric power generation capacity and led to severe power shortages, rolling blackouts, government mandated electricity demand restrictions in the summer of 2011. This was followed by the complete shutdown of all 50 commercial reactors as of May 2012 (Koyama, 2013), effectively eliminating 30% of Japan's total primary energy supply capacity.

6.3. Energy security indexes

Vivoda (2010) notes the wide ranging significance of energy security, citing its connections to "...high energy prices, the increased demand and competition for geographically concentrated resources, the fear of resource scarcity and/or depletion in the near future and the concerns with the likely social and political effects of climate change." It is in this context that many efforts are being made to quantify and subsequently improve energy security. Most notably, the 2015 Energy Trilemma Index published by the World Energy Council and the 2016 International Index of Energy Security Risk published by the U.S. Chamber of Commerce Institute for 21st Century Energy represent some of the more recent and comprehensive indexes the measure energy security using a diverse basket of sociopolitical and economic variable to calculate metrics with combine to represent overall energy security (or risk).

Under the pretext that it is imperative to countries should largely invest in reforming their energy systems to address the severe impacts of climate change, the 2015 Energy Trilemma Index published by the World Energy Council draws from 60 databases to measure energy policy impacts and the extent to which energy systems in countries are “stable, affordable, and environmentally-sensitive.” The overall country performance score is subdivided into two subcategories: energy performance and contextual performance. 13 metrics were developed for the former and subsequently grouped into energy security, energy equity, and environmental sustainability dimensions, collectively accounting for 75% of the overall index score. Another 10 metrics were created to measure the more circumstantial political strength, societal strength, and economic strength dimensions of the latter subcategory, accounting for the remaining 25% of the total score. The 23 metric, 6 dimension, and overall index calculations are then ranked, providing a clear glimpse into comparative performance across dimensions and overall for 130 countries in the index. These calculations are then normalized and assigned a rating from A to D (from highest to lowest), highlighting the performance tradeoffs and potential improvements among index dimensions and forming a three-letter balance score. Thus, the best performing countries with exceptional rankings across all three dimensions received AAA balance scores, while the worst performing countries were rated DDD.

Under this framework, the countries with the top five index scores were Switzerland, Sweden, Norway, the United Kingdom (UK), and Austria, possessing balance scores of AAA, AAA, AAB, AAB, and AAB, respectively. These rankings and scores reflect the highly environmentally friendly, stable, affordable balance of nuclear and hydropower of the first two countries, a diverse electricity portfolio and low import dependence of the UK, and the hydro-power centered, relatively diversified generation portfolio held by Austria (the lack of a country

profile for Norway prevents further articulation of its energy system details). The countries with the bottom five index scores were Yemen, Moldova, Senegal, Lebanon, and Benin, coinciding with their respective CDD, CDD, CDD, CDD, and DDD balance scores. Overall, the low energy production to consumption ratio and high electricity transmission and distribution losses, CO₂ emissions, and emissions intensity in Senegal and low electricity generation diversity, high fuel import dependence, and increasing emissions intensity in Lebanon serving as representative samples of the overall issues across the bottom of the pack (lack of country profiles for Yemen, Moldova, and Benin prevent further articulation of their energy system details).

The 2016 International Index of Energy Security Risk published by the U.S. Chamber of Commerce Institute for 21st Century Energy measures evolving energy security risks for the 25 largest national economies that account for over half of total global energy consumption. Specifically, it covers Australia, Brazil, Canada, China, Denmark, France, Germany, India, Indonesia, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Poland, Russia, South Africa, South Korea, Spain, Thailand, Turkey, Ukraine, the United Kingdom, and the United States 1980 to 2014. The steps involved in calculating the energy security risk score for each country per year were three fold.

First, 29 metrics that represent key energy security aspects were developed largely by employing antecedent metrics related to “energy supplies, energy end uses, generating capacity, operations, emissions” the comprise the U.S. Index of Energy Security Risk and adding some a handful of new, international-analysis oriented metrics. The numerical values of each metric were calculated using refinery and capacity data form British Petroleum (BP), general energy data from the U.S. Energy Information Administration (EIA), political rights and civil liberties

data from Freedom House, energy price and expenditure data from the International Energy Agency, and population, economic, and electricity data from the World Bank.

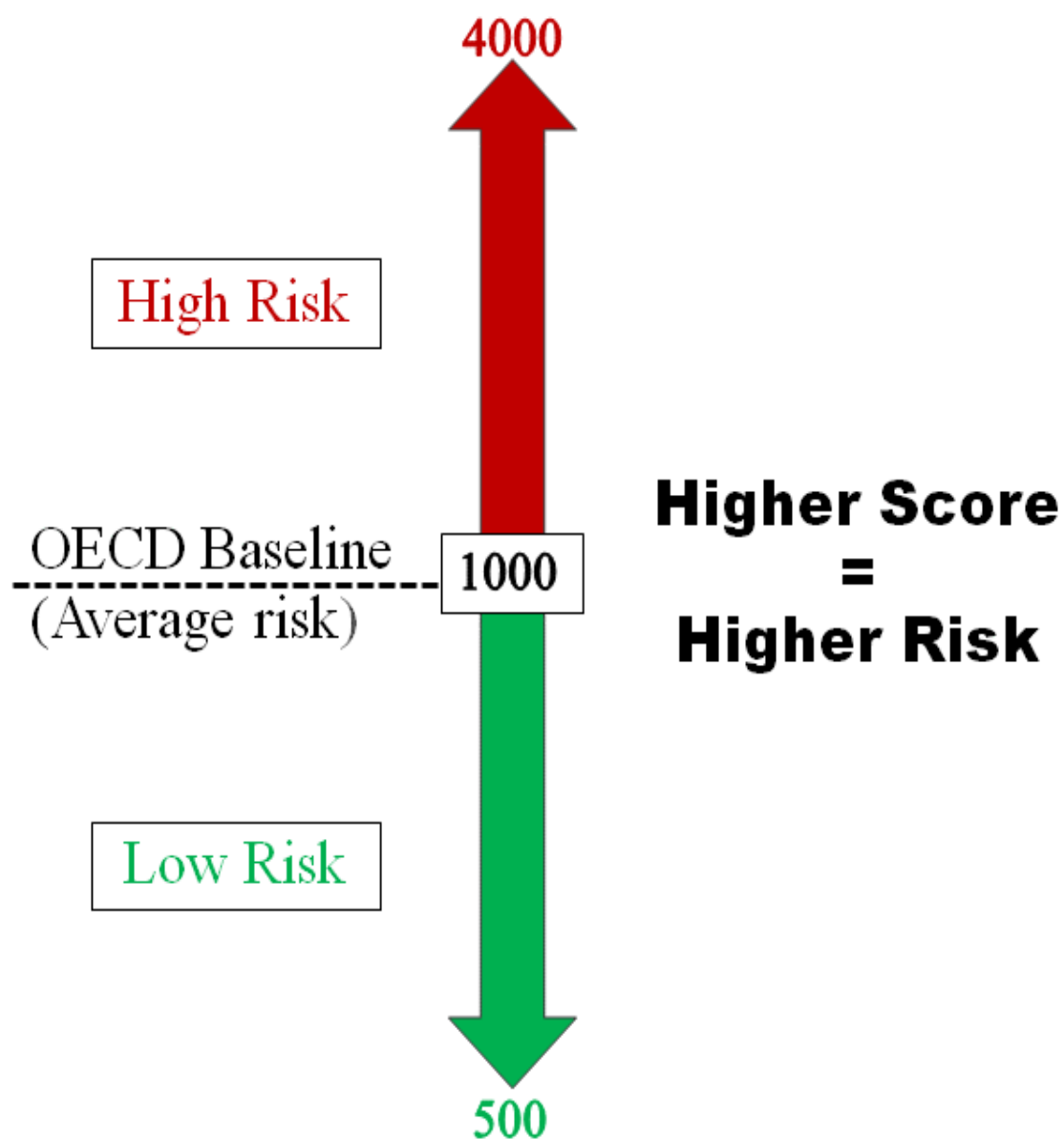
Next, the yearly averages for current Organization for Economic Cooperation and Development countries were calculated across all 29 metrics, and these values were normalized by setting 1980 values equal to 1,000. Any OECD metric that deviated in subsequent years, whether positive or negative, was expressed as relatively higher or lower than the 1980 baseline. Moreover, country-level metrics were also normalized with 1980 values set with reference to the same 1980 OECD value. Overall, the yearly changes of the normalized metrics depict both OECD-relative and absolute energy security risks per country over time. Figure 6.3.1 depicts the energy security risk spectrum and the meaning of risk scores above and below the OECD baseline score.

The final step in creating the international index was to group each of the 29 metrics into global fuel, fuel import, energy expenditure, price & market volatility, energy use intensity, electric power sector, transportation sector, and environmental subcategories. Each subcategory and individual metric was then assigned a weight that likely reflects their relative significance to overall energy security. The result was “an overall risk score for each country that represents their weighted average.” Table 6.3 depicts the names, weights, descriptions, and overall risk score impacts of the 8 energy security risk score metric categories

The metric categories, calculation methods, and relative weights in the overall energy security risk index score speak largely to the unique impacts that various aspects of energy security have. 6 “Global Fuels” metrics comprise 14% of the overall index score and serve to alleviate risk to the extent that global fossil fuel reserves and supplies are reliable and diverse. Five “Fuel imports” metrics consider the impact that fossil fuel imports have on national

economies. Collectively makeup 17% of the index scores, these metrics reduce overall risk in scenarios where imports from unreliable or concentrated sources are comparatively low. Three

Figure 6.3: Energy security risk score spectrum



Source: Created by author

“Energy expenditures” metrics account for 20% of the overall risk score, while four “Price &

Market Volatility” metrics account for 15%. The former improve energy security risk calculations to the extent that total energy costs and price shock exposures are low, while the later does so to the degree that energy price volatility is low. 14% of the overall risk score is

Table 6.3: Energy security risk metric descriptions

Metrics	Weight	Contents	Score Impact
<i>Global Fuels</i>	14	Reliability and diversity of global fossil fuel reserves and supplies	↑ supply reliability and diversity
<i>Fuel Imports</i>	17	Exposure to unreliable and concentrated fossil fuel supplies	↑ supply reliability and diversity
<i>Energy Expenditures</i>	20	National energy costs and consumer exposure to price shocks	↓ costs and exposure
<i>Price & Market Volatility</i>	15	Susceptibility to large energy price swings	↓ volatility
<i>Energy Intensity</i>	14	Energy use per population and economic output	↓ intensity
<i>Electric Power Sector</i>	7	Reliability of electricity generating capacity	↑ diversity
<i>Transportation Sector</i>	7	Energy use efficiency in transportation sector	↑ efficiency
<i>Environmental</i>	6	Greenhouse gas emission reduction mandates	↓ energy-related CO ₂ emissions

Source: Created by author from information within the Institute for 21st Century Energy, *International Index of Energy Security Risk, 2016 Edition*, 2016

comprised of three “Energy Use Intensity” lower energy security risks when less energy is required for economic output. Two “Electric Power Sector” metrics, 2 “Transportation Sector” metrics, and three “Environmental” metrics respectively occupy 7%, 7%, and 6% of the total index score. These metric groups reduce energy security risk to the extent that electricity generating capacity is diverse, transport sector energy intensity low and efficiency is high, and energy-related CO₂ emissions are low, respectively.

Based upon the breadth of energy security risk considerations and simplicity of use of available, energy security risk score integer values, this study will refer to scores from the *2016 International Index of Energy Security Risk* as the benchmarks of energy security risk.

6.4. Energy nexus studies

As is evident from the multitude of existing energy security indexes, there are many risk factors that affect energy security. In turn, energy security impacts energy consumption to an extent that may have both empowering or crippling impacts on society. The purpose of this study is to shed light on the impact that energy security and other significant factors have on both overall consumptions of each renewable and non-renewable energy source. There is plenty of existing literature that employs various methodologies to shed light on the relationships between energy consumption and some of the independent variables to be used in this study. The first group of these research precedents are those that investigate the energy consumption-gross domestic product (GDP) nexus studies through multivariate co-integration Granger causality tests. Stern (1993) shows unidirectional causality from energy consumption to GDP using a multivariate vector autoregressive (VAR) model, while Yuan et al. (2007) and Belloumi (2009) and Ghosh (2010) each use the Johansen-Juselius and vector error correction models (VCEM) to show bidirectional causality, long-term bidirectional causality and short-term unidirectional causality from energy consumption to GDP in the short-run, and multiple causalities in the short and long term, respectively (Ghosh also employs the autoregressive distributed lag, or ARDL, co-integration model).

Other studies examine the energy consumption-GDP-carbon dioxide (CO₂) emission nexus. Ang (2007), Soytaş et al. (2007), Apergis and Payne (2010), and Lean and Smyth (2010)

each employ the environmental Kuznets curve (EKC) hypothesis, alongside Johansen-Juselius models, VECM, and ARDL bounds tests in the first; Granger causality tests in the second; and panel VECM in the third and fourth of these studies. Zhang and Cheng (2009) employ the Toda-Yamamoto method. Halicioglu (2009) makes use of the ARDL bounds test, the Johansen-Juselius model, and VECM, as do Ozturk and Acaravci (2010), though they exclude ARDL. Soytaş and Sari (2009) use Granger causality tests, Chang (2010) uses Johansen co-integration VECM, and Omri (2013) uses two and three-staged least squares and generalized method of moments (GMM) estimations. Though the results of many of these studies show unidirectional causality from energy consumption to CO₂ emissions, it is worth noting that neither unidirectional nor bidirectional causality among the three variables are consistent across all studies, and that the scopes of the studies vary from single to 130-country analyses.

Studies on the energy consumption- carbon dioxide (CO₂) emission-urbanization nexus are also relevant to this work. Parikh and Shukla (1995) found positive correlations between urbanization and both energy consumption and greenhouse gas emissions using fixed effects multiple regression analyses. Poumanyvong and Kaneko (2010) used the Stochastic Impacts by Regression on Population, Affluence, and Technology (SIRPAT) model for 99 countries during the 1975-2005 time period, showing distinct impacts of urbanization on energy use and CO₂ emissions depending upon the developmental stage and income-levels across countries. Salim and Shafei (2014) similarly utilized a SIRPAT model with data from 1980-2011 for OECD countries to show the positive influence that urbanization has on non-renewable energy consumption. Al-Mulali et al. (2012) found a positive long run relationship between urbanization, energy consumption, and CO₂ emissions for 84% of the countries in the seven regions they analyzed for the period 1980-2008. Focusing on 19 Middle East and North African

(MENA) countries, while Al-Mulali et al. (2013) employed Pedroni co-integration and dynamic ordinary least squared (OLS) regressions to show long-run, bidirectional positive relationships between the three variables that vary across countries with their particular development level. And, Wang et al. (2014) employed the panel unit root test, Pedroni co-integration test, and panel Granger causality test to demonstrate long-run, positive bidirectional causality for the three variables from 1995-2011 in China.

6.5. Data and model

6.5.1. Data

This study analyzes a panel dataset of 64 countries from 1980 to 2014 using fixed and random effects regressions of energy security risk, GDP, and population on energy consumption. Energy consumption dependent variables are constructed using per capita oil, natural gas, coal, nuclear power, hydroelectric power, solar power, wind power consumption data published in the *BP Statistical Review of World Energy 2016*. Per capita GDP and population control variables are based on data from the *2016 World Development Indicators* provided by the World Bank. Lastly, energy security risk scores calculated in the *2016 Index of International Energy Security Risk* published by the U.S. Chamber of Commerce Institute for 21st Century Energy are used to denote the level of risk inherent in the energy systems of the countries assessed in this study.

The countries and timeframe selected for this study were based on data availability. The data is concisely described in Table 5.5.1. Before performing the analysis, correlation between the variables was checked to guarantee the absence of correlation that would limit the significance of this work. The correlation matrix is shown in Table 5.5.2. Note that all of the variables other than energy security risk are in the natural logarithm form.

Table 6.5.1: Regression model variables and data sources

Variable	Unit	Source
<i>Energy consumption</i>	Kilotonnes of oil equivalent (ktoe)/capita	British Petroleum (BP), <i>2016 Statistical Review of World Energy</i> , 2016
<i>Energy security risk</i>	Risk score in thousandths	Institute for 21 st Century Energy, <i>International Index of Energy Security Risk</i> , 2016 Ed., 2016
<i>GDP per capita</i>	2010 constant USD/capita	World Bank, <i>World Development Indicators</i> , 2016
<i>Population</i>	In millions	World Bank, <i>World Development Indicators</i> , 2016

Table 6.5.2: Energy consumption regression model variable correlation matrix

	<i>ln_oil</i>	<i>ln_gas</i>	<i>ln_coal</i>	<i>ln_nuclear</i>	<i>ln_hydro</i>	<i>ln_wind</i>	<i>ln_solar</i>	<i>ESR</i>	<i>ln_GDP</i>	<i>ln_POP</i>
<i>ln_oil</i>	1.000									
<i>ln_gas</i>	0.132	1.000								
<i>ln_coal</i>	0.472	0.165	1.000							
<i>ln_nucl</i>	0.385	0.468	0.301	1.000						
<i>ln_hydro</i>	-0.011	0.033	-0.133	0.444	1.000					
<i>ln_wind</i>	0.169	0.260	0.215	0.263	-0.016	1.000				
<i>ln_solar</i>	0.411	0.293	0.259	0.408	0.027	0.589	1.000			
<i>ESR</i>	-0.060	-0.136	0.049	-0.181	-0.301	0.036	0.182	1.000		
<i>ln_GDP</i>	0.397	0.651	0.183	0.822	0.318	0.357	0.431	-0.369	1.000	
<i>ln_POP</i>	-0.117	-0.354	0.114	-0.618	-0.182	-0.210	-0.245	0.004	-0.591	1.000

6.5.2. Model

This study applies the following econometric model to regression analysis:

$$EC_{i,t} = f(ESR, GDP, POP) \quad (6.1)$$

where,

EC is per capita energy consumption,

ESR is the energy security risk derived from the energy security risk score,

GDP is per capita GDP,

POP is population,

i is a given country, and

t is a given year in time.

As this model is assessed using panel data, it can also be expressed in the following panel form:

$$\ln_EC_{i,t} = \alpha_i + \delta_t + \beta_1 ESR_{i,t} + \beta_2 \ln_GDP_{i,t} + \beta_3 \ln_POP_{i,t} + \varepsilon_{i,t} \quad (6.2)$$

where,

α_i are country fixed-effects,

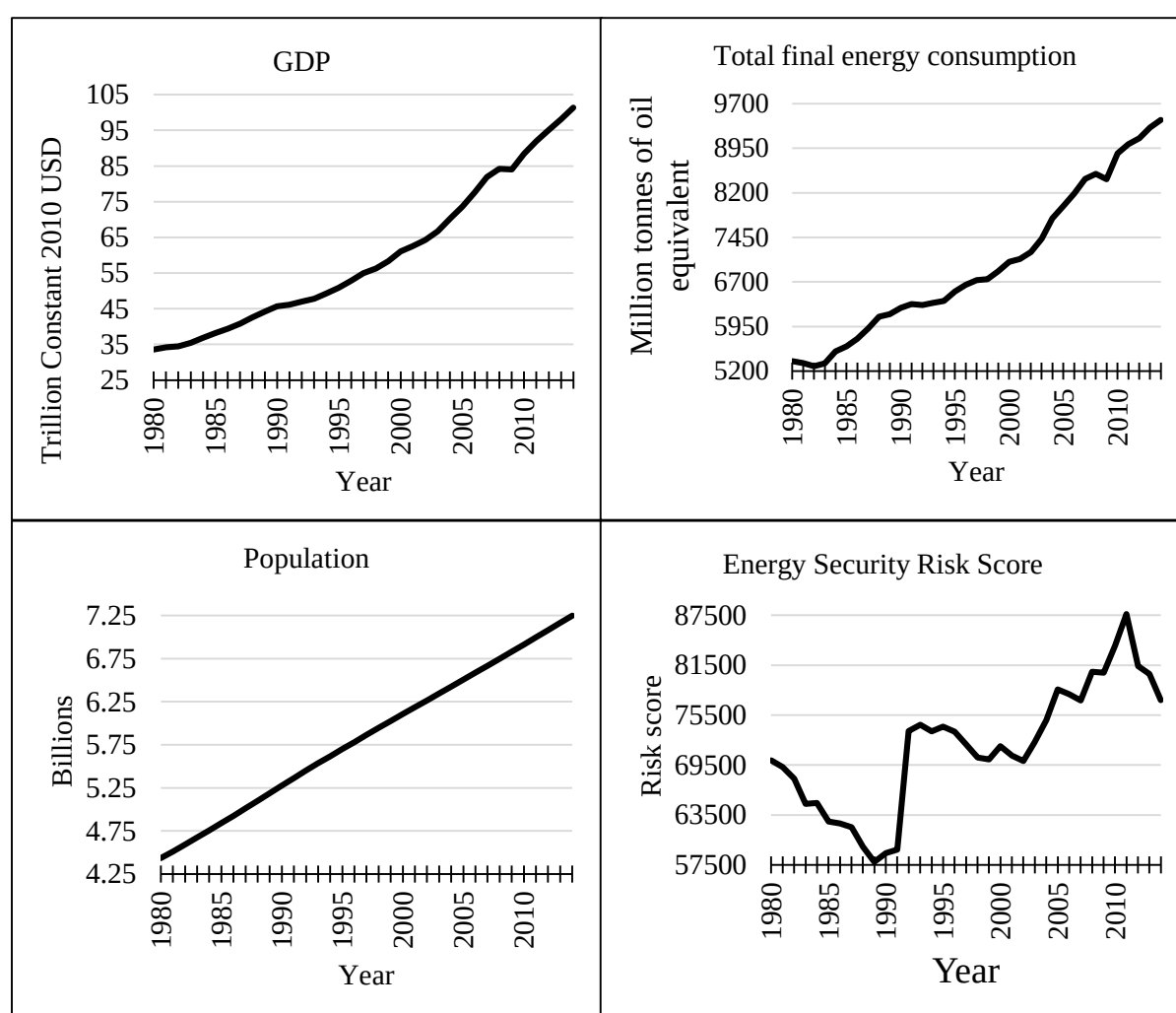
δ_t are time-fixed effects,

$\beta_1, \beta_2, \beta_3$ are correlation coefficients of independent variables, and

ε is the error term.

Note that *EC* stands for a particular energy source being assessed, meaning that analyses is performed with per capita oil, natural gas, coal, nuclear power, hydroelectric power, solar power, or wind power consumption in its place. Figure 6.5 shows trends for all variables included in this study. As depicted, there each variable proceeds upward and to the right over the 35-year time period from 1980 to 2014. GDP, population, and energy consumption growth

Figure 6.5: Global trends for energy consumption regression variables, 1980 to 2014



Sources: Created by author using data from World Bank, *World Development Indicators*, 2016; Institute for 21st Century Energy, *International Index of Energy Security Risk 2016 Edition*, 2016

undergo this trend most observably, with nearly linear upward progression over the years. Global energy consumption fluctuates, proceeding downward through the year 1990, making a sharp upturn through 1993, continuing downward through 2002, sharply increasing through 2010, and sharply dropping through 2014.

6.6. Results and discussion

6.6.1. Summary statistics

The variable definitions, number of observations, mean, standard deviation (std. dev.), and minimums and maximums are recorded in the summary statistics Table 6.6.1. While each energy consumption variable is originally measured using kilograms of oil equivalent per capita (koe/capita) and GDP is originally measured in constant 2010 U.S. dollars, they, as well as population, are converted to the natural logarithm (ln) form. This is in order to more clearly view the impact of marginal percent changes in these independent variables on the marginal percent changes in energy consumption. Energy security risk scores remain effectively the same, though they are scaled down to 1/1000th of their original values. In this non-logarithmic format, assessments of how marginal unit changes in energy security risk affect marginal percent changes in energy security consumption can be made.

Among the energy consumption dependent variables, note the comparatively higher number of observations for *ln_oil*, *ln_gas*, *ln_coal*, and *ln_hydro*, demonstrating their preponderance throughout the countries of this study. Moreover, from fossil fuels to nuclear power to large and small scale renewable energy sources, the general trend that emerges from this table is that the more conventional, widely used an energy source, the higher its mean, and the lower its standard deviation. Thus, coal and natural gas have the highest means and lowest standard deviations, solar and wind power have the lowest means and highest standard

deviations. Regarding the independent variables *ESR*, *ln_GDP*, and *ln_POP*, the standard deviations for *ln_GDP* and *ln_POP* are comparably higher than that of *ESR* due to large variations among GDP and population sizes throughout the countries and annual periods of this study.

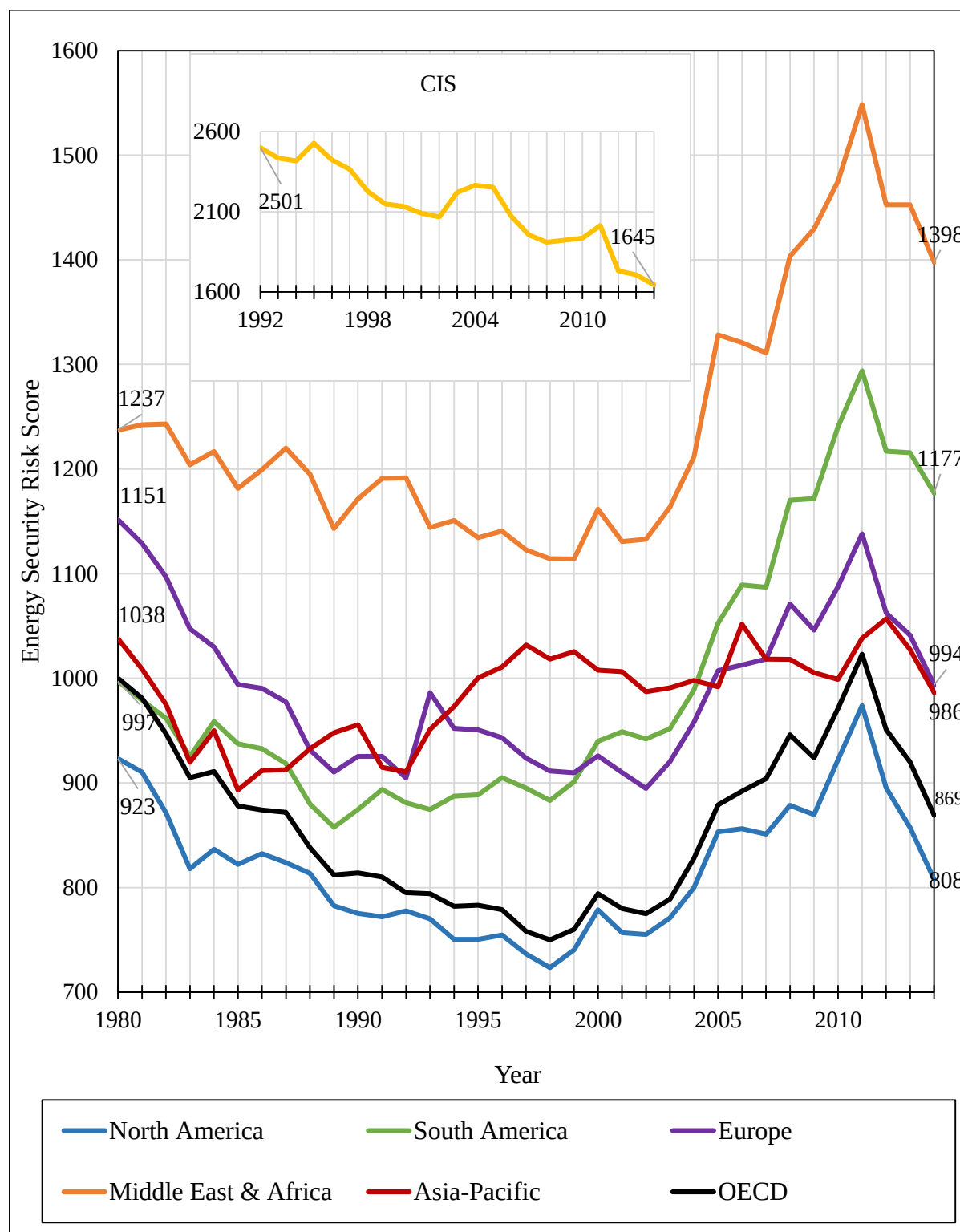
Table 6.6.1: Energy consumption regression variable summary statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
<i>ln_Oil</i>	2,201	6.33	2.77	-8.24	9.42
<i>ln_Gas</i>	2,139	-7.88	1.86	-16.51	-3.70
<i>ln_Coal</i>	1,994	-8.64	2.02	-16.66	-5.58
<i>ln_Nuclear</i>	902	-8.86	2.06	-16.37	-6.21
<i>ln_Hydro</i>	1,985	-9.77	2.13	-16.71	-4.94
<i>ln_Solar</i>	757	-15.96	2.85	-23.25	-9.20
<i>ln_Wind</i>	981	-13.82	3.17	-24.66	-7.54
<i>Energy Security Risk</i>	2,240	1.12	0.52	0.00	4.06
<i>ln_GDP</i>	2,088	9.24	1.33	5.84	11.65
<i>ln_Population</i>	2,237	16.94	1.47	12.32	21.03

6.6.2. Energy security risk trends

The rise and fall of source-specific energy consumption was linked to global and regional energy security risks changes from 1980 to 2014. Figure 6.6.1 depicts the average regional energy security risk trends from the years 1980 through 2014. Following the precedent set in the

Figure 6.6.1: Average energy security risk by region, 1980 to 2014



Source: Created by author using data from Institute for 21st Century Energy *International Index of Energy Security Risk, 2016 Edition* (2016)

2016 Index of International Energy Security Risk, the OECD-country trend was included as the baseline energy security risk.

Note that North American, South American, European, MEA, and OECD average energy security risk share a similar trend. From 1980, energy efficiency improvements and fuel switching from fossil fuels influenced steady energy security risk declined through local minima at 1998. From there, a surge in oil supply-related risks caused a risk upswing through the year 2011, when the global energy markets affected by the shale gas revolution pushed risk down through 2014. The Asia-Pacific trend differs most noticeably from 1992, where risk rose leading up to the 1997 Asian financial crisis. Another exception is the Commonwealth of Independent States (CIS) region risk, which began in 1992 following the collapse of the Soviet Union, fell sharply through 2014 with rising energy efficiency.

6.6.3. *Regression results*

Table 6.6.2 depicts the regression results for this study. Results for energy security risk score regressions on energy consumption revealed positive, 99% significant coefficients for wind power, nuclear power, natural gas, and oil consumption, and negative, 99% significant coefficients for hydroelectric power consumption. Coal and solar power consumption are insignificant. R-squared values are nearly 90% or greater for regressions on wind power, nuclear power, gas, coal, and solar power consumption, suggesting that changes in all independent variables explain nearly 90% or more of the changes in these particular dependent variables.

Based on the results of the Hausman specification test where Chi^2 is measured to determine the appropriateness of panel data analysis, fixed-effects regressions were run for wind power, nuclear power, gas, coal, and solar power in order to control for time invariant variable

among countries. Random-effects models were applied to oil and hydroelectric power consumption due to their Chi^2 values being less than significant, and the null hypothesis that the random-effects model is preferred is acceptable. Time-fixed effects were also included in the regression models for all energy consumption sources. The purpose was to create a dummy variable for yearly affects such as global oil shocks, wars, economic depressions, and other

Table 6.6.2: Energy consumption regression results

	ln_Wind	ln_Nuclear	ln_Gas	ln_Oil	ln_Hydro	ln_Coal	ln_Sol
<i>ESR</i>	2.440*** (0.673)	0.345*** (0.0753)	0.268*** (0.0523)	0.138*** (0.0157)	-0.223*** (0.0333)	-0.0808 (0.0520)	0.233 (0.753)
<i>ln_GDP</i>	1.462*** (0.253)	1.637*** (0.0977)	1.277*** (0.0792)	0.923*** (0.0234)	0.652*** (0.0504)	0.673*** (0.0760)	0.799*** (0.269)
<i>ln_POP</i>	-3.091*** (1.090)	1.583*** (0.224)	0.900*** (0.127)	0.604*** (0.0368)	0.410*** (0.0997)	2.029*** (0.158)	-7.792*** (1.417)
<i>Constant</i>	15.75 (18.32)	-52.83*** (3.881)	-35.69*** (2.396)	-12.23*** (0.768)	-22.37*** (1.771)	-49.57*** (2.735)	106.4*** (24.12)
Observations	981	869	2,026	2,087	1,903	1,912	757
R-squared	0.89	0.96	0.89	0.48	0.17	0.92	0.87
Country effects	FE	FE	FE	RE	RE	FE	FE
Time-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hausman test (Chi^2 test)	124.51***	96.97***	104.07***	12.85	14.04	136.35***	92.58

Note: standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

occurrences that may have affected changes in the dependent variable that may have misled interpretations of the impact of the independent variable.

6.6.4. Wind and nuclear power consumption

As risk rises, so too do wind and nuclear power consumption. These are mainly direct responses to policy mandates like Kyoto Protocol and European Union Emissions Trading

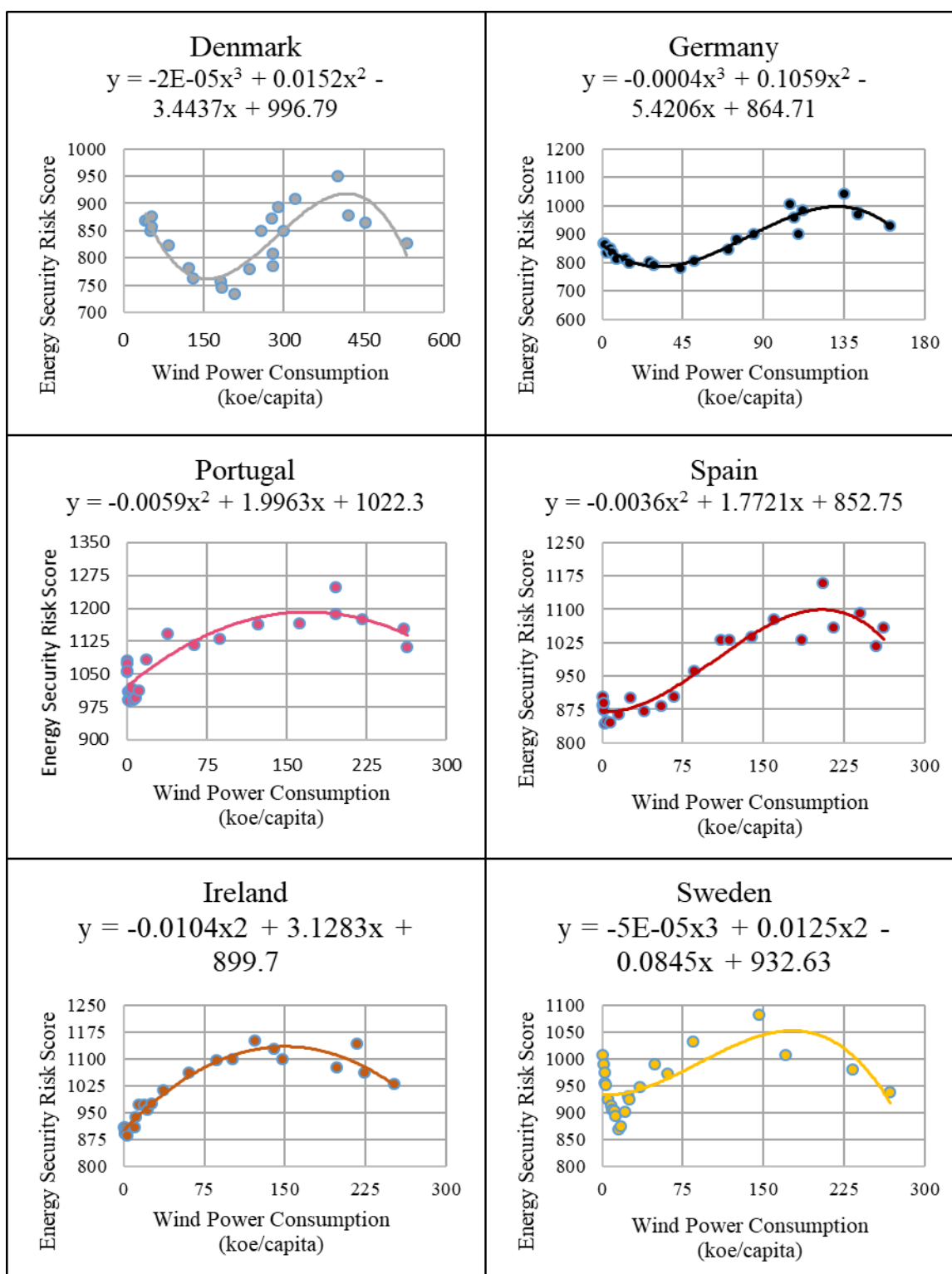
System, and other policies for addressing greenhouse emissions and climate change. Wind and nuclear power have some of the lowest emissions over their generation lifecycles, while wind is highly deployable and has many supportive pricing schemes. Additionally, wind power and nuclear power are risk-averse by default. In effect, then, these results reveal that the sustainability-enhancing features of wind and nuclear power incites greater consumption of each to the extent that energy security risks are high.

The IEA (2013) notes that cumulative wind power capacity from 2000 to 2012 grew by 24% annually, noting also an average 33% decrease in investment costs from 2009 and an average 44% decrease in operation and maintenance (O&M) costs from 2007. Moreover, wind turbines can range in size and functionality, smaller models installed to meet residential or building demand in rural or non-grid connected areas, and larger models that feed electricity into a greater grid, whether conventional or smart (Kumar et al., 2016). Figure 6.6.2 depicts energy security risk score and wind power consumption for top wind power-consuming OECD nations.

With all of these factors are considered alongside their zero-emission generation capability, it is clear that cheaper costs and greater technological applicability among evolving wind power supplies led to their expanded use and greater consumption. Before they were affordable or widely applicable, these power sources were sparsely consumed. However, once they became more deployable, they were generally consumed to alleviate energy security risk.

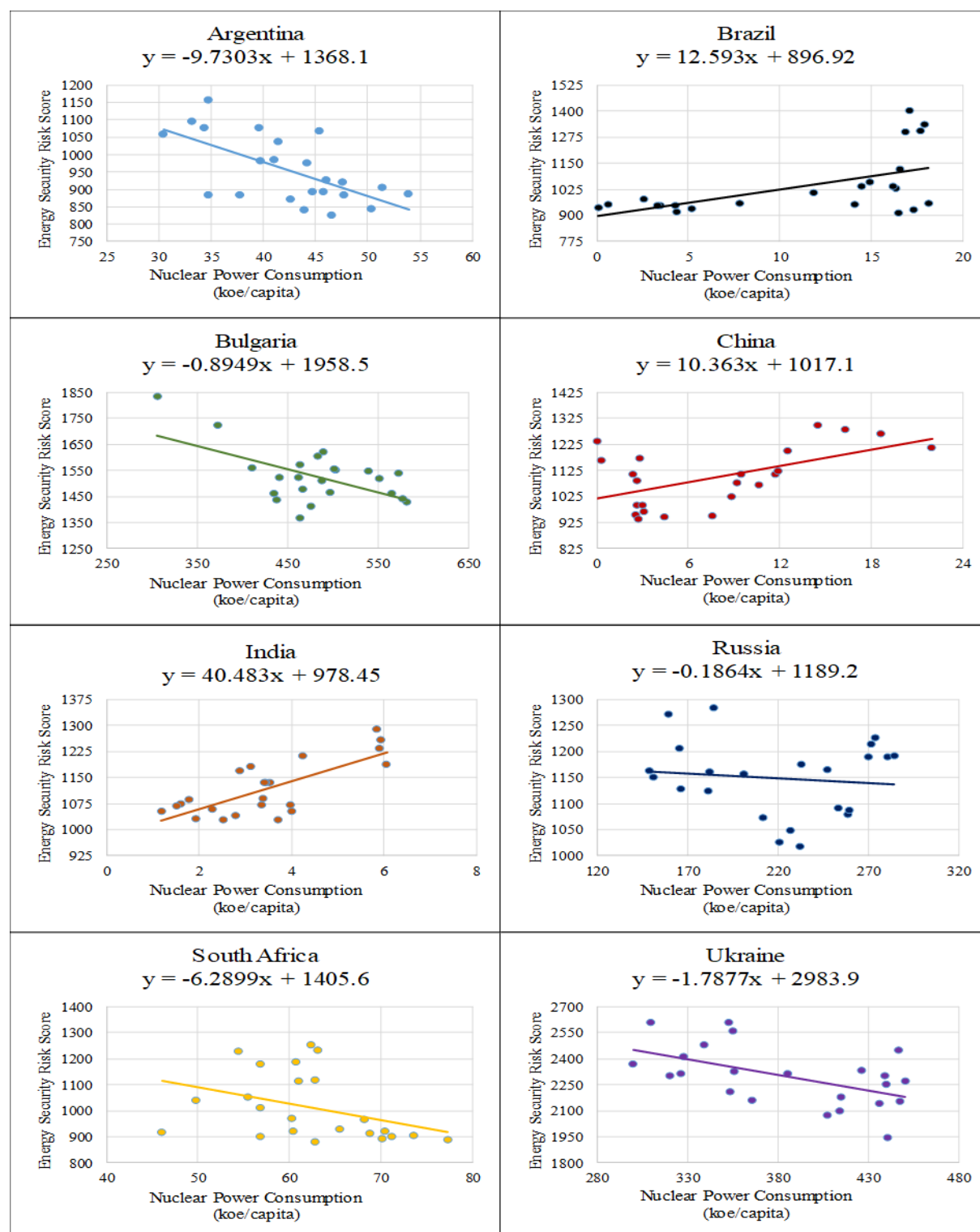
Positive correlations between nuclear power consumption and energy security risk reveal that countries consumed more to the extent that risk was high. Figures 6.6.3 and 6.6.4 depict predominately positive correlations between per capita nuclear power consumption and energy security risk scores for top nuclear power consuming non-OECD and OECD countries, respectively.

Figure 6.6.2: Per capita wind power consumption and energy security risk score trends in top wind power consuming OECD countries



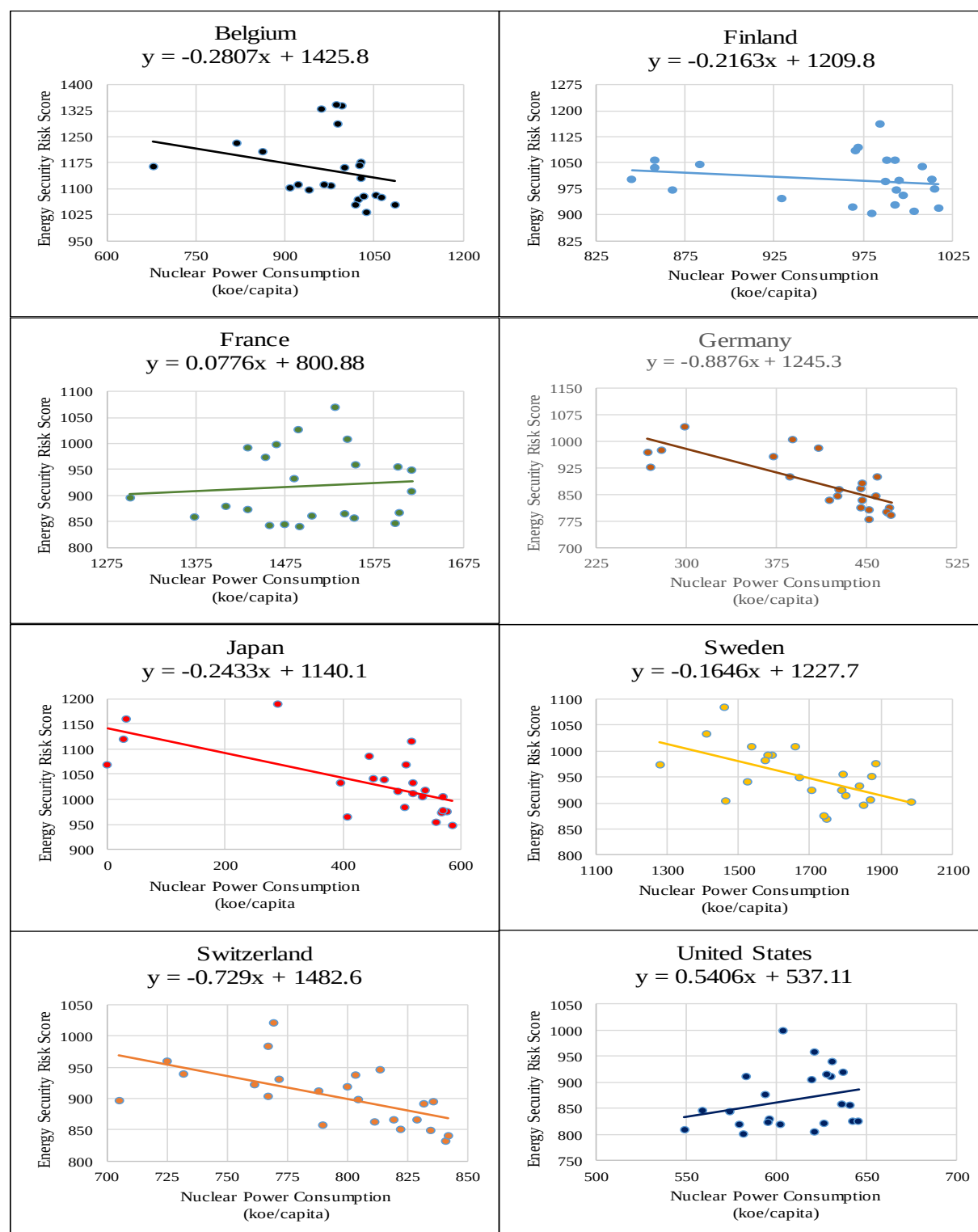
Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

Figure 6.6.3: Per capita nuclear power consumption and energy security risk score trends in top nuclear power consuming non-OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

Figure 6.6.4: Per capita nuclear power consumption and energy security risk score trends for top nuclear power consuming OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

As a non-conventional, alternative energy source, nuclear power has traditionally faced a number of barriers to its widespread acceptability. To begin with, due to the wide range of advanced technologies involved in controlling and harnessing energy from nuclear fission, depending upon the design and scale of potential generation facilities, nuclear power could have prohibitively high capital investment costs. For instance, the World Energy Council (2013) notes that capital expenditures are roughly \$6.52 million/MW for high cost (top-end) projects, \$4.8 million/MW for mid-level projects, and \$3.57 million/MW for low cost nuclear power projects, compared with the global average capital expenditure cost of \$0.97 million/MW for combined-cycle gas turbines and \$0.66 million/MW to \$3.7 million/MW cost of coal plants.

Furthermore, while nuclear energy is estimated to only require 0.5 km of land per terawatt hour (TWh) of electricity generation (Gagnon et al., 2002), radioactive waste storage requirements could, depending on the scale and duration of overall nuclear power operations, add substantial spatial requirements that would be particularly challenging for nations that are densely populated or have limited land space. The results of this study reveal that for countries that could overcome these implementation obstacles, higher energy security risk generally meant greater nuclear power consumption.

The explanations for the relationships between nuclear power consumption and energy security risk are largely rooted in the difference between the risks to nuclear power and energy security overall. Regarding nuclear power risks, Sovacool et al. (2015) assessed the history of energy accidents from 1950 to 2014, depicting the frequency of occurrence, the number of human casualties, and scope of monetary damages of accidents of each primary energy source including nuclear power. Proceeding from the notion that energy accidents can occur at any point in the fuel extraction, construction, operation, waste storage, decommissioning, and

environmental pollution stages in lifecycle of an energy system, they found that nuclear accidents, though responsible for an astounding 70% of all energy accident damages, accounted for a mere 16% of all accidents that actually took place.

In a following study by Sovacool et al. (2016), the authors outline the top 52 nuclear energy accidents in history, citing only 36% (16/52) to have occurred during the reprocessing and waste storage lifecycle phase, while the majority 67% (35/52) arose as failures during the operation and maintenance phase. The one exception was the Fukushima Daiichi nuclear power plant incident of March, 2011, which was induced by the 40-meter-high tsunami that followed the 9.0-magnitude earthquake off the coast of northeastern Japan. Moreover, of the 27 nuclear power accidents that fall within the timeframe of this study, 3 occurred during waste processing/storage stages, while the remaining 24 arose in the operation phase of the energy facility lifecycle.

From this, it is clear that nuclear power risks traditionally arise in two of the six aforementioned energy system lifecycle stages. Energy security risk, on the other hand, is calculated based on a narrower basket of metrics, each grouped into global fuel, fuel import, energy expenditure, price and market volatility, energy use intensity, electric power sector, and transportation sector categories. These metrics are it is not only less inclusive for risks across all energy system lifecycle stages, but they are often neither significantly influence nor are influenced by factors related to nuclear power. For instance, as uranium nuclear fuel imports can be stored on site for extended periods of time, and moreover, since their reserves are relatively evenly distributed across the globe, this makes them more accessible and tradeable among nuclear power consuming nations. Nuclear power is thereby not directly or significantly linked to

the global fuel and fuel import metric categories, which largely reflect a nation's reliance on fossil fuel imports and combine to affect 31% of the complete risk score.

At the same time, nuclear power is absorbed by the metrics in a manner that serves to lower composite risk scores, by lowering electricity prices affecting the *retail electricity prices* metric (6% of the total risk score), while also contributing to the *electricity diversity* (5%), *non-CO₂ emitting share of electricity generation* (2%), (energy-related) *CO₂ emissions trend* (2%), *energy-related carbon-dioxide emissions per capita* (2%), and *energy-related carbon dioxide emissions intensity* (2%) metrics. In other words, similar to the case of wind, the sustainability aspects of nuclear power rendered it a preferred consumption source when energy security was high.

Regarding the first of these metrics, the World Energy Council (2013) reported the range of levelized cost of energy (LCOE) range from \$91 million/MWh to \$147 million/MWh. This is competitive with other baseload generation technologies, including the \$61 million/MWh to \$148 million/MWh LCOE range for combined-cycle gas turbine generation and the \$35 MWh to \$172 million/MWh range for coal-fired plants. And, regarding the CO₂ emissions metric considerations, Gagnon et al. (2002) estimate average lifecycle estimates across various nuclear reactor types to be about 66 grams of carbon dioxide equivalent per kilowatt hour (gCO₂e/kWh), compared with the 443 gCO₂e/kWh for combined-cycle gas turbines, 960 gCO₂e/kWh for scrubbed (carbon capturing) coal-fired generators, and 1,050 gCO₂e/kWh for non-scrubbed coal-fired generators.

All of the above sustainability properties of nuclear power, which either fail to contribute to energy security risk or serve to lower risk are accurately summarized by the World Nuclear Association (2016), which states: “There are a number of characteristics of nuclear power which

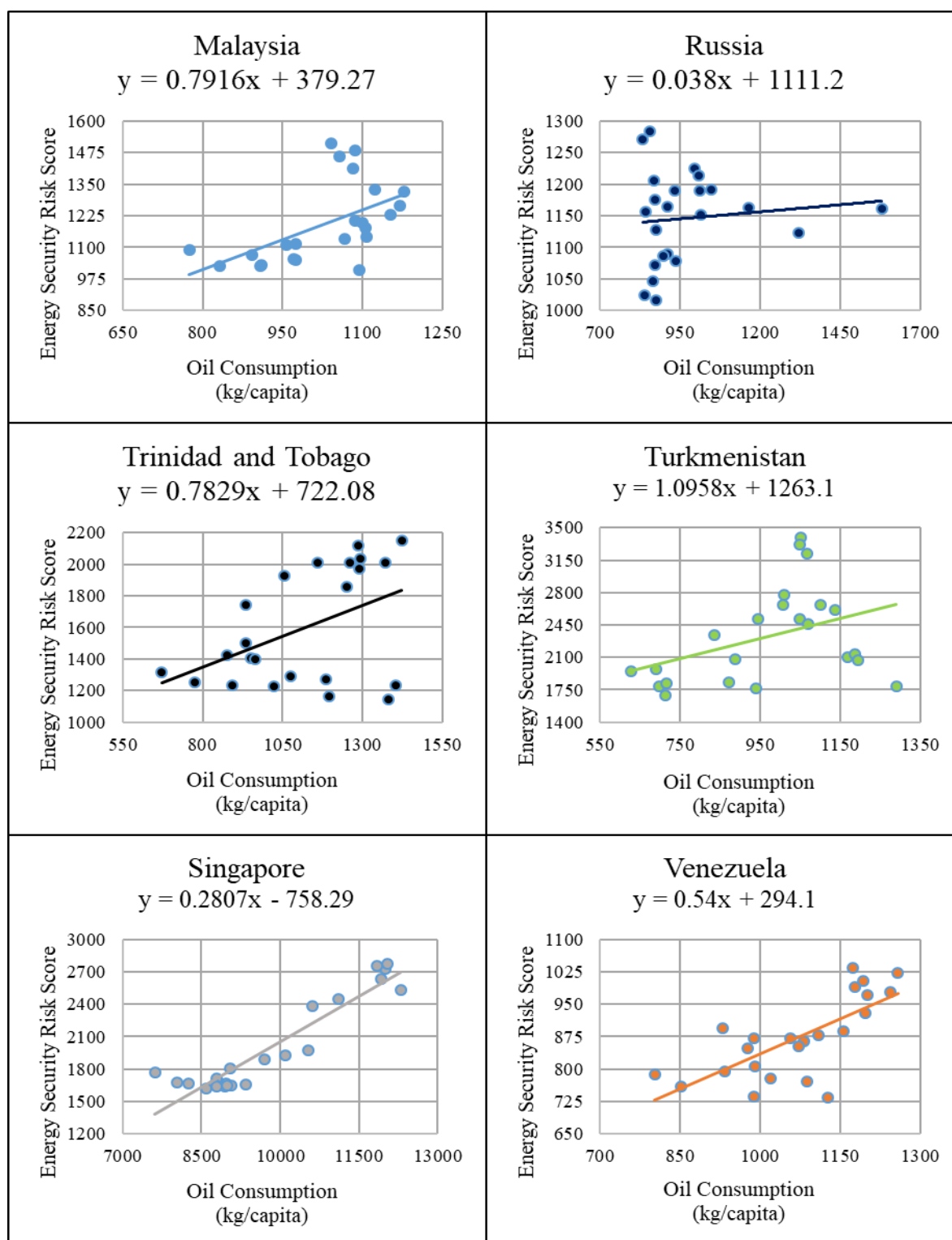
make it particularly valuable apart from its actual generation cost per unit – MWh or kWh. Fuel is a low proportion of power cost, giving power price stability, and is stored onsite (not depending on continuous delivery). The power from nuclear plants is dispatchable on demand, it can be fairly quickly ramped-up, it contributes to clean air and low-CO₂ objectives, it gives good voltage support for grid stability. Reactors can be made to load-follow. These attributes are mostly not monetized in merchant markets, but have great value which is increasingly recognized where dependence on intermittent sources has grown.”

6.6.5. *Oil and natural gas consumption*

During the 35-year period from 1980 to 2011, average oil consumption increased by 6.1% from 1,381 to 1,465 kg/capita, while average energy security risk scores increased by 24.8% from 1,089 to 1,359 over the same period. There were noticeably similar trends in the graphs of the two variables during the period of 1999 to 2005, where each hit a local low point before rising to the highest point in their respective historical trends. These declines likely reflect a number of global oil supply disruptions that interfered with consumption patterns and contributed to greater energy security risk, including

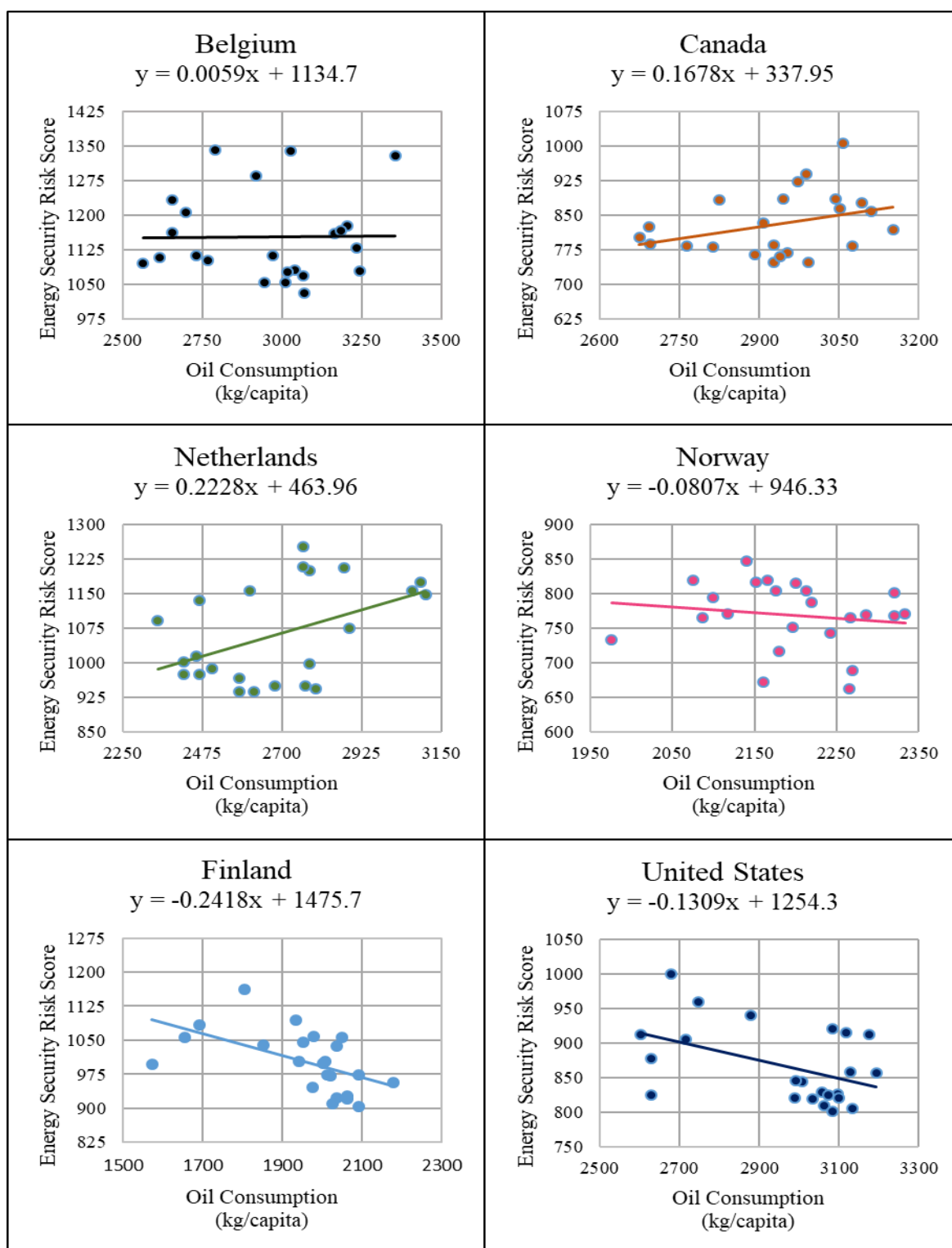
1. The suspension of Iraqi oil exports from June to July, 2001, halting 2.1 million barrels per day;
2. The Venezuelan oil strike of December, 2002 to March, 2003, disrupting 2.6 million barrels per day;
3. The War in Iraq from March to December, 2003, disrupting 2.3 million barrels per day; and

Figure 6.6.5: Per capita oil consumption and energy security risk score trends in top oil consuming non- OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

Figure 6.6.6: Per capita oil consumption and energy security risk score trends in top oil consuming OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

4. Hurricanes Katrina and Rita in the U.S. in August and September, 2003, disrupting 1.5 million barrels per day.

Figures 6.6.5 and 6.6.6 depict scatterplots that show the relationship between per capita oil consumption and energy security risk scores in top oil consuming non-OECD and OECD countries, respectively.

For many developing countries that face technological and infrastructural limitations to implementing alternative energy sources, international oil shocks may cause them to score worse in oil-related metrics, directly leading to greater energy security risk. Yet, particularly because they lack substantial energy alternatives while still depending on oil as the standard transportation fuel, these countries may consume similar or even greater amounts of oil even when energy security risk rises. Out of the nations listed in Figure 5.6.5, this is particularly true for Singapore, which consumed over 25 times more oil per capita than any other energy source at any given time (BP, 2016) during sharp economic growth and growing transportation sector energy (oil) demand. Though per capita oil consumption for Malaysia, Trinidad and Tobago, and Turkmenistan was outstripped by natural gas consumption, the former remained markedly higher than all other energy sources while energy security risk remained high.

For Venezuela and Russia, considerable oil reserves (an estimated 80 billion barrels by Venezuela and 103.2 billion barrels by Russia as of the end of 2014) (BP, 2016) influenced their decision to consume larger amounts of domestic supplies to the extent that energy security risk was high. Detailed energy security risk summaries for Russia (which are not available for the other non-OECD countries of this group) show that although Russia scored well in the oil-related metrics, it scored poorly in most other metrics, suggesting that it would have scored much worse had it halted or switched from consuming oil. (Institute for 21st Century Energy, 2016)

Venezuela, similarly having oil resource endowments, likely consumed more oil to keep risks low, which appears to be a trait held in common among this group of non-OECD countries. Importantly, all of these positive consumption-risk correlations are in line with the positive correlations shown in the regression results of Table 5.6.2.

A major percentage of the energy security risk scores calculated in the *2016 International Index of Energy Security* is derived from oil and petroleum-centered risk metrics, including *security of world oil reserves* (2% of total score), *security of world oil production* (3%), and *petroleum import exposure* (3%) of the *global fuel* metrics category; *fossil fuel import expenditures per GDP* (5%) of the *fuel import* category; *crude oil prices* (7%) of the *energy expenditure* category; *crude oil price volatility* (4%), *world oil refinery utilization* (2%) of the *price & market volatility* category; and *transportation energy per capita* (3%) and *transportation energy intensity* (4%) of the *transportation sector* category. These metrics (which comprise 32% of the overall risk score) measure the majority of oil-related risks facing oil-dependent countries, from the availability of global oil reserves, to levels of import dependence and the impact of oil market price swings on economies, and countries that score well (causing them to lower risk) on them tend to consume more oil to abate risk.

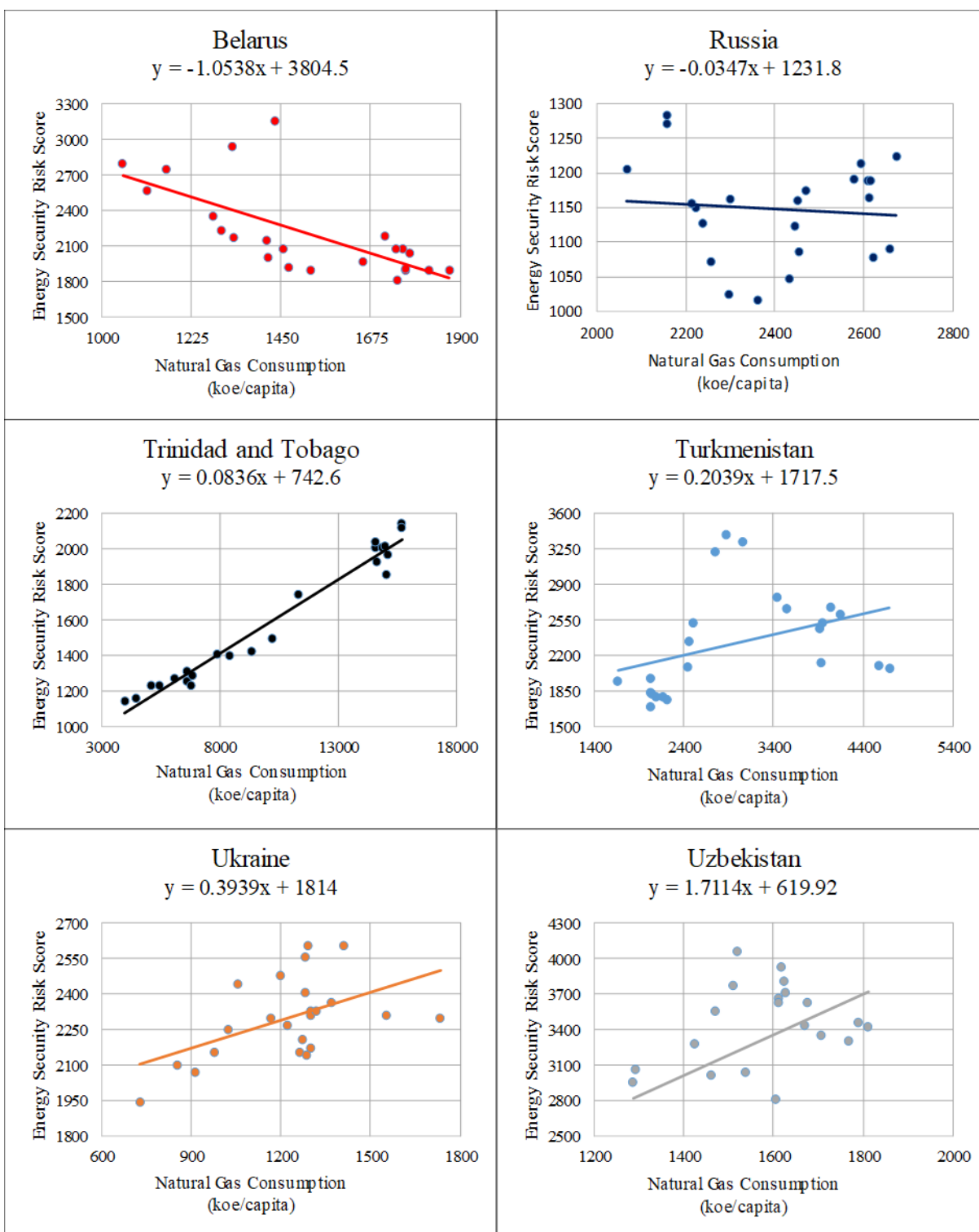
For many developing countries that face technological and infrastructural limitations to implementing alternative energy sources, international oil shocks may cause them to score worse in oil-related metrics, directly leading to greater energy security risk. Yet, particularly because they lack substantial energy alternatives while still depending on oil as the standard transportation fuel, these countries may consume similar or even greater amounts of oil even when energy security risk rises.

Average natural gas consumption experienced a 71% increase from 801 to 1,371 koe/capita over the period of this study. The increase in natural gas consumption is likely a reflection of the fuel switching that took place during this period. Specifically, from the early 1970s through the early 2000s, as oil use diminished outside of the transportation and petrochemical sectors, natural gas became the fastest growing fuel for electricity generation due to high efficiency, low capital costs, peak and base-load capacity, short plant construction times, and compatibility with environmental regulations (Toth & Rogner, 2006).

Scatterplots in Figures 6.6.7 and 6.6.8 depict the relationship between per capita natural gas consumption and energy security risk score in top natural gas consuming OECD and non-OECD countries, respectively. These trends reflect the fact that natural gas has become critically vital to modern energy systems, rendering it preferred or irreplaceable even when energy security risk is high. Many developed countries prefer natural gas due its cleaner, more efficient energy generation, especially when energy security risks are low and obstructions to consumption (e.g. supply disruptions) and prices are correspondingly low.

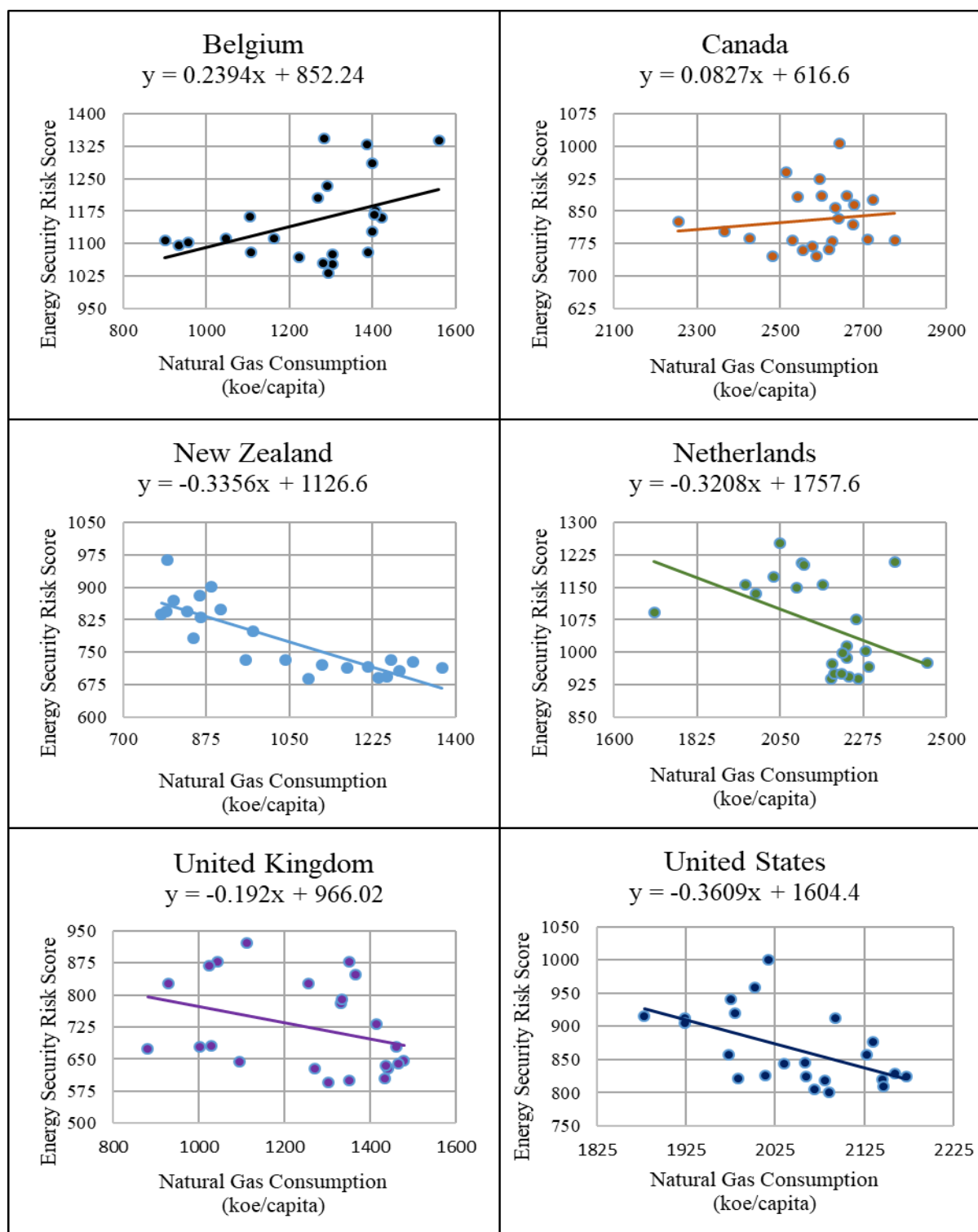
The merits of natural gas make it suitable for alleviating certain aspects of energy security risk. For example, IEA stockpiling and stock drawing ordinances also apply to natural gas, it is conventional for IEA signatory nations to consume domestically produced or reserve natural gas in the event of a crisis similar to the aforementioned oil supply disruptions. Thus, events like the 2006 Russian gas cutoff, where Russian state-run gas monopoly Gazprom cut natural gas supplies destined for western Europe due to political and economic disputes with Ukraine (amounting to roughly 30% of the natural gas imports of OECD Europe) (Nichol et al., 2006), as well as 2005 Hurricanes Katrina and Rita that halted 20% of U.S. natural gas output (and prevented production of the 17% of the natural gas consumed in the U.S.) (Bamberger &

Figure 6.6.7: Per capita natural gas consumption and energy security risk scores in top natural gas consuming non-OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

Figure 6.6.8: Per capita natural gas consumption and energy security risk scores in top natural gas consuming OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

Kumins, 2005) may have allowed for continued large consumption despite, and in response to, upswings in energy security risk.

The positive correlations between oil and natural gas consumption and energy security risk are rooted in two major considerations. The first is that fossil fuels, particularly oil and natural gas, are the fuels turned to during energy crises, placing them at the center of responses to greater energy security risk or shocks. This is supported by the fact that the IEA, established in the wake of the oil crises in the 1970s, mandates that signatory countries hold oil and natural gas stocks sufficient for 90 days-worth of consumption to mitigate the negative effects of sudden or severe fuel supply disruptions. It also advises countries to consume said stockpiles while increasing domestic production in such emergency situations. Considering these institutionalized practices alongside numerous international energy supply disruptions that occurred during the time frame of this study, it is reasonable to conclude that fossil fuel consumption was higher when risk is higher due to policies that aimed to use the former to address the latter.

The second aspect that justifies the positive correlation between fossil fuel consumption and energy security risk is that fossil fuels are heavily influential on the calculation of risk based upon their inclusion in a greater number of metrics than other fuel sources. Most exemplary of this is that fact that fossil fuel consumption ought to be lower when conditions conducive to worsening the *Global Fuel* and *Fuel Import* metric categories, which make up 31% of the overall risk score, are present. For example, when an oil price shock occurs, the energy security risk score of a given country may be downgraded by worsening *security or world oil reserves*, *security or world oil production*, and *petroleum import exposure* metrics, which alone account for 8% of overall risk.

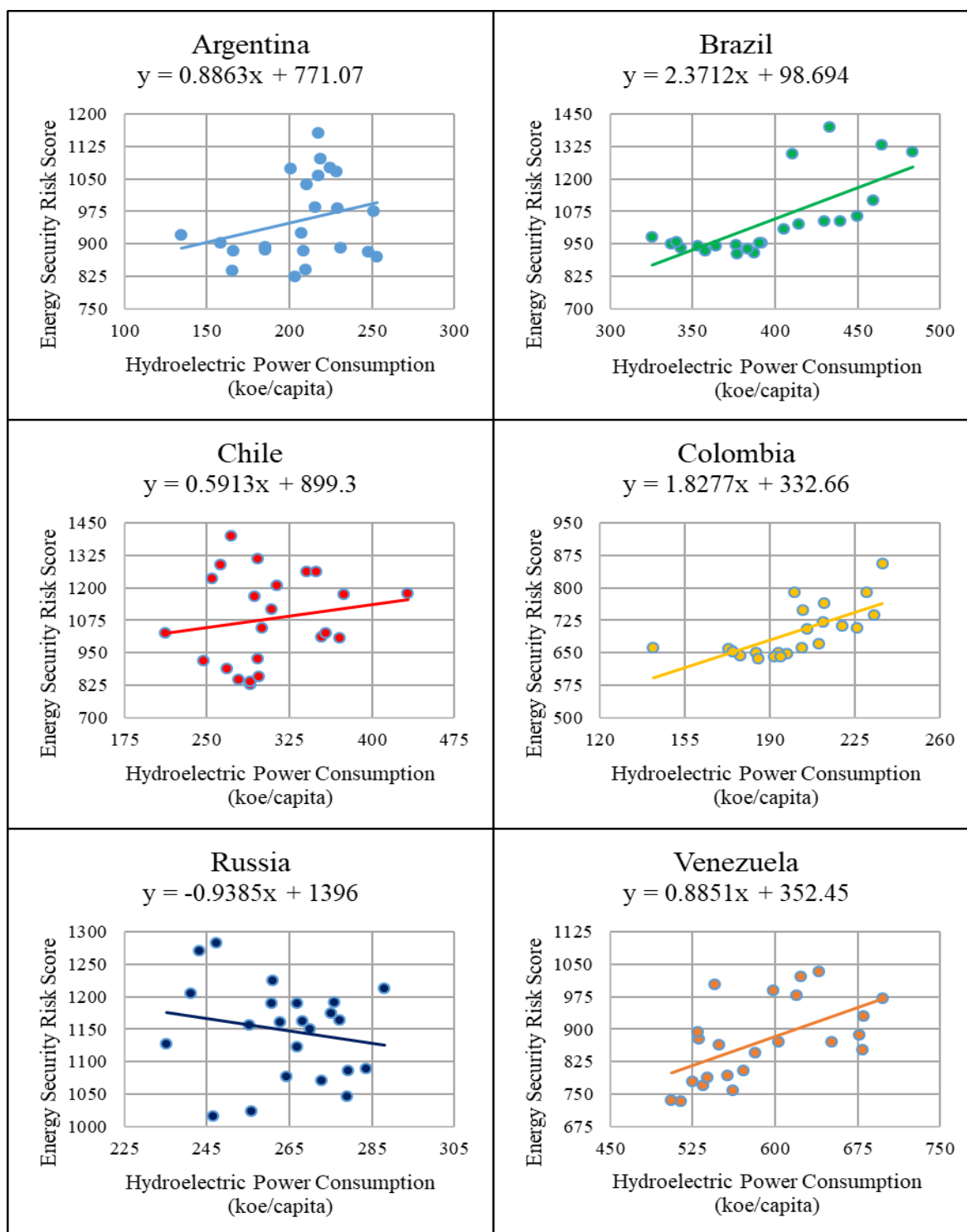
6.6.6. *Hydroelectric power consumption*

From 1992 to 2014, total hydroelectric power consumption among the countries in this study sample nearly doubled, increasing by 80% from 455 to 802 Mtoe. (BP, 2016) It was negatively correlated with energy security risk largely due to the consumption patterns in developed countries that consume more as risk decreases. Thus, while developing countries show a different trend, the global results reflect the experiences in developed countries. Figures 6.6.9 and 6.6.10 are scatterplots that depict the relationship between per capita hydroelectric power consumption and energy security risk scores for top hydroelectric power consuming non-OECD and OECD countries, respectively.

It is worth noting that as of 2005, hydroelectric power was the world's most widely adopted renewable energy source, responsible for 17.4% of global electricity supply at the time. (Jacobson, 2009; U.S. Department of Energy, 2016). Moreover, the fact that the number of observations and countries involved in the hydroelectric power consumption analysis are comparable to those for the more exhaustively consumed fossil fuels yield a negative correlation with energy security risk alludes to the value of hydroelectric power as an alleviation of risk.

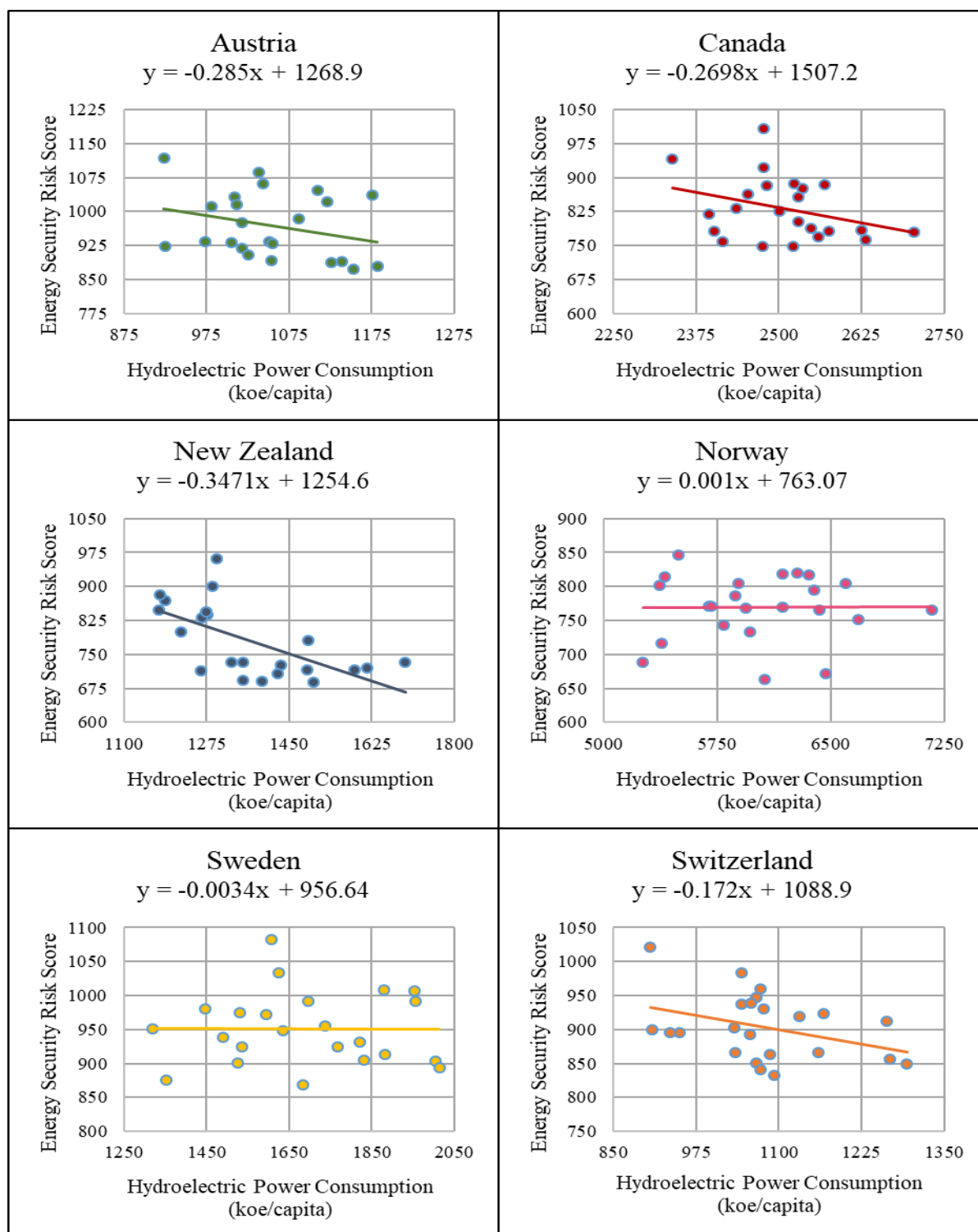
Consider Norway in Figure 6.6.11. It possessed the consistently highest average hydroelectric power consumption and the 8th lowest average energy security risk score (795) among OECD countries over the target period. In 2000, Norwegian hydroelectric consumption peaked at 7,167 koe/capita (a 54% increase from the 4,651 koe/capita of 1980), while its energy security risk reached a 21-year low of 766 (falling by 16% from 916 in 1980). Moreover, the following year, Norwegian energy security risk reached an all-time low of 663, still maintained a relatively high consumption level of 6,061 koe/capita. Even by 2007, when the 6,422 koe/capita consumption level comprised 98.9% of total Norwegian electricity generation (IEA, 2007; Jacobson, 2009), Norwegian energy security risk equaled 765, the 2nd lowest risk score of that

Figure 6.6.9: Per capita hydroelectric power consumption and energy security risk score trends in top hydroelectric power consuming non-OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

Figure 6.6.10: Per capita hydroelectric power consumption and energy security risk score trends in top hydroelectric power consuming OECD countries



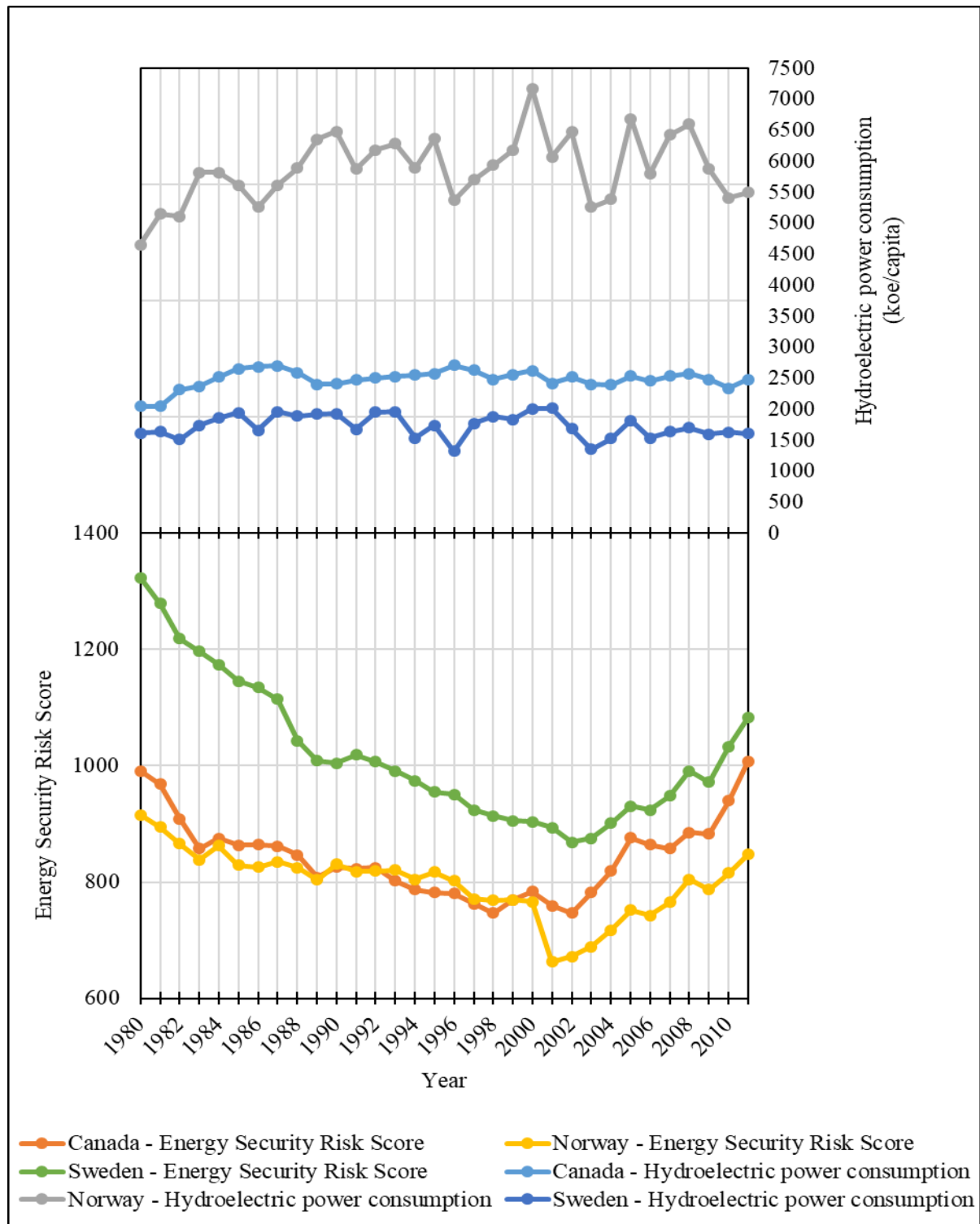
Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

year.

Venezuela, with the highest average hydroelectric power consumption among non-OECD countries, clearly depicts a pattern of greater hydroelectric power consumption alongside lesser energy security risk scores. As shown in Figure 6.6.12, this is especially true for the periods from 1982 to 1988, 1989 to 1992, and 2003 to 2008, each marked by uninterrupted energy security risk decreases alongside increasing hydroelectric power consumption. By 1993, when Venezuelan energy security risk score reached an all-time low of 736 (the 5th best score of that year), hydroelectric energy consumption reached 505 koe/capita (8th largest in the world). Similarly, by 2008, hydroelectric power accounted for 80% of all the electricity generated (IEA, 2007), and hydroelectric power consumption peaked at 698 koe/capita (8th largest, globally) while energy security risk amounted to 971, the lowest of all non-OECD countries (12th lowest, globally).

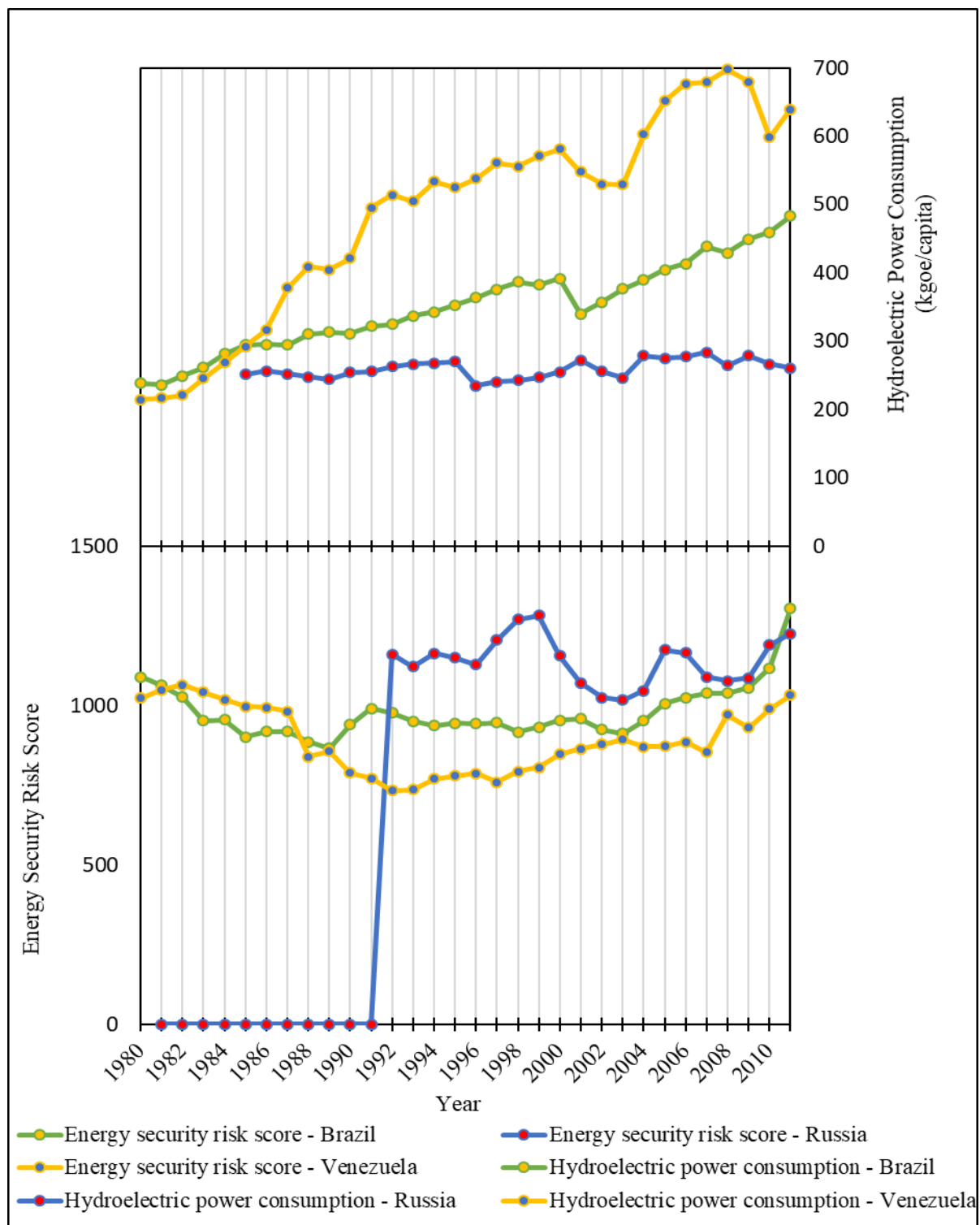
Despite these trends among the countries above, there are still factors that prohibited many countries from employing hydroelectric power to the same extent, which could subsequently had affected that country's energy security risk during the same or following years. Of these factors, the fact that hydroelectric facilities are large, complex, and, compared to other electricity sources, more materials-intensive on a per-megawatt (MW) basis, weighs quite heavily on the choices to adopt it in an energy system. Hydroelectric power development is restricted to areas with adequate water resources and needs to control water flow, which makes it more applicable to public safety than to energy security risk. The fact that hydroelectric facilities are large, complex, and, compared to other electricity sources, more materials-intensive on a per-megawatt basis, weighs quite heavily on the choices to adopt it in an energy system. Moreover, these facilities are largely dependent upon a number of unique construction processes and

Figure 6.6.11: Hydroelectric power consumption and energy security risk score trends in top three hydroelectric power consuming OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

Figure 6.6.12: Hydroelectric power consumption and energy security risk score trends in top three hydroelectric power consuming non-OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

considerations, including large scale excavation to make suitable space and siting that allows the facility to serve multiple purposes (e.g. electricity generation along with irrigation, flood control, etc.).

Correspondingly, the global range of capital expenditures for small hydroelectric facilities spans from \$1.40 to \$3.68 million/MW, while the range for large hydro is \$1.59 to \$4.15 million/MW. In the end, however, these comparatively higher initial cost ranges are potentially offset by lower LCOE costs. Global LCOE for small hydro ranges from \$19 to \$314/MWh, while that for large hydro ranges from \$24 to \$302/MWh. The “mature and relative simplicity” of hydroelectric technology typically renders it cost-competitive (e.g. capable of capturing low-end LCOE) and economically attractive if siting and facility size considerations are overcome (WEC, 2013).

Perhaps the largest drawback to hydroelectric power is that they are dangerous in the event of accidents. Sovacool (2015) notes that 15/15 of the hydroelectric power-related accidents from 1950 through 2014, and 8/8 of the accidents that occurred during the 1980 to 2014 time frame of this study, led to the largest number of total deaths compared with all other energy generation sources.

6.6.7. Solar power and coal consumption

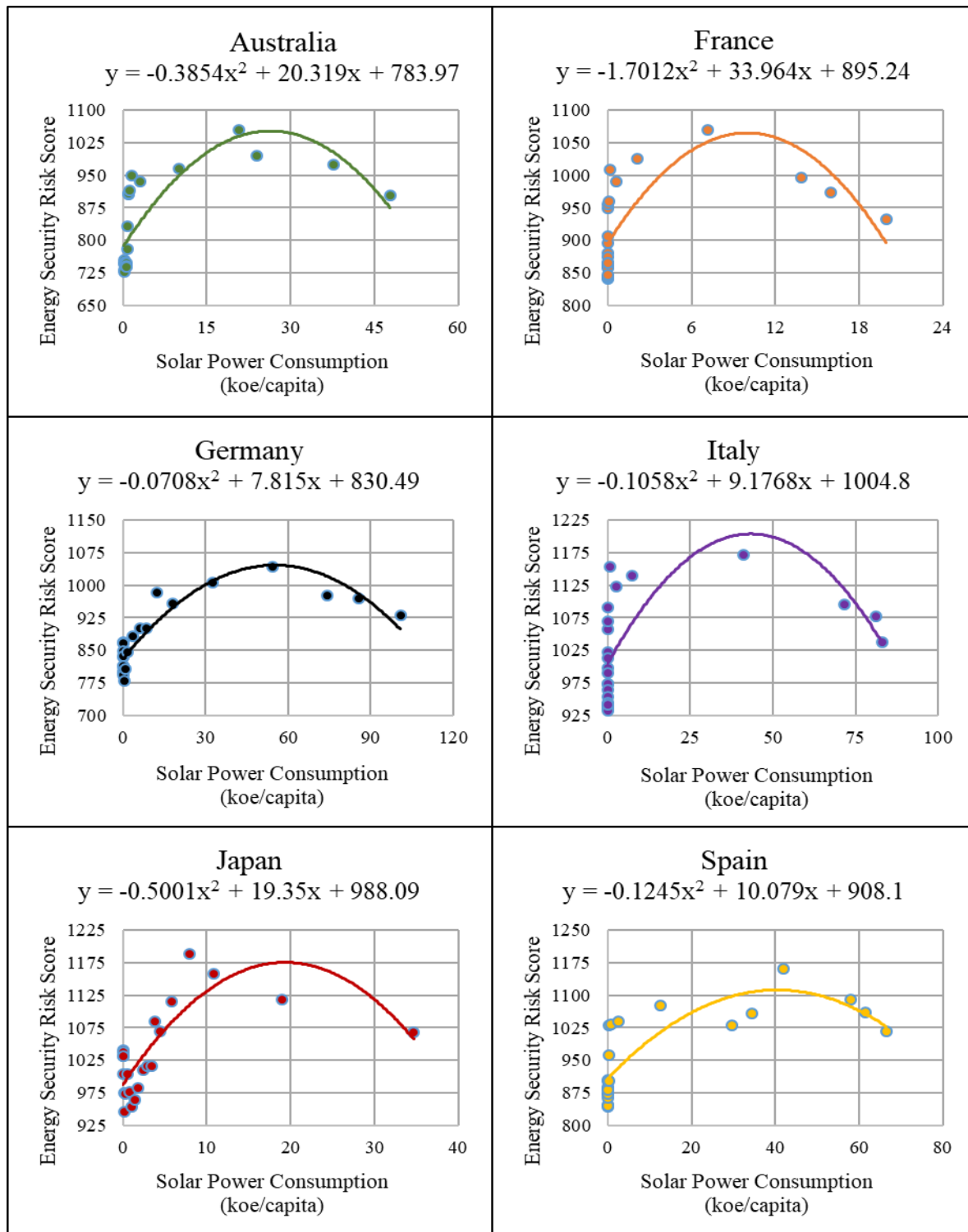
Solar and coal power consumption were not significantly correlated with rising energy security risk, but they remain important within a number of energy systems around the world, and there are a number of important facts to mention regarding them. From 1992 to 2014, total solar power consumption increased from 0.1 to 43 Mtoe. Unlike most other energy sources, most of this consumption growth occurred in OECD countries, which accounts for 34/43 Mtoe, or

79%, of total growth. Over the same period, total wind power consumption grew from 1 to 159 Mtoe, 69% of which (109 Mtoe) occurred in OECD countries. Due to this substantial growth disparity between OECD and non-OECD countries, along with lack of available consumption data with which to observe consumption-energy security risk trends, the following assessments will only consider developments in OECD countries. Figure 6.6.13 is a scatterplot that depicts per capita solar consumption and energy security risk trends for top solar power-consuming OECD countries.

Due to technological constraints and costs, solar power consumption did not increase significantly until the first decade of the 2000's for solar power. The mean capital cost and marginal levelized cost of electricity (LCOE) for solar PV plants in the United States was estimated at to be \$5,850 (ranging from \$4,700 to \$7,000) and \$0.39/kWh, topping both lists (Sovacool & Watts, 2009). This, and other technology-related barriers to consumption are reflected in the fact that, compared to the other sources, there were less observations for solar power consumption. Even still, solar underwent exponential growth, increasing by 4,200% from 2005 to 2014.

Regarding the technological advancements that allowed for greater consumption, the IEA (2014b) notes that cumulative solar photovoltaic (PV) capacity grew by 49% per year from 2003 to 2013. They note the "...considerable increases in [PV industry] manufacturing capabilities and a move of module manufacturing from European countries and the United States to Asia, notably China and Chinese Taipei. Market prices have been drastically reduced by a factor of almost 3 for systems." Other technical advantages of solar PV systems include that they are applicable to stand-alone off-grid systems that eliminate the need for expensive power lines, which could be ideal for rural populations among developing countries; they can also be linked

Figure 6.6.13: Per capita solar power consumption and energy security risk score trends in top hydroelectric power consuming OECD countries



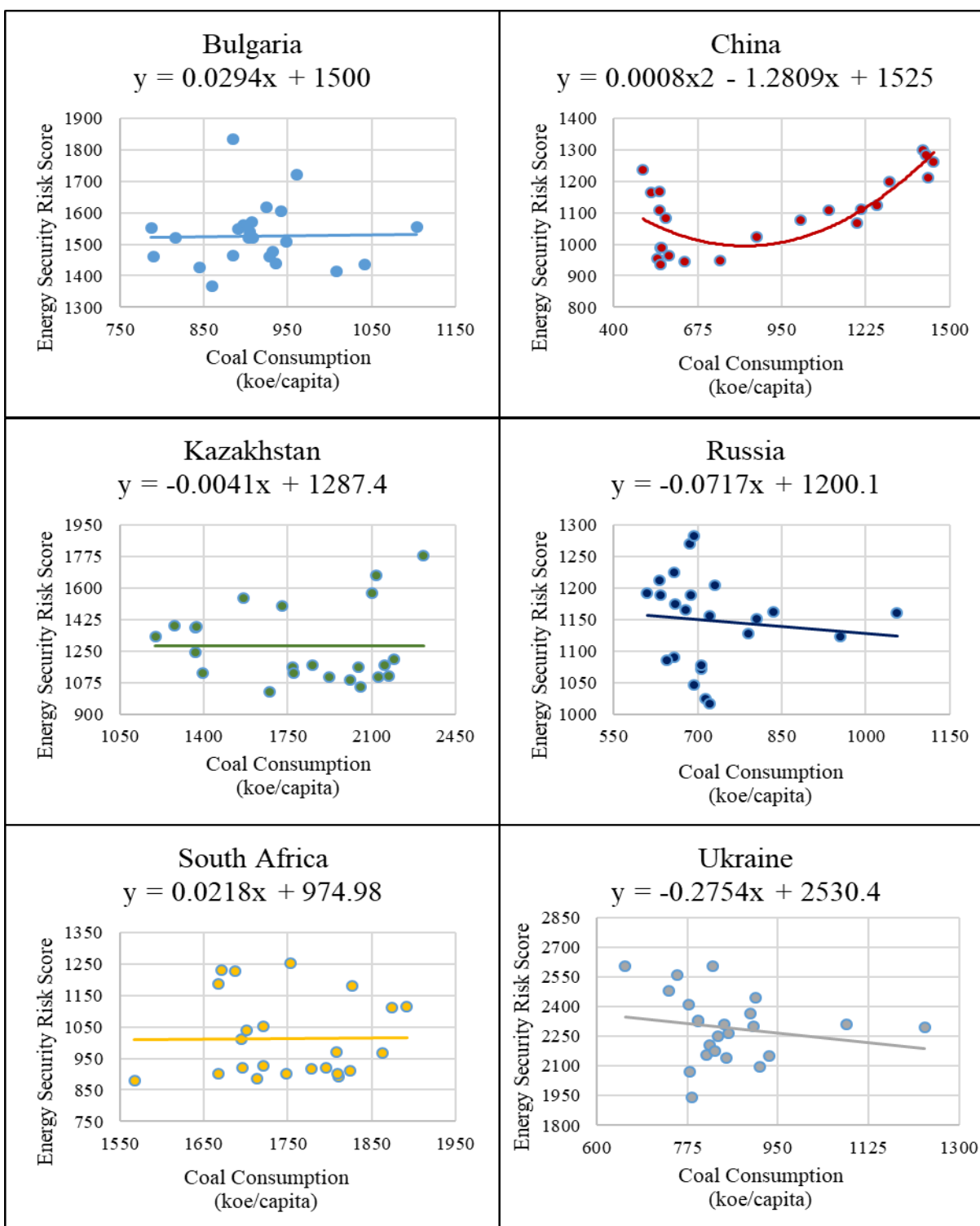
Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

to utility-owned grids to allow for electricity purchase and sale depending upon supply and demand; and large-scale PV plants could potentially provide bulk electricity and be constructed and expanded more quickly than conventional power plants. (Papaefthymiou et al., 2009) Thus, solar PV, notwithstanding the possibilities of solar thermal power, is deployable in a variety of scenarios, which explains recent skyrocketing consumption patterns.

Total coal consumption among the countries of this study increased by 79% from 2,133 in 1992 to 3,808 Mtoe in 2014. Similar to oil and natural gas consumption, the bulk of this growth was due to greater consumption in non-OECD countries. In fact, while total OECD coal consumption decreased by 2% from 1,050 in 1992 to 1,030 Mtoe in 2014, non-OECD consumption expanded by 156% from 1,084 to 2,778 Mtoe over the same period. The negative consumption growth rate among OECD countries represents the tendency of more economically developed countries to shift consumption priorities from coal to more environmentally-friendly natural gas, nuclear power, and renewable energy sources. Environmental factors, such as the 255 to 442 grams of CO₂ emissions per kilowatt hour (gCO₂/kWh) of power produced over the lifecycle of clean coal and carbon capture and storage system plants, support this trend.

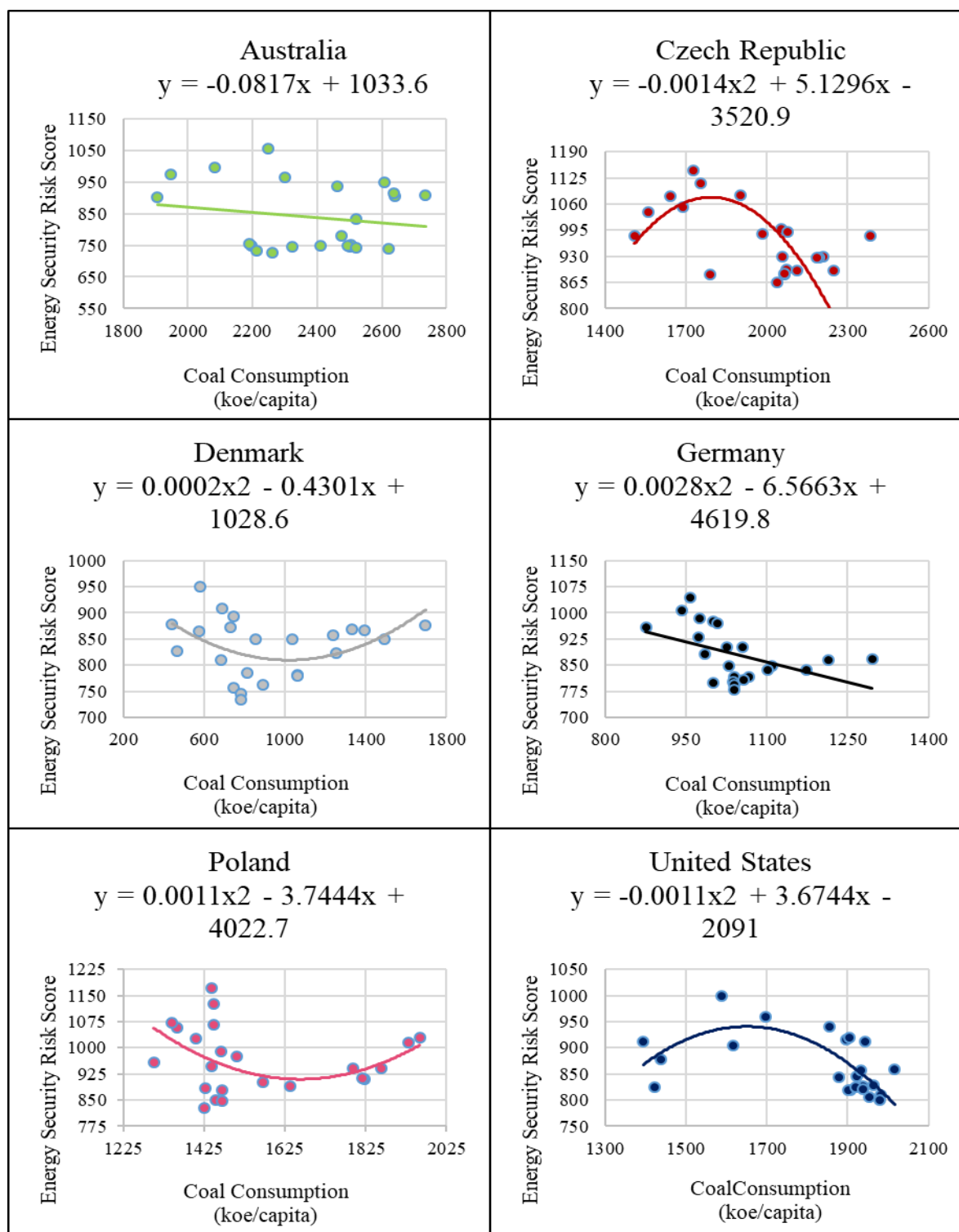
As recently as 2015, China possessed 114,500 million tonnes (BP, 2016) of proven domestic coal reserves (rendering it the world's largest coal producer), and its domestically produced coal are less risky than foreign oil imports. Denmark generated roughly half of its power from coal (Institute for 21st Century Energy, 2016), which compliments the other half of its power generation from renewable energies. Proven coal reserves for Germany amounted to 40,548 million tonnes as of the same year (BP, 2016), and coal was Germany's cheapest domestic power generation source. Czech proven coal reserves amounted to 1,052 million tonnes (BP, 2016), while coal consumption made up 45% of the national energy mix. (WEC, 2015) In

Figure 6.6.14: Per capita coal power consumption and energy security risk score trends in top coal power consuming non-OECD countries



Sources: Created by author using BP 2016 Statistical Review of World Energy (2016); Institute for 21st Century Energy International Index of Energy Security Risk, 2016 Edition (2016)

Figure 6.6.15: Per capita coal power consumption and energy security risk score trends in top coal power consuming OECD countries



Sources: Created by author using BP 2016 *Statistical Review of World Energy* (2016); Institute for 21st Century Energy *International Index of Energy Security Risk*, 2016 Edition (2016)

the same year, the U.S. was a major coal producer, consumer and exporter, holding 237,295 million tonnes of coal reserves (BP, 2016) and with 40% of its thermal power sector fired by coal. (Institute for 21st Century Energy, 2016) And, Poland held 5,465 million tonnes of coal reserves while coal occupied a large percentage of its power generation. Thus, coal reserve availability and coal-fired capacity likely incentivized greater coal consumption in general.

Figures 6.6.14 and 6.6.15 show scatterplots that depict the relationship between per capita coal power consumption and energy security risk in top coal power-consuming non-OECD and OECD countries, respectively. Related to the country-specific production factors, economic development levels, and availability of alternative resources, trend lines for these relationships are variegated and support the regression results of Table 6.6.2, where coefficients for coal consumption were insignificant.

6.6.8. GDP per capita and population considerations

Regarding GDP per capita, coefficients for all energy consumption sources are positive and 99% significant. As shown by Yuan et al. (2007), Belloumi (2012) and Ghosh (2013), GDP promotes energy consumption as more energy is required to fuel economic processes. Regarding population, coefficients for most energy consumption sources were positive and highly significant. Like the case of GDP, rising population gives rise to greater energy demand, incentivizing policy makers to develop potential energy sources. Solar and wind power consumption are the exceptional cases due to their high upfront capital expenditures that limit their immediate applicability to rising risks. With further investment in these technologies, falling costs are making them accessible to a wide range of countries.

6.7. Conclusions

The results of this study show that energy security risk is positively correlated with wind power, nuclear power, natural gas, and oil consumption at 99% statistical significance. For wind and nuclear power increases, this signifies rising consumption of sustainable energy sources in response to rising manmade, environmental, technical risks. Both wind and nuclear power emit negligible amounts of emissions over the duration of their power generation lifecycles, and wind is highly applicable to a variety of situations while nuclear power provides valuable baseload electricity. Both energy sources are also generally constructed in relatively safe domiciles that do not experience high levels of domestic terrorism or other manmade risk factors. The positive correlations between oil and natural gas reflects two realities: 1) since the oil shocks, countries have stockpiled oil and gas supplies to account for sudden supply disruptions (e.g. they could consume more even in the event of decreased output from other sources); and 2) oil and natural gas consumption decreased with falling risk in the wake of greater consumption of sustainable energy sources. As price and volatility, industrial intensity, environmental, and other risk factors went down, so too did fossil fuel consumption as they were supplanted by other clean, highly efficient energy consumption sources. Rising energy security risk resulted in decreasing hydroelectric power consumption due to the lack of availability, expandability, and applicability of hydroelectric power to energy functions outside of electricity generation in areas where water resources are abundant. Results for coal and solar power consumption were not significant.

GDP per capita exerted positive, highly significant effects on consumption of all energy sources. This suggests that greater amounts of all energy sources are consumed as rising GDP yields rising energy demand to fuel expanding economic processes, and this is consistent with the findings in previous literature. The results also showed positive, highly significant impacts of

population on consumption of all energy sources excluding solar and wind power. The majority of sources were positive due to the rising energy demand that coincides with population growth and results in greater consumption. Solar and wind power consumption are the exceptions due to their high initial capital expenditures and a lack of conventional energy storage and distribution technologies that would enable their immediate, more widespread application to satisfy the high energy demands of large populations.

In the future, it is important to recognize the many different ways to define and measure energy security. While many modern indices appropriately focus on proven resource reserves, supply costs, technological development and proliferation, and other important energy security considerations, greater emphasis on natural disasters (e.g. large-scale earthquakes and tsunamis), human interferences (e.g. terrorism and economic sanctions), and technological failures should be incorporated into more precise, energy source-specific measurements of energy security and its risks.

Furthermore, the fact that energy security risk is correlated with greater consumption of sustainable energy sources is useful information for policymakers. Though conventional fossil fuel stockpiles had traditionally been viewed as the ideal means for alleviating energy security risk (particularly in the event of physical supply disruptions that occur in such cases as OPEC oil embargos), modern energy systems require supply sources that are robust to a broader spectrum of risks. Environmental, manmade, and technical risks extend beyond merely the excavation, transportation, and distribution levels of the upstream-downstream framework. Communities around the globe will likely show increasing demand for energy supplies that alleviate environmental cost externalities, enable access in geographically, climatically, and economically diverse regions, and contribute to many other facets of sustainability.

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Chapter 7: Conclusion

As sustainability lies at the crossroads of climate and economic development agendas, instruments for closing the finance gap for sustainability enhancing infrastructures remain critical to agenda-setting and pragmatic action in both developed and developing countries. This aim of this Thesis was to contribute an investigation of green bonds as financial tools capable of achieving such aims. For this purpose, this Thesis conducted broad yet thorough qualitative and quantitative analyses of green bonds distinguishing features, environmental impacts, market drivers, and capacity to finance investments in various projects and assets conducive to sustainability. To perform such extensive analyses, this Thesis employed originally constructed green bond allocation panel datasets spanning over one hundred countries and twenty years. This Thesis also utilized unique green bond issuance data available upon request and subsequent screening of applicants that was provided by the Climate Bonds Initiative. The main findings from this study are summarized as follows:

- In Chapter 3, this Thesis aimed to estimate the recent growth of green bond issuances outstanding within the greater context of global international bonds outstanding. An original panel dataset of 1,851 green bond proceeds allocations from 53 issuing organizations to sustainability-enhancing projects and assets in 96 countries between 2008 and 2017 was constructed to track the volume and frequency of green bond finance in both developing and developed countries. In addition to revealing the comparatively greater proceeds allocations to renewable energy, energy efficiency, low-carbon transportation, and green buildings and infrastructure sectors, results from Chapter 2 revealed that the underlying projects and assets financed at least partially by green bonds were collectively responsible for 108,754,366 tonnes of carbon dioxide equivalent (tCO₂e) in greenhouse gas (GHG) emissions reductions,

1,551,854 megawatts (MW) in added renewable energy capacity, 57,303,917 megawatt hours (MWh) in added renewable energy generation, and 737,235,746 MWh in annual energy savings. Such results demonstrate the immense impact that green bond finance has had on sustainable outcomes in the first decade of market activity and suggest that they will continue to be integral to financing infrastructures conducive to sustainable outcomes through the future.

- In Chapter 4, this Thesis built upon preceding studies on the determinants of conventional capital market growth to measure the impacts of conventional market drivers, Nationally Determined Contributions (NDCs) to the Paris Agreement, and Organization of Economic Cooperation and Development (OECD) membership on green bond market growth. The results revealed that NDCs exerted the largest, 20% direct impacts on green bond issuance volumes of any single variable, alluding to the importance of robust NDCs in promoting green bond market growth. Macroeconomic and institutional factors also exerted substantial impacts on green bond market growth, which is in line with previous literature on conventional market studies. Overall, the results imply that Macroeconomic, institutional, and NDC factors will be integral to investing in sustainability due to their ability to accelerate green bond markets that spur climate and other eco-friendly investments.
- In Chapter 5, this Thesis investigated the importance of energy consumption to sustainability based on the finding from Chapter 3 that over 50% of all green bond proceeds have been allocated to renewable energy and energy efficiency investments. As energy consumption is integral to economic growth and impacts environmental and sustainability aspects of host countries, this Chapter assessed the impact of energy security risk on consumption of nine primary energy sources of varying impacts on sustainability. The results revealed that wind

and nuclear power were consumed in the greatest volumes to the extent that energy security risk was high. This suggests that their low emissions, supply disruption, and sustainability-enhancing features serve to alleviate energy security risk and thus render them ideal consumption sources. Though to a lesser degree than the former two sources, natural gas and oil were also positively correlated with energy security risk, highlighting the importance of diversity of supply when risk is high.

- In Chapter 6, this Thesis built upon existing empirical literature on renewable energy policy supports to investigate the impact of economic, regulatory, and financial policy supports on green bond finance for renewable energy infrastructure. In addition to the positive, statistically significant influences exerted by each policy support, NDCs also affected green bond allocations to renewable energy, reinforcing the market driving influences exerted by green bonds that were measured in Chapter 4.