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SUSTAINABLE FINANCING FOR SUSTAINABLE DEVELOPMENT: COMPUTER SIMULATIONS FOR RENEWABLE ENERGY INVESTMENTS

BY

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ABSTRACT

Renewable energy investments require a substantial amount of capital to provide affordable and accessible energy for everyone in the world, and finding the required capital is one of the greatest challenges faced by governments and private entities. In a macroeconomic perspective, national budget deficits and inadequate policy designs hinder public and private investments in renewable projects. These problems lead governments to borrow a considerable amount of money for sustainable development, although such excessive debt-based financing pushes them to unsustainable economic development. This substantial amount of borrowing makes a negative contribution to the high global debt concentration, putting countries' economic and social development at risk. In line with this, excessive debt-based financing causes an increase in wealth inequality, and when wealth inequality reaches a dramatic level, wars and many other social problems are triggered to correct the course of wealth inequality. In this regard, the motivation behind the study is to develop a set of policy guidelines for sustainable financing models as a solution for these intertwined problems, which are: 1) a financial gap in energy investments; 2) an excessive global debt concentration; and 3) a dramatic increase in wealth inequality. To this end, this study presents a proof of concept analysis of alternative financing models in a solar farm investment simulation to investigate the change in wealth inequality and social welfare by reducing debt-based financing and increasing public participation. There is a gap in the literature, and investigating the effects of various policy rules on the evolution of wealth inequality in a future time frame needs to be explored in order to discuss possible policy implications beforehand. In this respect, this study contributes to the literature by enabling to investigate the changes in wealth inequality and social welfare as a result of various policy implications throughout the simulation time.

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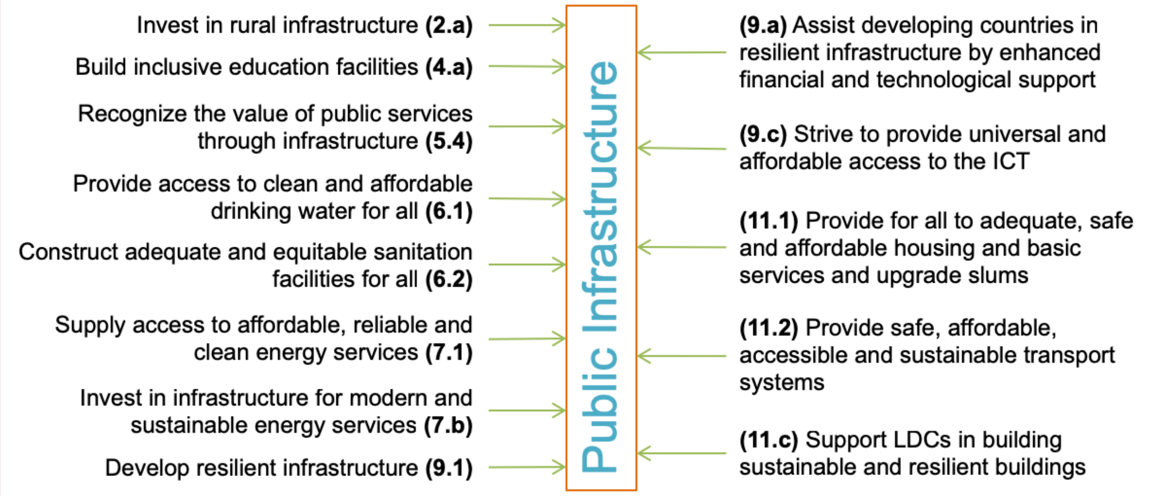
DEDICATION

This dissertation is dedicated to my wife, Rukiye, who always encourage me to pursue my dreams by providing her continued and endless support with enormous patience during my Ph.D. studies.

CHAPTER 1: INTRODUCTION

Public infrastructure plays a profound role in ensuring and sustaining the welfare of nations by satisfying almost all of the United Nation's (U.N.) sustainable development goals (SDGs) for a better planet by promoting social, economic, and environmental benefits of the public (see Figure 1.1, United Nations 2016). In a broader perspective, public infrastructures, in which governments have a large share in building such assets through public investment, include many tangible and intangible assets for a sustainable future such as energy, water, transportation, health, education, and information and communication technologies (ICT). In particular, energy investments have a significant influence on economic growth and development as widely discussed in the literature [3,4]. Global energy investment, along with renewables, amounted to around US$1.8 trillion in 2017 funded by both public and private investments, and power sector took the largest portion which was about US$ 750 billion (IEA 2018). Electricity investment in the power sector has shifted towards renewables, networks, and efficiency. In line with this, renewable power valued US$ 300 billion in 2017, accounted for two-thirds of power generation investments, and hit record levels of spending on solar photovoltaic (PV) (IEA 2018). It is apparent that providing affordable and accessible clean energy for everyone requires substantial public infrastructures, hence public and private investments, in order to achieve the Paris Agreement target, which is a promise to hold temperature rise below 2°C by 2050 (UNFCCC 2015).



Adopted from Global Sustainable Development Report, 2016 (United Nations, 2016)

Figure 1.1. Sustainable Development Goals (SDGs) are directly related to the public infrastructure

1.1. Problem Statement

Renewable energy investment plays a critical role in building a sustainable future and a better planet for everyone. Renewables mitigate greenhouse gas (GHG) emissions and provide alternatives resources, rather than fossil fuels, for harnessing energy which is a necessity for economic and social development. However, there was a substantial gap nearly of US$ 1.7 trillion in 2017 for financing energy infrastructure including renewables (IEA 2018; OECD/IEA and IRENA 2017). This statistic shows that finding the required capital is one of the greatest challenges for clean energy investment faced by governments and private entities. In a macroeconomic perspective, national budget deficits and inadequate policy designs hinder public and private investments in renewable projects. These problems lead governments to borrow a considerable amount of money for sustainable development, although such excessive debt-based financing pushes them through unsustainable debt zone (Ari and Koc 2018) and into unsustainable economic development. In this regard, high global debt concentration is a great challenge that needs to be addressed for truly sustainable development (PWC 2017). Over the last decade, the global debt-to-GDP ratio has increased relentlessly from 269% in 2007 to 325% in 2016. This increase might induce economic collapse and financial instability because severe economic and financial crises usually occur when the debt ratios go beyond certain thresholds (C. M. Reinhart and Rogoff 2009).

In particular, renewable energy projects were funded about 90% by debt-based financing from 2009 to 2017 (see Figure 1.2) (IRENA 2017). This substantial amount of borrowing makes a negative contribution to high global debt concentration putting countries' economic and social development at risk and unsustainable. In line with this, excessive debt-based financing causes an increase in wealth and income inequality. Piketty advocates that when wealth inequality reaches to a dramatic level, then wars and many other social problems are triggered to correct the course of wealth inequality (Piketty and Zucman 2014; Piketty 2014). In short, these facts show that finding the required capital is one of the greatest challenges for clean energy investments faced by governments and private entities.

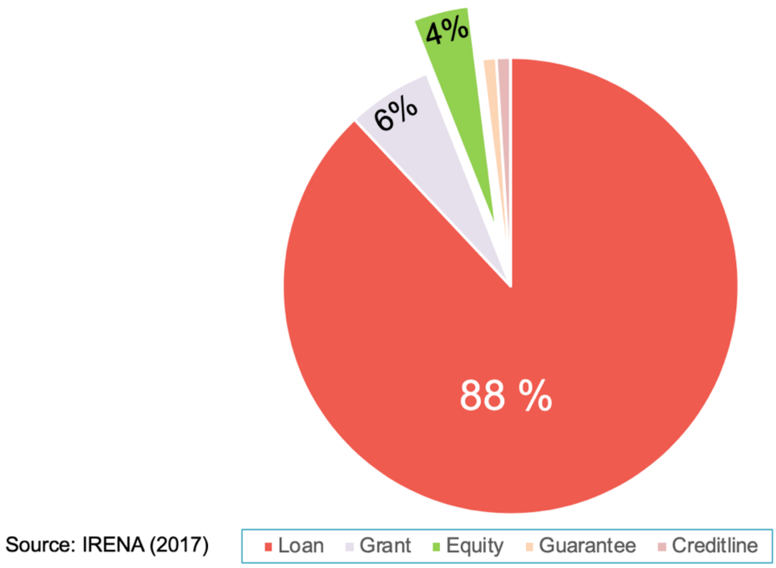


Figure 1.2. Financing instruments of public investments in renewables.

In short, the research goal is to develop and recommend a set of policy guidelines to respond to the intertwined problem among (1) financial gap for energy investments, which lead to (2) excessive global debt concentrations, which lead to (3) economic and social conflicts, which are illustrated in Figure 1.3 as the triangle of unsustainability.

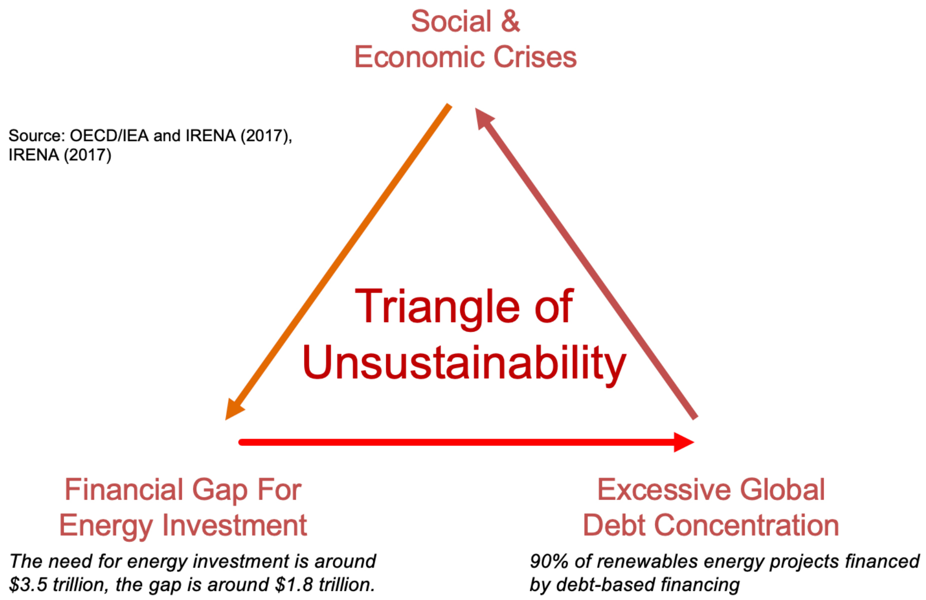


Figure 1.3. Problem Statement.

1.2. Research Issues

Many countries develop strategies and take initiatives for long-term sustainability by expanding their science and technology for economic development and the welfare of their nation. While expanding research and application capacity, many challenges appear in achieving simultaneously sustainable development that is to overcome extreme poverty, hunger, and significant income inequality, inadequate education and health services, energy crises, climate change, and national economic dependency on global financial institutions. There are two main underlying reasons for these problems:

i. *The concentration of capital.* Few individuals, or entities, accumulate more and more capital by transforming many small enterprises to large companies by only considering self-interests without any constraints such as ethics and social inclusiveness (Piketty, 2014); in short, "the larger capitals beat the smaller" (Marx 1887).

ii. *The centralization of capital.* This is a redistribution problem of existing capital by attracting more capital by capital, similar to the snowball effect, to exert absolute power of the market under control in fewer hands (Werner, Piketty 2014), or in a single hand (Marx 1887).

Because of such capital monopoly, national economies become heavily dependent on global and domestic financial institutions with different levels and layers. Furthermore, the concentration and centralization of capital cause relentlessly to increase inequities within and among countries and regions, social unrests, mass immigration and refugees, cyclic economic crises and ultimately unhappiness of people. These problems induce careless use of resources (i.e., natural, human, and financial) and pollution of the planet, and thereby leading irreversible catastrophes such as climate change. In this regard, research issues have been identified as follows to overcome all of these challenges and mitigate their adverse impacts as follows (United Nations 1992; United Nations 2003; United Nations 2012; UNEP 2015; World Bank 2005).

1. Mobilizing domestic financial resources and savings for local, regional and national development through collective trust-building and transparency.
2. Creating new and additional, sufficient and predictable financial resources.
3. Eliminating economic dependency on global financial institutions particularly for public investment (Financial localization) (Werner 2012; Werner 2014).
4. Mobilizing international resources for development: foreign direct investment and other private flows. Developing international trade as an engine for sustainability.
5. Reducing, first, external and then domestic public debt.

1.3. Research Questions

This study attempts to provide quantitative evidence for the following questions. First, if renewable projects are financed excessively by debt-based financing, either from domestic or external creditors, how it may affect the long-term sustainable economic and social development for the benefit of the public? Second, how public participation through private sector may affect the long-term sustainable economic development by funding public infrastructure? Third, the critical question to be answered eventually is: what kind of policy applications for sustainable financing should be developed for renewables, and other public infrastructures, without damaging the long-term sustainable economic and social development? To this end, this dissertation seeks the answers by investigating public debt sustainability, and examining public participation through private investment, and developing agent-based modeling on alternative financing models for typical solar farm investments to study their long-term impact on the change in wealth inequality and social welfare. In line with this, there are several questions under these main-stream questions based on the problem statement as follows.

1. How it may affect the long-term sustainable economic and social development for the benefit of the public if renewable projects are financed excessively by debt-based financing, either from domestic or external creditors?
    a. How can the countries be classified based on their public debt sustainability?
    b. Do the countries have a long-term relationship between sovereign debt and public investment?
    c. What and why do countries need to do for mobilizing domestic savings and innovating alternative financial models to promote sustainable development?

2. How public participation through private sector may affect the long-term sustainable economic development by funding public infrastructure?
    a. What is the relation between public and private investment for sustainable development?
    b. How should governments encourage public participation through private investment in funding public infrastructure?
3. What kind of policy applications for sustainable financing should be developed for renewables, and other public infrastructures, without damaging the long-term sustainable economic and social development?
    a. What kind of financial models would contribute to filling in the financial gap for clean energy investment without breaching public-debt sustainability and promoting public participation through private investment?
    b. How should an alternative financial model be designed to attract enough private capital, together with public investment, to mobilize domestic savings for a clean energy project?
    c. How can individuals and small enterprises with considerably limited budget participate in alternative financial models for clean energy projects along with large enterprises and individual investors with a high level of savings?
    d. How should alternative financial models fairly distribute a project's future revenue through society (in a broad sense) by protecting the public benefits and reducing economic and social inequity?

1.4. Research Objectives

The ultimate aim of this study is to establish empirical evidence with a quantitative methodology to support the idea of filling the financial gap by mobilizing domestic resources and innovating new financial models, rather than pure debt-based financing before sovereign debt breaches the certain thresholds for public-debt sustainability. In this regard, the following objectives are set for this study in line with the research questions above:

1. To evaluate long-term sustainability effects of public debt on public investment.
    a. To determine debt sustainability levels to classify countries into the sustainable, quasi-sustainable, and unsustainable debt zones according to the gross government debt-to-GDP ratios.
    b. To evaluate a long-term relationship between external-domestic public debt and public infrastructure with a co-integration test analysis.
    c. To explore the causality between external-domestic public debt and public infrastructure investments for selected countries.
2. To assess public participation through the private sector for the long-term sustainable economic development by funding public infrastructure.
    a. To evaluate the causal relationship between public and private investment for sustainable development.
    b. To envision potential actions to encourage public participation through private investment in funding public infrastructure.
3. To develop alternative financial models, rather than pure debt-based ones, to invest in public infrastructures, such as clean energy projects, by considering economic and social inclusiveness.

a. To investigate equity-based project financing models as an alternative to debt-based financing systems for clean energy investments.
b. To explore and identify decisions and behaviors of small enterprises and individuals with a limited budget for mobilizing domestic savings and attracting mattress money for a clean energy project.
c. To comparatively demonstrate the improvements of sustainable financing models by implementing it on a clean energy project
d. To develop rules and guidelines under alternative financing models to involve small enterprises and individuals with a limited budget along with large corporates and governments by considering economic and social benefits equally in a broad sense.
e. To develop rules and guidelines under alternative financing models to distribute the project's future revenues fairly and equally by protecting the public benefits and reducing economic and social inequity.
f. To develop rules and guidelines under alternative financing models to ensure minimizing or eliminating economic dependency on global financial institutions particularly for public investment (Financial localization).
g. To demonstrate that alternative financing models can reduce public, particularly external, debt.

1.5. Research Rationale

The findings of this study are expected to support decision- and policy-makers in industry, financing and government with evidence-based analysis and demonstration on the alternative financing models to enabling them to evaluate policy implications and shape their implementations in a wide variety of long-term public investments, which will strongly influence the requirements of a true sustainable development. They can evaluate wealth inequality throughout the society and wealth accumulation (along with liquid and illiquid assets) among various current and potential players such as the public, non-profit institutions for the benefits of the public, large enterprises, financial intermediaries, and individuals. Furthermore, the proposed model enables to examine social welfare by formulating and implementing a foundation-based (non-profit institution for the public/common good) structure as a redistribution mechanism. Such an institution (i.e., such as a foundation) enables to transfer a certain share of wealth to the benefit of the public such as public infrastructure, education facilities, and health centers in the long run.

1.6. Dissertation Outline

The rest of this dissertation proceeds as follows: Chapter 2 summarizes the U.N. reports and financial instruments after addressing the literature reviews under each related section of the three papers (henceforth interchangeable with phases) which are designed to reach research objectives. Chapter 3 presents the overall research methodology linking three successive phases in Chapter 4, 5, and 6, which are detailed in the following paragraphs, and gives a brief description for each methodology section under these chapters. Chapter 5 concludes the dissertation with a statement that performing a public infrastructure project, such as solar photovoltaic (PV) farm, for sustainable development by implementing unsustainable financing models will end up with unsustainable economic outcomes; hence it proposes alternative and sustainable financing models along with the policies.

Chapter 4 investigates the causal relationship between public investment and sovereign debt to evaluate the need for an alternative financing model by reducing the debt concentration. This chapter results provide quantitative evidence based on empirical findings to support the claim that sovereign debt is harmful to the financing of public infrastructure if it breaches certain thresholds, as proposed in this study, and according to the literature. By this approach, the findings enable to make recommendations about the need for mobilizing domestic resources and innovating new financial models to promote sustainable development within the limits of sustainable public debt.

Chapter 5 examines the interrelations between public and private investments from 1960 to 2015 in the GCC countries which are known as hydrocarbon-based rentier states striving significant policy changes to diversify their economies. This chapter shows that there exists a non-linear dependency on public and private investments, and thereby non-linear causality is conducted to extract accurate information behind the scene, beyond the linear causality. In this regard, Qatar shows a limited success on that public and private investment should move up together by triggering and reinforcing each other towards sustainable, balanced and growing economics as well as social and environmental development. As a result, the findings show a need for alternative financing policies to promote public participation through private investment in building sustainable public infrastructures such as green power plants.

Chapter 4 and 5 show that there is an essential need for alternative sustainable financing models to promote sustainable development by reducing debt-based financing and increasing private participation in public infrastructures, such as power plants harnessing renewable energy. In this regard, Chapter 6 attempts to answer the following critical question: what kind of policy applications for sustainable financing should be developed for renewables, and other public infrastructures, without damaging the long-term sustainable economic and social development? To be able to answer this question, Chapter 6 provides an agent-based model, as a proof of concept, on alternative financing models for public infrastructures under a case study of solar farm investments with a power purchasing agreement to investigate the accumulation and change in wealth inequality and social welfare over a long period. To this end, as an alternative financing entity, an equity-foundation-based financial intermediary is designed using the agent-based computational economics with simple, yet powerful, policy rules and regulations, and compared with the conventional banking system and financing.

CHAPTER 2: LITERATURE REVIEW

This dissertation is designed as consecutive and connected research in three separate parts which are explained in Chapter 4, 5, and 6. In each of these, the literature is surveyed separately to present a coherent flow of the study by providing the relevant parts under these chapters. In this regard, Chapter 4 reviews sustainable development along with a brief history before providing the connection with public infrastructure and hence the public investment. Besides, public debt sustainability, which is the core subsection of that chapter, is presented comprehensively after giving information about the infrastructure investments in the past, present and future along with the associated financial gaps. Chapter 5 discusses public participation through private investment in financing the infrastructure in the GCC countries. That chapter presents an extensive literature review on public-private investments in rentier states and the influence of these investments on economic growth and diversification in the GCC countries. Chapter 6 conveys previous phases' recommendations and conclusions to the ultimate goal of the research which is to develop an agent-based model on sustainable financing policies for sustainable development. To this end, Chapter 6 conducts a critical literature review on global debt concentration, wealth and income inequality, social equity, financial localization, and, finally, agent-based computational economics. The rest of this chapter proceeds with the remaining literature associated with the general context of the research which is not included in Chapter 4, 5, and 6 in order to avoid interrupting the coherence and flow of the text. In this respect, this chapter performs a literature survey on the financing problem of sustainable development, existing financing and business models, and project finance.

2.1. A Brief History of The Financing for Sustainable Development From The U.N. Reports

Sustainable development is the concept taking roots both in the social movements and the environmental protection acts of the 1960s and 1970s, inspired by Rachel Carson's impressive book Silent Spring written in 1962 (Carson 2002). During this period, a growing concern over the high impact of environmental pollution by massive industrialization induced to the formation of the first Earth Day (Odum and Barrett 1971) and the establishment of the number of national environmental agencies such as the United States Environmental Protection Agency in 1970 (EPA 1970). However, sustainable financing was out of the scope of the development process until sustainable investing had become a mainstream paradigm of sustainable development since 1992, Agenda 21 (United Nations 1992). Since the 1970s, developed countries have emerged sustainable development and followed by developing countries to maintain their economic growth with social and environmental responsibility.

In 1987, the World Commission on Environment and Development, under the chair of Gro Harlem Brundtland, the former Norwegian Prime Minister, originally defined the sustainable development as follows: *"Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (Brundtland 1987). As understood from this statement, sustainable development should not limit the next generation's ability to live, work, and progress, thereby this brings a need for strategic long-term development planning. Furthermore, this supports the expression of Eisenhower, the former president of the U.S., in terms of the impact of sovereign debt on future generations as follows: *"Personally, I do not feel that any amount can be properly called a surplus as long as the nation is in* *debt. I prefer to think of such an item as a reduction on our children's inherited mortgage"* (Bowen, Davis, and Kopf 1960).

Many countries realized the importance of sustainable development to discuss at the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil. In 1992, the leaders set out the principles of sustainable development at the Rio Summit and committed them to paper as the Agenda 21, 21 stands for 21st Century. The agenda primarily focuses on poverty, rural development, environment, population increase, and financing the implementation of these goals. It describes poverty as a "complex multidimensional problem with origins in both the national and international domains" (United Nations 1992). Therefore, there is not any uniform solution for globally solving it due to multidimensional problem originated from national and/or regional domain and contexts. Moreover, international efforts are also required for supporting country-specific programs to struggle with poverty.

The Monterrey Consensus not only realized that financing is the fundamental issue for achieving internationally agreed development goals, but also stated that there was lack of financial resources, particularly in developing countries, to fulfill all of the goals; actually the same problem has been still continued since adoption of the consensus (United Nations 2003). In other words, it would not be possible to succeed in any level of sustainable development without adequate and sustainable financial resources. Therefore, mobilization of domestic capital and effective use of financial resources is required to achieve Sustainable Development Goals (SDGs). A critical challenge is to develop innovative financing models for mobilizing domestic savings and sustaining productive investments always contributing back to the society in general, not to the hands of few.

In 2002, the Earth Summit, which is also known as Rio 10, was held by the U.N. under the theme of sustainable development in Johannesburg. The outcome document highlighted needs for generating new public and private innovative financing models along with public-private partnerships (PPPs) for sustainable development as in Monterrey Consensus (United Nations 2002). By doing these, they would benefit for large- and small-scale investment projects that are performed by large enterprises and small entrepreneurs by ensuring the transparency and accountability of new innovative models. Furthermore, such innovations in financing would facilitate the development and reduce the unsustainable debt of developing countries those economies in transition from a centrally planned economy to a market economy. Because, mobilizing of domestic capital and effective use of financing is attained by new innovative mechanisms, and will allow doing megaprojects with indigenous financing sources of a country.

There were two meetings of the United Nations during the economic crisis between 2007 and 2009, which was the worst one since the Great Depression of the 1930s. First, The Doha Declaration, which was the outcome document of the U.N. conference in Doha, 2008, on financing for development emphasized economic aspects of sustainable development. This conference related to progress on the six main thematic issues of the Monterrey Consensus, stated before, in 2002 (United Nations 2008). Second, United Nations convened a three-day summit on the World Financial and Economic Crisis and Its Impact on Development from 24 to 26 June 2009 at its New York headquarters to discuss and evaluate the global economic downturn. The outcome document of this conference reported negative impacts of the economic crisis directly relating to internationally agreed sustainable development goals such as rapid increases in unemployment, poverty, and hunger; reduced ability to maintain social safety nets and provide health and education (United Nations 2009). After giving major underlying factors in the crisis, the report stated that implementation of MDGs required effective use of credit and liquidity facilities, regulation of local financial markets, institutions, instruments and capital flows. Another major point was the case of reduced public confidence in a financial institution during the crisis; that is why mobilizing domestic capital and innovation for new financing models was limited at that time.

The Rio+20, or Earth Summit 2012, held in Rio de Janeiro, in 2012 to discuss the economic and environmental goals of sustainability. In Future We Want, which is the name of the outcome document, the mobilization of domestic capital and effective use of financing are emphasized including the international projections of capital mobilization for achieving sustainable development goals (United Nations 2012). In 2013, such innovations in mobilizing capital and creating additional financing resources were discussed in the conference of the Intergovernmental Committee of Experts on SD Financing (United Nations 2014).

The Addis Ababa Action Agenda is the outcome document of the U.N. conference on financing for sustainable development held in Ethiopia in 2015. Sustainable Development Goal (SDG) #17 is stated that "Strengthen the means of implementation and revitalize the global partnership for sustainable development", therefore discussing the targets between 17.1 and 17.5, which were devoted to finance (United Nations 2015a). In target 17.1, domestic resource mobilization and other revenue collection should be increased including the domestic capacity for tax. In target 17.2, some quantitative aims for gross national income (GNI) are given to fully implement official development assistance (ODA) commitments to developing and least developed countries. In target 17.3, it is attached importance to mobilize additional financial resources from different and multiple sources, especially for developing countries. In target 17.4, it aims to attain long-term debt sustainability, to reduce debt distress for poor countries, debt relief, and debt restructuring to sustain financial stability relating debt within and among countries. In target 17.5, the implementation of investment promotion systems for least developed countries.

In another important aspect of sustainable development, the global economy requires significant transformations and thinking to prevent the misuse of terrestrial ecosystem, desertification, deforestation, land degradation, biodiversity loss, climate change, air pollution, waste of water and goods, over consumption and production towards inclusive sustainable development. At this point, Agenda for Sustainable Development makes a commitment to economic growth through both individual and national prosperity emerging in harmony with nature (United Nations 2012; United Nations 2015b). In this context, transformation of the world economy is in need to create safe and clean constructive financing systems for sustainable development, and to ensure existing financing methods and industries become greener, meaning that they directly or indirectly promote and incentivize clean and green production and consumption behavior within individuals, firms, organizations, societies and governments (UNEP 2016b; UNEP 2015). In short, sustainable financing was addressed in the 2030 Agenda for SD as the significant and central part of the means of implementation for sustainability under SDG 17 as well as under each of the other goals, SDG1 – 16 (United Nations 2015b).

2.2. Existing Financial and Business Models

Cooperative Banks and Credit Unions. Cooperative banking is an interest-based financial institution that are owned by their members and regulated by both cooperative and banking legislation. There are different forms of cooperative banks changing according to their operational mechanism, member selection, and service area such as a mutual savings bank (Masulis 1987), a trustee savings bank (Fishlow 1961), and credit union(D. J. Smith, Cargill, and Meyer 1981). For instance, credit unions are an interest-based, but not-for-profit, financial institutions for the purpose of promoting thrift that are regulated by cooperative principles. They are mainly funded by their members and avoid borrowing from outside.

Microcredit Financing. Microcredit is an interest-based financing system that provides small-scale financing to support entrepreneurs and individuals who are not creditworthy. There are two main financial institutions, namely Grameen Bank and Village Bank. Grameen Bank is built on small-scale loans without any collateral that is the biggest problem for the poor to take a loan from the conventional bank (Bornstein 1996). By operating in this way, it motivates small individual entrepreneurs by helping them to strive their own business to improve their own wealth in each cycle of loan. Although a village bank has also similar operating principles, it strongly relies on solidarity lending which is a system of cross-guarantees, where each borrower ensures the loan of each other member (Hiatt and Woodworth 2006). It usually consists of small group of people around 30 self-help supporters who are mostly local females.

Credit Associations (ROSCA and ASCA). A rotating savings and credit association (ROSCA) aims to mobilize savings of individuals who arrange periodic meetings to lend and borrow together without interest or profit share (Besley, Coate, and Loury 1993). In each meeting, each member lends same amount of money to the one member in order. Hereby, members have access to larger amount at once in their turn of the cycle. An accumulating savings and credit association (ASCA) has the same logic with ROSCA while collecting money, but it differs while distributing. In other words, money is collected in a common fund, not in a member like ROSCA, and members appoint a manager inside them to manage the internal fund for making loans to grow (Bouman 1995).

Equity Based Financing. Equity-based financing is a system that is basically based on profit and loss share in return for stake ownership. An entrepreneur raises money needed for a start up company or enhancing the existing firm by selling the ownership stakes instead of borrowing from bank by a loan. The most known examples of this system are Venture Capitals (Hillner 2000; Ghosh and Nanda 2010) and Business Angels (Harrison and Mason 2000). Venture capitals are firms to invest on a startup company right after beyond the "valley of death" (Auerswald and Branscomb 2003), whereas business angels are individuals to invest on entrepreneurs during the valley of death.

Web-based Financing. Crowdfunding is an alternative finance method raising money needed for a project or venture from many people by a platform, mostly a website (Mollick 2014). It can be either equity based or donation based by business angels and others.

Peer-to-Peer lending is an interest-based financial system that is matching lenders and borrowers directly via mostly a website platform (Duarte, Siegel, and Young 2012). This system has no financial institution to put additional interest rate on lenders money while borrowing, but has an intermediary to operate mostly online services, such as a match-maker website for a business, with low cost. Therefore, lenders usually earn more returns than conventional banking services, while borrowers also decrease the cost of loan with lower interest rates.

Donation-based Financing. Foundations collect assets and own them from donators to provide services to the public. This is a distribution mechanism and can also be thought as a financial institution if asset is liquid. For example, under the Islamic economy goals and approaches, a novel financial institution known as "Cash Waqf" was innovated and implemented (Çizakça 1998). In definition, Cash Waqf is a philanthropic foundation institution that collects liquid endowments from the founder and donor to provide its usufruct in perpetuity for the welfare of society (Toraman, Tuncsiper, and Yilmaz 2007). This provides an alternative financial system offering no cost to the state and reducing government expenditure for social objectives. The gained profit will also be used for funding poverty alleviation programs, while the principal of funds will be reinvested in various highly profitable investment opportunities (Asutay 2007).

Business Models. A public-private partnership (PPP) is a cooperative business model that is an agreement of long-term project between the government and private sectors (Hodge and Greve 2007). Recently, UN has realized that public and private partnership has prominent role in infrastructure financing with different mechanisms such as PPP and blended finance (United Nations 2015a). Blended finance is also an emerging business model that promotes to mobilize private capital by attracting and incentivizing with both development finance and philanthropic funds (OECD 2015a). This model promises tremendous potential for meeting sustainable development goals which is requiring additional \$2.5 trillion annually for developing countries (UNCTAD 2014), and \$13.5 trillion for all countries to achieve the goals of COP21 by 2030 (IEA 2015).

2.3. Project Financing Model

Public infrastructure requires a substantial amount of upfront financing to realize large public projects and pays back in a longer period than private projects. This brings some key questions; who does provide this much amount of money, and how to collect it. This infrastructure investment can be funded by either (i) large corporations bearing entire risk of the failure by accounting the financing of the project on their balance sheet; or (ii) through Special Purpose Vehicles (i.e. project financing), which is a risk averse financing methodology for the project owner and developer, but not for the investors, by having only future cash flows of the project as collateral, in addition to projects own assets (Brealey, Cooper, and Habib 1996). This study focuses on project financing approach, particularly investor's side, that employs two common techniques to collect the necessary amount of money namely debt-based and equity-based financing.

Project finance is a long-term financing method that is commonly used for public infrastructure, power plants, airports, seaports, bridges, and many other areas in public and private sector. It differs from corporate finance in the sense of being a standalone financing model for a certain project and clearly demarcated financial transactions (Weber, Staub-Bisang, and Alfen 2016). This model is a non-recourse financing with the lending arrangements depend only on the future cash flows generated by the project (OECD 2015b).

In the recent past, public-private partnerships (PPPs) have gradually increase in the form of project finance due to the rise of governments budgetary constraints (OECD 2015b). Financing through PPP is considered as an important methodology of money collection, although there exists controversy about whether it brings higher efficiency and less cost. However, PPPs cannot promise to solve the funding gap in public infrastructure because they share only 5 to 10 percent of global investment (Woetzel et al. 2016). Therefore, there is a need to investigate, formulate and develop alternative and sustainable project financing models. Equity-based project financing will be the focal point of this study.

CHAPTER 3: RESEARCH METHODOLOGY

This study is formulated based on a hypothesis that unsustainable financing of sustainable large public infrastructures (such as energy, education, clean water, housing, and so on) would lead to unsustainable economic development, hence overall unsustainable development, in the long-run due to overaccumulation and unfair distribution of wealth. In line with this hypothesis, this research investigates the impacts of debt-based financing on public investment in the long-run and the need for public participation through private investment in funding the infrastructure projects to develop sustainable financing policies for clean energy. To this end, this dissertation is designed as consecutive and connected research in three phases following (i) public debt sustainability on public investment, (ii) public and private investment in hydrocarbon-based rentier states, and (iii) developing an agent-based model of sustainable financing policies on solar farms, which are explained in Chapter 4, 5, and 6, respectively. In line with this, following specific research tasks are performed under three phases (see Figure 3.1).

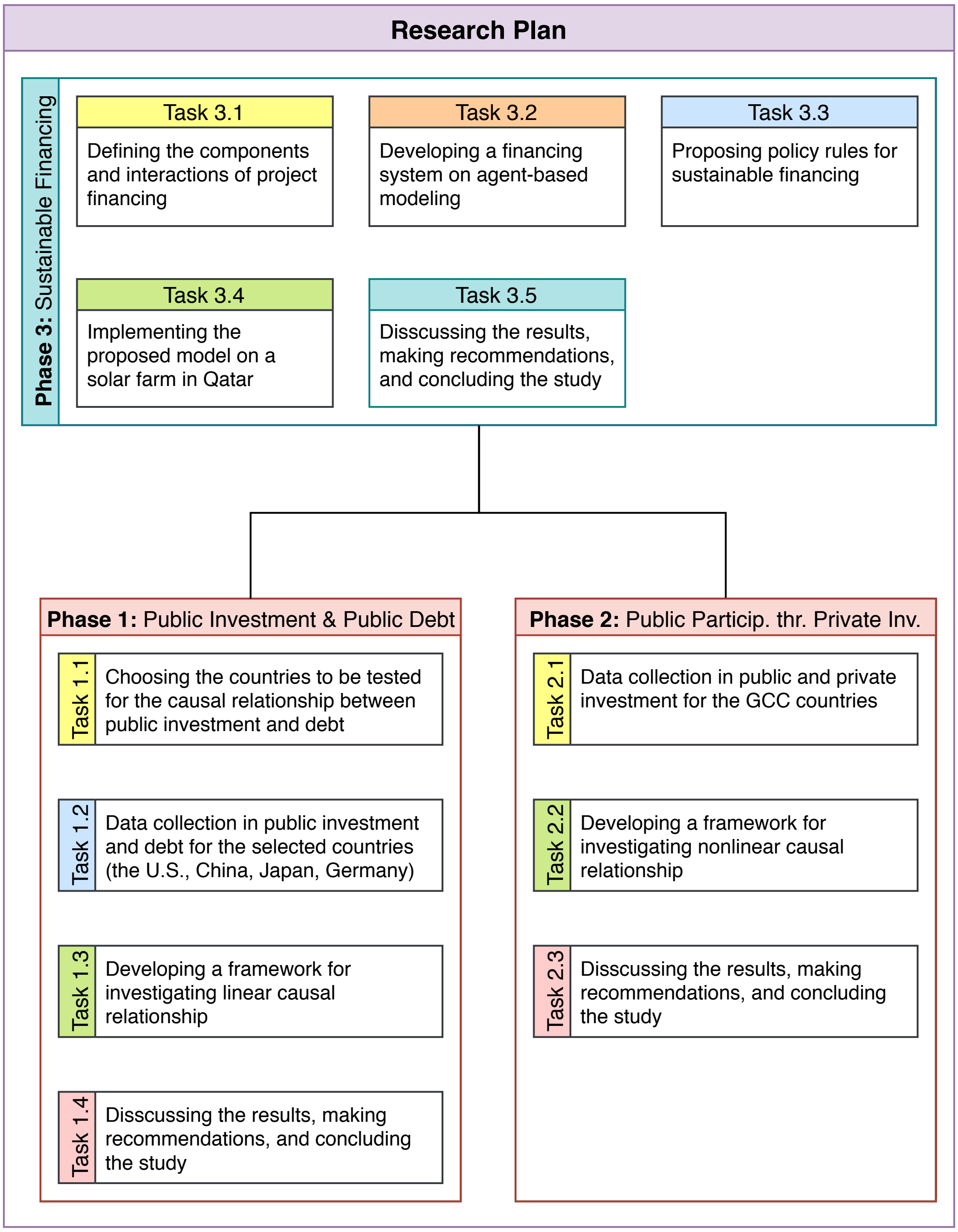


Figure 3.1. Research plan consisting of three phases.

3.1. Phase 1 – Sustainable Financing for Sustainable Development: Understanding The Interrelations Between Public Investment and Sovereign Debt

In Phase 1, the research aims to provide quantitative evidence-based empirical findings to support the claim that sovereign debt is harmful for the financing of public infrastructure if it breaches certain thresholds as proposed in this study according to the literature (Ari and Koc 2018). To this end, this chapter shows the research plan in several tasks followed by Phase 1 as follows. First, the study explains our approach and criteria to choose the countries those are considered for further analysis, and second, acknowledges the data-gathering process. The following task describes the framework for data analysis by summarizing the methodology (see Figure 3.2), and the last task is to discuss the results and make recommendations. In detail, Chapter 4 explains the methodology of Phase 1 by providing descriptions in detail regarding country selection, data collection, as well as, unit root tests, along with structural breaks, confirmatory analysis, cointegration, and Granger Causality.

Task 1.1 – Country Selection: This study, first, brings a systematic approach to select the countries for the following tests in Task 1.3. For this purpose, public debt sustainability zones (sustainable, quasi-sustainable, and unsustainable debt zones) were determined with two limits from the literature with respect to the countries' debt-to-GDP ratios. The first four countries by the GDP (the U.S., China, Japan, and Germany) were selected for each debt zone after applying the limits of public debt sustainability on the top 20 countries with highest GDP. These are the four pioneer countries in sustainable energy by building more than half of the global renewable power capacity (REN 21 2017) and good representatives for the global economy because they constitute approximately half of the world's GDP.

Task 1.2 – Data Collection: This study analyses how external and domestic public debt influences public infrastructure investments with respect to debt sustainability zones in the selected countries. Therefore, public investment, domestic and external public debt data are required for the framework mentioned in Task 1.3. The data for public investment was gathered from IMF Fiscal Affairs Department based on annual data for the time period of 1960-2015, which is why our analysis is limited up to 2015 (IMF 2017b; IMF 2017a). External public debt was collected from the World Bank (World Bank 2017) based on quarterly data considering the last quarter of each year as annual data. Domestic public debt was obtained by subtracting the external public debt from gross government debt (IMF 2017c) , thereby domestic public debt data is limited to the time period starting from 2000 (except for China), during which external public debt data is available.

Task 1.3 – Framework for Causality: Phase 1 follows the framework that presents a systematic approach enabling us to analyze the structural time breaks and causality among public investment, domestic and external public debt. The holistic framework consists of two parts represented by color-coded columns in Figure 3.2.

Pretesting. In the orange-colored column, two unit root tests, Augmented Dickey-Fuller (ADF) (Dickey and Fuller 1981) and Zivot-Andrew (ZA) (Zivot and Andrews 1992) tests, are chosen to investigate the integration orders of time series for each country considered in this phase. In addition, the ZA test enables to evaluate the relationship between sovereign debt and economic crises by obtaining insights from structural time breaks. Next, the integration orders of time series obtained from ADF and ZA tests are examined pairwise to check whether the results from both are matched by confirmatory analysis. Last, the study assess the long-run relationship among the debt and public investment by performing co-integration test.

Linear Causality. In the blue-colored column, Granger (1969) or Toda-Yamamoto Granger (Toda and Yamamoto 1995) causality test, both are a linear model, is employed on the datasets for further analysis. The selection, which one of the causality tests will be used, depends on the pretests. These pretest results enable to perform Granger causality if and only if the integration numbers of the time series are equal, and there exists no cointegration between them. In the opposite case, Toda-Yamamoto Granger causality (see Figure 3.2).

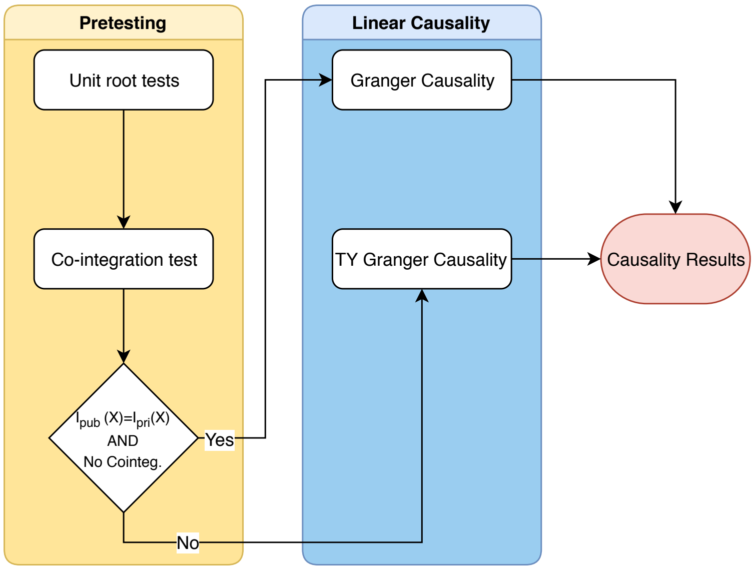


Figure 3.2. Framework for linear causality.

Task 1.4 – Discussions, Recommendations, and Conclusion: In Phase 1, the results are expected to provide quantitative evidence based on empirical findings to support the claim that sovereign debt is harmful to the financing of public infrastructure if it breaches certain thresholds, as proposed in this study, and according to the literature. By this approach, the findings have a potential to enable us to make recommendations about the need for mobilizing domestic resources and innovating new financial models to promote sustainable development within the limits of sustainable public debt. Therefore, Phase 1 is expected to bring evidence for Phase 3 to reduce debt-based financing by developing sustainable financing policies.

3.2. Phase 2 – Public and Private Investment in the Hydrocarbon-Based Rentier Economies: A Case Study for the GCC Countries

In Phase 2, the study attempts to provide evidence that there is a need for promoting public participation through private investment in developing alternative financing policies to building sustainable public infrastructures such as green power plants (Ari et al. 2019). To this end, this chapter presents the research plan in a couple of tasks followed by Phase 2 in the following subtasks. The study explains the framework for data analysis by summarizing the methodology (see Figure 3.3) after acknowledging the data-gathering process. Last, Task 1.3 discusses the results and makes recommendations for public participation in the infrastructure projects through private investment. It is worth to note that Chapter 5 details the methodology of Phase 2 by providing descriptions regarding data-gathering, unit root tests, along with structural breaks, confirmatory analysis, cointegration, Granger Causality, as well as, BDS test, and nonlinear Granger causality.

Task 2.1 – Data Collection: This study examines the behavior of public and private investment in the hydrocarbon-based rentier economies as in the case of the GCC countries (i.e., Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates). Therefore, public and private investment data are required for the framework described in Task 1.2. In this regard, panel data involves public and private investment spanning the period of 1960-2015 for each country. This annual data for public and private investment was gathered from the International Monetary Fund (IMF) Fiscal Affairs Department (IMF 2017b; IMF 2017a; IMF 2015).

Task 2.2 – Framework For Causality: Phase 2 places a nonlinear causality on top of the framework in the previous phase, and the remaining parts follow the same methodology with Phase 1. This holistic framework represented by color-coded columns in Figure 3.3 presents a systematic approach enabling us to examine the structural time breaks, linear, and nonlinear Granger causality for the time series of public and private investment. In what follows, only nonlinear causality part is explained in brief because pretesting and linear causality parts have already been given in Phase 1.

Nonlinear Causality. In the green-colored column, this phase performs the BDS to ascertain nonlinearity of the public investment. The BDS computes the test statistic for the null hypothesis that public investment is a series of *independent and identically distributed* (i.i.d.) random variables (Brock, Dechert, and Scheinkman 1987). Next, nonlinear Granger causality proposed by Diks and Panchenko (2006) is conducted to investigate nonlinear causality between public and private investment if the BDS test confirms that there exists a nonlinearity in one of the time series (see Figure 3.3).

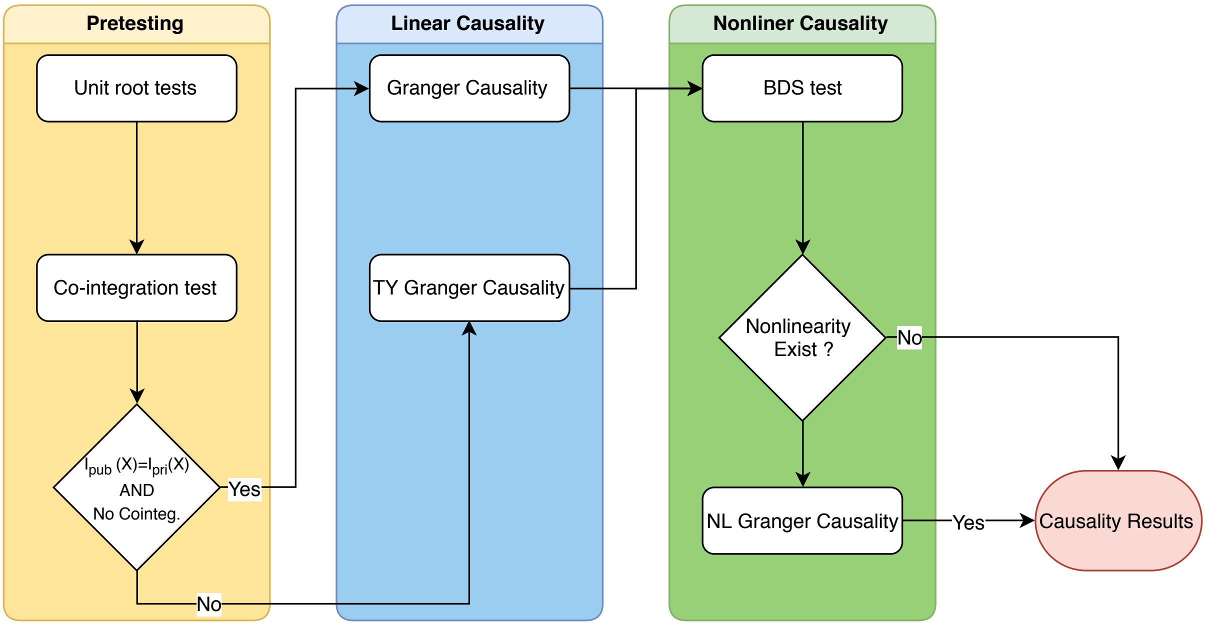


Figure 3.3. Framework for nonlinear causality.

Task 2.3 – Discussions, Recommendations, and Conclusion: In Phase 2, the findings are expected to provide quantitative evidence to support the claim that, first, oil-based rentier economies strongly rely upon public investment, and second, economic diversification is limited in these countries. In this respect, the GCC countries should diversify their economies by creating physical and knowledge-based assets away from the hydrocarbon-based sector and encourage the private sector to balance public investment. To this end, the public participation through private sector plays a prominent role in promoting non-oil-based business. In this regard, the government should establish institutional and relational trust between the state, ruling elite(s) and the private sector based on a larger portion of their population. The private sector should feel secure regarding calculative risks and investment failures. Therefore, the oil-based rentier states should establish strong institutions with higher quality and apply dynamic decision-making structure on the investments to benefit from the feedback effect of public and private investment. In short, Phase 2 is expected to bring a need for promoting public participation through private investment while developing sustainable financing policies in Phase 3.

3.3. Phase 3 – Sustainable Financing for Sustainable Development: Agent-Based Modeling of Alternative Financing Models for Clean Energy Investments

In Phase 3, the research attempts to develop sustainable financing models and policies on funding clear energy projects to investigate the change in wealth inequality and social welfare by utilizing the findings from Phase 1 and Phase 2 which are decreasing debt-based financing, and increasing public participation through private investment (Ari and Koc 2019). To this end, this chapter presents the research plan in several tasks followed by Phase 3 in the following subtasks. First, Phase 3 provides the descriptions of the project finance employed in the study for funding the projects and then explains the agent-based model (ABM) on sustainable financing policies for a solar farm. This chapter provides brief information about project finance and agent-based modeling but explained comprehensively in Chapter 6. Next, the study explains the model implementation along with the proposed policies after giving information about the simulation platform, which is the AnyLogic software (Abar et al. 2017). Last, the research discusses the results, make recommendations and concludes the study.

Task 3.1 – Project Finance: This task is to describe the structure of project finance followed by Phase 3 and define the shareholders and stakeholders, and interactions among them regarding the cash flows and legally binding agreements (see Figure 3.4). Chapter 6 explains the project finance employed in the study in detail, except the basic definitions of shareholders and stakeholders. These definitions are given under this task by extracting from Chapter 6 to prevent interrupting the flow and coherency. In this regard, the investors, project owner(s), project developer(s), Special Purpose Vehicle (SPV), commodity, and consumers are defines as follows.

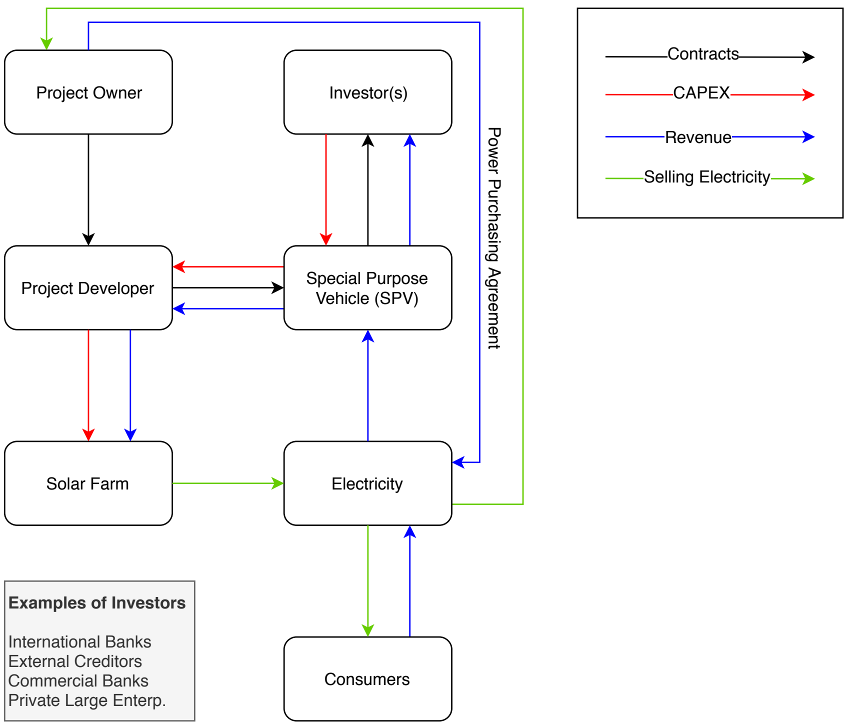


Figure 3.4. The basic schema of project finance for a solar farm.

Investor. An investor can be in the form of both person and institution that commits capital to pursue the financial returns as well as the social benefits by either equity-based or debt-based financing models. Performing a project with a huge financial need requires many investors to collect an adequate amount of capital with different investment vehicles such as stocks and bonds. By the same token, institutional investors, including but not limited to commercial banks, direct equity investment funds, pension funds, hedge funds, endowment funds, even governments, commonly form a consortium to accomplish a mega project. Although they might have different investment instruments and purposes for their clients, they always perform a technical, cost, and risk analysis to opt for most favorable investment opportunity by minimizing risk while maximizing profit.

Investors can be divided into two main groups with respect to their perception of the risk and profit. First, risk-averse investors only tolerate considerably low-risk investments, and that consequently lead to conservative gains such as many fixed income instruments. Second, risk-taking investors bear moderate, even sometimes high, risk in order to gain a larger profit mainly from the equity-based investments.

*Project Developer***.** A project developer is a principal company that plays many roles to perform a project by planning, building, installing, operating and maintaining the needs from feasibility analysis to end product, along with taking full responsibility for the realization of project. To implement a project from concept to the fulfillment, the developer also examines entire cost breaking down planning, construction, installation, operation, and maintenance expenditures for the investment to provide sufficient and effective capital for the project's budget by choosing right financial instrument (i.e. equity-based or debt-based) and investors such as individuals, commercial banks, capital markets, multilateral agencies, direct equity investment funds, governments, and so on.

Project Owner. A project owner (PO) has an ultimate possession of the project assets and deliverables after clearing legal liabilities, subject to the fundraising of the project developer for the project investment. However, project developer can become temporary owner for a certain time before transferring it to the ultimate owner due to its full responsibility for the project completion and, more importantly, fundraising of the project's budget. The PO is an initiator of a project by creating and presenting the idea to the public to attract project developers for the realization of a project by providing them different incentives such as free use of land, purchase guarantee, operating concessions, legal permits, and licenses. In the case of public infrastructure, governments play a vital role in achieving sustainable development for the benefit of the public thereby they participate in these projects as the PO and exercise their legal power and aforementioned investments.

Special Purpose Vehicle (SPV). Special Purpose Vehicle (SPV), sometimes called a project company, is a legal entity created exclusively for very limited task to only execute the project according to its objectives. In the management part of SPV, the project developer governs this single-purpose entity by performing the project through its legal agreements with constructors, contractors, suppliers, operators, and consumers. SPV is a main body of a project financing that takes full responsibility for entire financing activities by fundraising from different investors with different financial instruments; paying whole expenditures to the related parties during the life time of project; and managing future cash flows. There exist two main reasons to establish the SPV as follows. First, SPV has the capability to manage many and complex business processes, along with paper works, together at the same time; to fundraise for the investment; and to repay project's outstanding debt or dividends for equity-share holders. Second, SPV, in essence, isolates the risk of project developer from loan default, bankruptcy, or any loss on project assets by collecting capital from investors with the non-recourse financial instruments. In this case, investors should examine carefully the entire risk of costs that differ from expectations and calculate accurate future cash flows. Therefore, the project owner commonly provides a guaranteed-purchase with a legal agreement for the commodity, end product, of project to attract investors to the project by satisfying their expectations in case of success.

*Commodity***.** A commodity is a tangible or intangible object produced as a result of physical or mental process that is subject to the trade by serving a need or satisfying a desire. Therefore, commodities can be anything in a broad range of products available in the open market from raw materials to end products as well as from an idea to an information. In project management, commodities are called products formally defined as the project deliverables that forms objectives of the project. In this study, electricity and power distribution is considered as a commodity generated from renewable energy sources.

*Consumer***.** A consumer is an individual or an organization that demands and consumes commodities regardless of whether a consumer is willing to purchase or not. In order to clarify the commodity, it is a project output that might be a product such as electrical power as well as a service such as electrical power transmission. In the absence of consumer demand, suppliers suffer due to lack of the key motivation to produce for selling to the consumers. In this regard, consumers play a prominent role in the demand-side management and a national distribution chain.

Task 3.2 – Modeling Approaches and Agent-Based Modeling:

Modeling is a method of resolving problems in the real world when prototyping or experimenting with the real system is expensive or challenging, even impossible. In line with this, modeling enables us to develop policy rules before the implementation in the real world by solving the predefined problem. To be able to design a policy, the process of abstraction, which is mapping a real-world problem to a mathematical structure (i.e., to a model), is conducted to search a solution for the problem (see Figure 3.5). Following the proposed policy, the process of realization, which is mapping the solution back to the real-world, is performed to answer the problem. The modeling approach can be divided into analytical and simulation models. The analytical model is a static structure that can be implemented in a spreadsheet, but finding an analytical solution might be challenging, or even impossible. In this case, the simulation model addresses the difficulties and deficiencies of the analytical model by its dynamic structure consisting of a set of rules such as flowcharts and state charts. These rules along with the equations define the future behaviors of the system with a given current state. Simulation can be considered as an experiment that evolves the outputs through state transitions over time. In this regard, simulation modeling is a more convenient methodology for a complex system running with time dynamics.

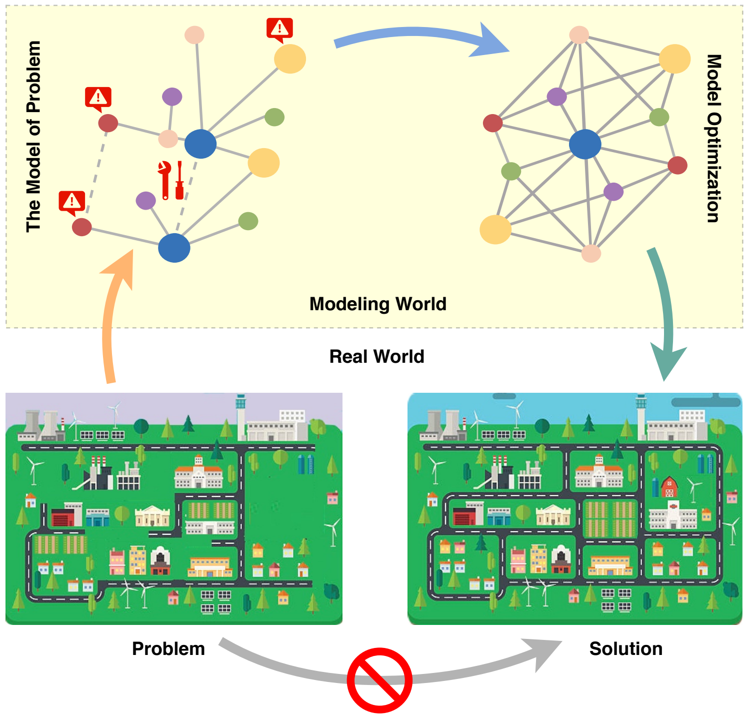


Figure 3.5. Mapping a real-world problem to the model world, and then mapping back to the real world.

This study describes the simulation modeling by dividing into time structure and abstraction level (see Figure 3.6). The horizontal axis shows the time structure consisting of continuous and discrete systems. The vertical axis denotes the abstraction level consisting of low-level, mid-level, and high-level in terms of details, scope, and objectives of the output. In low-level abstraction, the simulation model is very close to the analytical model that considers many features with limited scope and aims to develop a solution for science, rather than an engineering problem. Low-level abstraction requires precision and accuracy in the value of variables such as distance, velocity, and time, hence it suits for the problems more in physics, chemistry, mechanics, electronics, and so on. In mid-level abstraction, the simulation model includes less feature but larger scope than the low-level and targets the engineering problems, rather than science. This is because mid-level abstraction employs average timings that cause less precision, yet accurate, in broader applications such as supply chain management. The high-level abstraction widens the scope of the model into macro dimensions such as economic, social, and environmental concerns, in return, it has a limited feature in comparison to the other abstractions. This limitation raises from a high level of aggregation of the modeling components, thereby the high-level abstraction loses the individual properties, values, histories, and dynamics. However, this abstraction is utilized for long-term and strategic modeling by understanding the structure and dynamics of complex systems to design more effective policies.

Simulation modeling encompasses four major approaches consisting of Dynamic Systems, System Dynamics, Discrete Event, and Agent-Based (see Figure 3.6). The modeling of Dynamic Systems has a low-level abstraction and generally employs in the design processes of scientific disciplines and high-tech engineering problems. This approach becomes closer to analytical modeling because of the underlying mathematics of a complex system including a number of state variables and algebraic differential equations of various forms over these variables. This approach focuses on dynamic systems including various state variables corresponding to physical quantities such as distance, velocity, acceleration, temperature, and so on, and different forms of algebraic differential equations over such variables. In most of the cases, the mathematical structure is built on a continuous time framework. The modeling of System Dynamics (SD) has a high-level abstraction and enables to simulate macrosystems such as economic, social, and environmental problems, mostly, in continuous time. System dynamics modeling simplifies the mathematical structure of DS modeling by defining basic components consisting of stocks, flows, balancing and reinforcing loops, and time delays. However, this simplification brings a limitation for SD because the model runs only with aggregates and not holding individual values in the previous time steps, hence not recording the history of states. In addition, the modeler is responsible for providing accurate quantitative data regarding the global structural dependencies because of the high-level abstraction. The modeling of Discrete Event (DE), which is also called process-centric modeling, is structured mainly in mid-level abstraction, but may also include some low-level abstraction. This modeling considers events in discrete time that are abstracted from the significant instants of the continuous processes in the real-world problem. DE designs the simulations based on the entities, resources, and block charts governing entity flow and resource sharing. Entities are passive objects corresponding to such as people, lorries, conveyors, tasks, and so on. These entities are processed in the queues of the flowchart blocks by various operations such as the splitting, combining, being seized by resources, releasing from resources, and so on.

Last, Agent-Based modeling can be structured in a broad range of abstraction from low-level to high-level for many applications diversified across all disciplines of science and engineering (see Figure 3.6). This model has a unique feature that is being decentralized modeling based on the agent's behaviors. In this modeling, agents are active objects, in contrast to DE, that can be any type of item such as people, banks, power plants, financial instruments, buildings, and so on. These agents determine the global system dynamics by defining individual behaviors and agent interactions (i.e., reactions to events, main drivers of an agent, and actions according to history, and so on). Therefore, AB modeling is considered as an inductive, or a bottom-up, approach because global behavior emerges from the interactions of many agent's behaviors. This study provides an AB model on alternative financing models for a solar farm to investigate the change in wealth inequality and social welfare. This is because of two main reasons stated in the following sentences. First, power plants are created recurring in a frequency during the runtime of the simulation, and thereby the model requires the expansion feature which is supported by only AB modeling. Second, the financing model of solar farms requires a broad range of abstraction from low-level, such as distinguishable population agents, to high-level, such as the government agent, this feature is also supported by only AB modeling. Furthermore, AB modeling provides flexibility in design by allowing the transitions across the abstraction levels and evolving the model by creating agents with different types during the simulation.

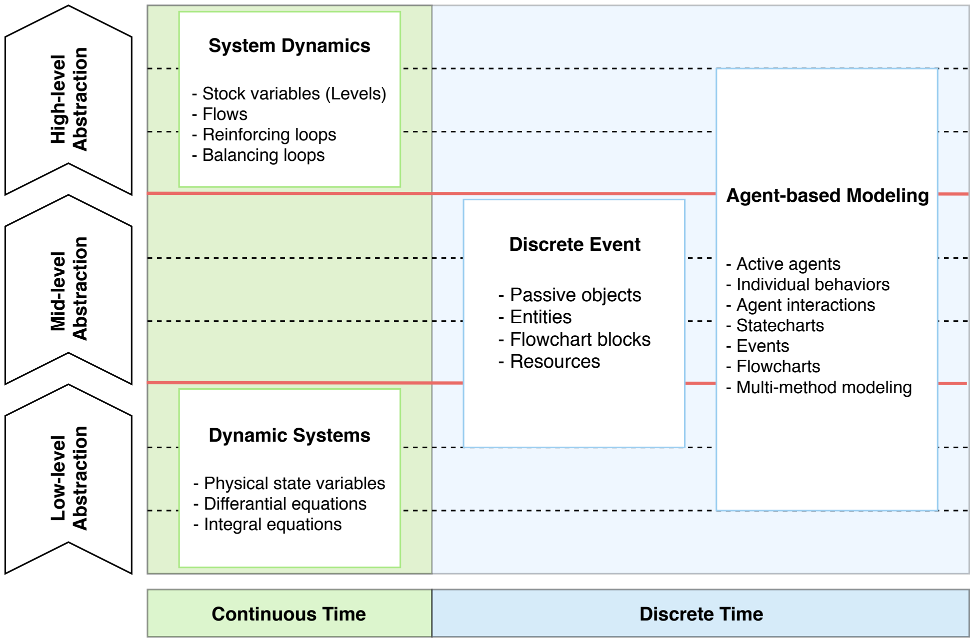


Figure 3.6. The abstraction levels of the major approaches in simulation modeling.

Figure 3.7 shows the agent-based model and agent interactions which represents the communications of agents with each other. The agents of individuals and large enterprises can be considered as depositors or investors, or both, at the same time. The individuals (IN) and large enterprises (LE) behave as investors while communicating with the equity-based financial intermediary (EBIN). On the other hand, the IN and LE act as depositors while interacting with the bank agent (BANK). The EBIN communicates with a power plant (PP) agent through the EBIS agent if the equity share is greater than zero. The BANK interacts with a PP agent through the LOAN agent if the loan share is greater than zero. The EBIN agent communicates with the foundation pool (FP) if the foundation share is greater than zero. The FP reaches out to the public by spending money in public infrastructure, philanthropic purposes, and social venture capital. The FP also enables the proposed model to provide social impact finance.

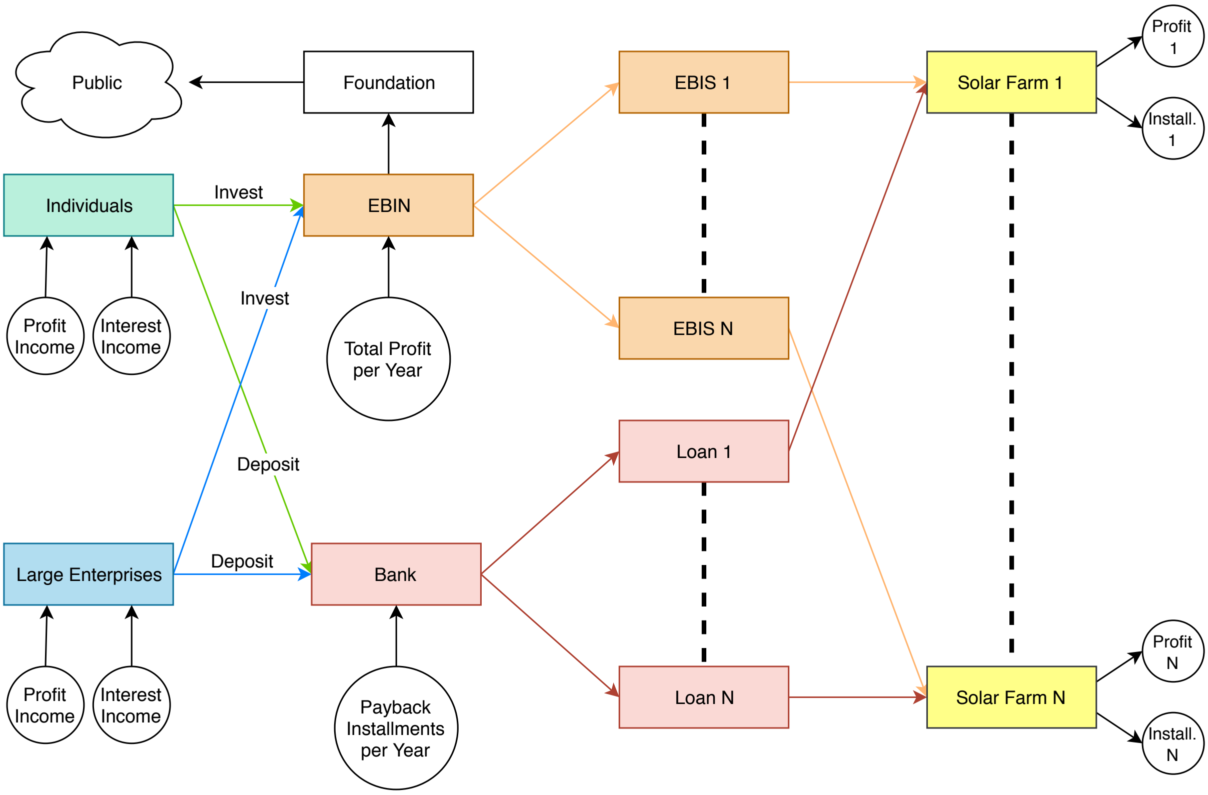


Figure 3.7. Agent-based model structure and agent interactions.

Task 3.3 – Policy Proposal:

This study proposes policy regulations on alternative financing models for a solar farm with a power purchasing agreement to investigate the change in wealth inequality and social welfare. The potential policy rules are as follows.

i. The individuals should be prioritized to invest in a power plant as much as they have savings.

ii. This phase defines four types of shareholders that are individuals (IN), large enterprises (LE), a bank, and an equity-based financial intermediary (EBIN). The shareholders should be listed in a given order to participate in a power plant investment depending on their savings. For example, assuming that the potential shareholders were listed in order as the individuals and large enterprises if the individuals do not have enough money for the entire investment, the remaining amount is provided by the large enterprises.

iii. The shareholders should have an upper bound to join in the investment. This upper bound can be set a hundred percent for individuals. In other words, the individuals can invest up to 100 percent of the total investment of a power plant.

iv. The equity-based financial intermediary (EBIN) should enable to become a self-sufficient financial intermediary in the end.

v. There should be a share for foundation (i.e. not-for-profit institution) out of the EBIN's profit. The foundation share should be accumulated in the foundation pool to support the future public infrastructure investments. In this regard, the proposed scheme with the inclusion of a foundation can contribute to the social welfare.

Task 3.4 – Model Implementation: A Case Study:

Qatar has made limited progress in renewable energy generation despite the great potential for harnessing solar power. Therefore, the current share of renewable energy over the total generation capacity, which is planned to reach 13GW by 2019 (Bayram, Saffouri, and Koc 2018), is negligible (MDPS - Ministry of Development Planning and Statistics 2018). However, the government set quite promising targets to achieve a considerable share in total power capacity and to diversify the energy mix. The targets for renewable power in the first and second-stage are 2% and 20% of total energy production by 2020 and 2030, respectively (REN 21 2017). In line with this, the Ministry of Energy and Industry is developing and implementing a strategy for utilizing renewable energy along with its policy (MDPS - Ministry of Development Planning and Statistics 2018). In addition, a group of researchers from Kahramaa, which is Qatar general electricity and water corporation, has developed a solar farm project, along with the feasibility studies and geographic location, with the collaboration of Hamad Bin Khalifa University (HBKU) as a capstone project (Al-Aali and Bughenaim 2018). This study adopts their project's input data and assumptions for the technical part of the powerplant agent (see Chapter 6 for details). It is important to note that the project developer and the government sign a power purchasing agreement, which is a legal contract stipulating that the government buys the whole electricity generated by the powerplant during the lifetime.

Task 3.5 – Results, Discussions, and Conclusion:

In business-as-usual case, the modeling approach commonly stands to solve profit maximization problem for the large enterprises to make them even bigger. This study brings a novel approach by setting the objectives to prioritize the benefit of the public through individuals instead of profit maximization of large companies. In this regard, the research will compare the results from the proposed sustainable financing framework with conventional debt-based project financing approaches with respect to the wealth accumulation and wealth inequality; put differently, economic inequality and social inequity.

CHAPTER 4: SUSTAINABLE FINANCING FOR SUSTAINABLE DEVELOPMENT: UNDERSTANDING THE INTERRELATIONS BETWEEN PUBLIC INVESTMENT AND SOVEREIGN DEBT*

Chapter 4, which is Phase 1 of the dissertation, investigates the causal relationship between public investment and sovereign debt (i.e., external and domestic public debt) with respect to the limits of public-debt sustainability for four countries with the highest GDP (i.e. the United States, China, Japan, Germany) during the period of 2000-2015. In summary, this phase establishes quantitative evidence based on empirical findings to support the claim that sovereign debt is harmful to the financing of public infrastructure if it breaches certain thresholds as proposed in this study according to the literature. By this approach, the findings enable us to make recommendations about a need for mobilizing domestic resources and innovating new financial models to promote sustainable development within the limits of sustainable public-debt. In short, this chapter provides a base for Phase 3 in Chapter 6 and concludes that performing a project for sustainable development by implementing unsustainable financing models will always end up with unsustainable economic outcomes.

4.1. Introduction

Public infrastructure plays a profound role in ensuring and sustaining the welfare of nations by satisfying almost all goals of the U.N.'s sustainable development goals (SDGs) (see Figure 4.1, United Nations 2016). In a broader perspective, public investment entails public infrastructures such as energy, water, transportation, communication, health and

* Ari, Ibrahim, and Muammer Koc. 2018. "Sustainable Financing for Sustainable Development: Understanding the Interrelations between Public Investment and Sovereign Debt." *Sustainability* 10 (11). doi:10.3390/su10113901.

education along with vital intangible investments in nurturing human development, improving social efficiency, fostering quality of the public operations, implementing better management structure and conducting relevant research and development (R&D). Public infrastructure, hence public investment, is an expensive concept as it aims to cover the entire society by providing all needs at an adequate level. It requires substantial up-front capital to construct, install, and build, as well as ongoing capital for proper operation and maintenance to ensure basic services and benefits over a long time (Fay et al. 2010). If public infrastructure is mainly built with debt-based financing, it may have quite serious and long-term adverse effects on the entire economy and society eventually. First part of the study focuses on trying to understand the boundaries and effects of debt-based financing of public investments.

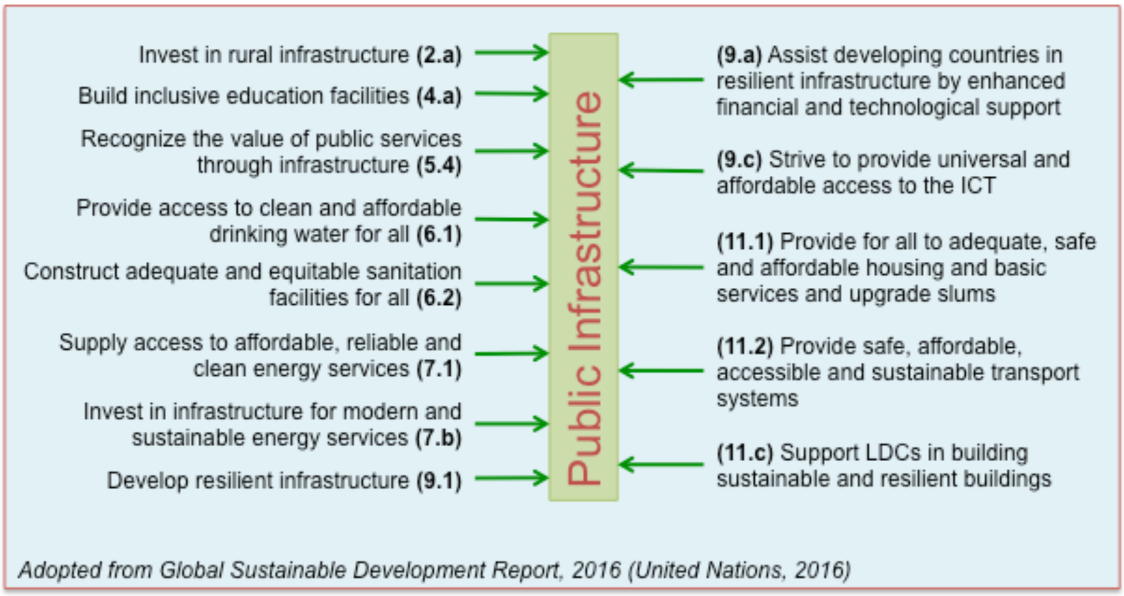


Figure 4.1. Sustainable Development Goals (SDGs) directly related to the public infrastructure

Thus far, governments have played a prominent role for building, owning, renovating, and operating the public infrastructures such as harnessing energy, generating and distributing electricity and water as well as the facilities of education, health, transportation, communication, sanitation, etc. The main driver for governments' role in public investments is to protect the public from formation of natural monopolies (Chan et al. 2009). Another reason for government involvement is that the private sector is reluctant to undertake responsibility and associated risks for building and operating large and expensive infrastructure projects with long-term pay back, thereby such public infrastructure projects are commonly financed by government revenue (Glomm and Ravikumar 1994; Kern 2007), aid-based (Moss, Pettersson, and van de Walle 2006; Pedersen 1996), equity-based (UNCTAD 2016; Yildiz 2014), and debt-based financing. Debt-based financing, averaged at 75% of infrastructure projects (Weber, Staub-Bisang, and Alfen 2016), is commonly used by the countries (Wagenvoort et al. 2010) mainly due to fact that many do not have a reliable stream of public revenue (Fischer and Easterly 1990), and many domestic and external creditors are always inclined to go for the guaranteed returns from a debtor country even with other means of collateral (Mitchener and Weidenmier 2010; Bulow and Rogoff 1988).

Borrowing enables individuals to balance their income and expenses (consumption) under fluctuations more than estimated levels. It also enables corporations to offset their production and investment when their sales fluctuate in severe and unpredicted levels and times. Additionally, it enables governments to smooth their revenue fluctuations and uncertainties from taxes, other incomes and expenditures. However, governments are warned to avoid borrowing beyond certain thresholds, such as the Maastricht criteria as adopted by the EU (European Communities 1992), to keep their debt at controllable and safe levels providing a buffer zone when extraordinary events happen to push their debt to the levels damaging their long-term economic growth and stability (Fischer and Easterly 1990). As debt levels rise beyond the estimated threshold level, borrowers' ability to pay back their debt decreases and becomes more sensitive to income fluctuations, which puts them into even more vulnerable and risky conditions in the long-run. Furthermore, borrowing more to pay back previous debt becomes progressively more difficult and more expensive than before as interest rates set by lenders/creditors increase exponentially due to increasing risks. In this regard, lenders become unwilling to lend anymore, which leads to severe damages to economic development and the general welfare of society due to critically significant reductions in public investment. Put differently, higher debt levels cause financial volatility, damage financial stability, and reduce economic growth in the long run. As a result, higher public debt decreases economic and financial well-being, which is a main driving force for sustainable development, so this may limit essential government functions eventually affecting the society and causing social instability (Cecchetti, Mohanty, and Zampolli 2011).

This study contributes to the literature in several ways. In this paper, we investigate fiscal sustainability of the countries under consideration by performing a causality test between public investment and, separately, domestic-external public debt by considering the public-debt sustainability thresholds. To the best of authors' knowledge, this is the first attempt to decipher domestic and external public debt effects on public investment by considering sustainability thresholds, and vice versa. This research also attempts to reveal the structural breaks of sovereign debt, long-term relationships, and causality between external-domestic public debt and public investment in terms of public-debt sustainability during the period of 2000-2015 for the countries under consideration. By conducting this study, the results enable us to make recommendations about a need for mobilizing domestic resources and innovating new financial models to promote sustainable development within the public-debt sustainability. This paper concludes that performing a project for sustainable development by implementing unsustainable financing models will always end up with unsustainable economic outcomes.

The rest of this paper proceeds as follows. Section 2 presents extensive literature review on sovereign debt (domestic and external), relations between sustainable development and public infrastructure, and sustainable debt levels. In section 3, the methodology is discussed in terms of the selection of countries, unit root tests, structural breaks, and framework for causality. Section 4 discusses the empirical results and key findings as well as provides recommendations for filling the financial gap by mobilizing domestic resources and innovating new financial models for public infrastructure. Finally, section 5 concludes that performing a project for sustainable development by implementing unsustainable financing models will always end up with unsustainable economic outcomes.

4.1.1. Problem Statement

High global debt concentration is a great challenge that needs to be solved for sustainable economic development (PWC 2017). Over the last decade, debt to GDP ratio on a global scale has increased relentlessly from 269% in 2007 to over 325% at the end of 2016. In other words, this ratio has risen more than 5.5% per year over the last decade (MGI 2015; Tiftik et al. 2017). This increase has high-risk for economic growth and financial stability because severe economic and financial crises are more likely to happen when the debt ratios go beyond certain thresholds (C. M. Reinhart and Rogoff 2009). However, macroeconomic debt is not always harmful; indeed, it might even be beneficial up to a certain level, as long as it is balanced.

It is well known that public infrastructure needs of a society are key issues to be met for a prosperous, wealthy and coherent country and world as quality public infrastructure guarantees social and economic equity among different segments and regions, which is a fundamental pillar for sustainable development (Calderón and Servén 2014; Fay et al. 2010). Therefore, there exist a constant and urgent need to invest in planning, building and maintenance of public infrastructure, which demands a reliable stream of financing. For example, McKinsey (2013) estimated that US$57 trillion is needed by 2030 for global public infrastructure investments for electricity generation, transmission and distribution; water, telecommunications, transport (MGI 2013), while OECD (2007) estimated the figure at US$71 trillion. The European Commission reported that EU will need around €2 trillion for public infrastructure investments by 2020 (EU 2011). In the United States, if today's investment gap in public infrastructure is not addressed, the economy is expected to lose almost US$4 trillion in GDP by 2025, and US$18 trillion in GDP by 2040, averaging over US$700 billion per year (American Society of Civil Engineers 2016). As can be seen, there is a huge financial gap to fill in public infrastructure investments. Thus, the main problem that this study aims to investigate and provide evidence with quantification is the following: If the majority of the financing for public infrastructure comes from debt-based financing sources, either from domestic or external creditors, how may it affect the long-term economic and social development to the benefit of society? Then, the key question being answered eventually would be what are sustainable financing mechanisms to invest in public infrastructure without damaging the long-term sustainable economic and social development?

4.1.2. Research Questions and Objectives

Based on the discussions and problem statement, the following research questions are determined:

(Q1) How can the countries be classified for the public debt sustainability?

(Q2) How do the countries behave during the economic crises in terms of external and domestic debt?

(Q3) Do the countries have a long-term relationship between the sovereign debt and the public investment?

(Q4) Does any causality exist between sovereign debt and public investment? If so, which directions do the countries have causality between them in terms of public-debt sustainability zones? What is the meaning of these causalities?

(Q5) Is there any pattern in causality results in terms of public-debt sustainability?

(Q6) What and why do countries need to do for mobilizing domestic savings and innovating alternative financial models to promote sustainable development?

The main objective of this paper is to evaluate sustainable financing for sustainable development by using the terms of "sovereign debt" and "public investment" in order to analyze how public investment reacts against external and domestic public debts, and to assess the need for mobilizing domestic resources and creating new financial models.

In line with the research questions above, the following specific objectives are set for this study:

(i) To set debt sustainability levels to classify countries into the sustainable, quasi-sustainable, and unsustainable debt zones according to their gross government debt-to-GDP ratios.

(ii) To investigate the structural breaks of sovereign debt (external and domestic) for obtaining meaningful results on economic crises.

(iii) To evaluate a long-term relationship between external-domestic public debt and public infrastructure with a cointegration test analysis.

(iv) To explore the causality between external-domestic public debt and public infrastructure investments for selected countries.

(v) To conclude with a need for mobilizing domestic savings and innovating alternative financial models to promote sustainable development.

This study's ultimate aim is to establish empirical evidence with a quantitative methodology to support the idea of filling the financial gap by mobilizing domestic resources and innovating new financial models, rather than pure debt-based financing, before sovereign debt breaches the certain thresholds for public-debt sustainability.

4.2. Literature Review: Sustainable Infrastructure Investments and Sovereign Debt

4.2.1. Sustainable development, public investment and infrastructure

Sustainability and public infrastructure share a common purpose that is to provide sufficient needs of society for the current and long-term period. In 1987, the World Commission on Environment and Development, under the chair of Gro Harlem Brundtland, the former Norwegian Prime Minister, originally defined the sustainable development as follows: *"Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (Brundtland 1987). As understood from this statement, the main goal of sustainability is to attain the development for both generations together at the same time under the current generation's responsibility by considering the needs for the next generation without limiting their ability to live, work, and progress. Furthermore, this supports the expression of Eisenhower, the former president of the U.S., in terms of the impact of sovereign debt on future generations as follows: *"Personally, I do not feel that any amount can be properly called a surplus as long as the nation is in debt. I prefer to think of such an item as a reduction on our children's inherited mortgage."* (Bowen, Davis, and Kopf 1960)

Sustainable investing is the concept taking roots both in the social movements and the environmental protection acts of the 1960s and 1970s, inspired by Rachel Carson's impressive book Silent Spring written in 1962 (Carson 2002). During this period, a growing concern over the high impact of environmental pollution by heavy industrialization induced to the formation of the first Earth Day (Odum and Barrett 1971) and the establishment of the number of national environmental agencies such as the United States Environmental Protection Agency in 1970 (EPA 1970). However, sustainable financing was out of the scope of the development process till sustainable investing has become a mainstream paradigm of sustainable development since 1992, Agenda 21 (United Nations 1992). This economic paradigm has important milestones over the period of this economic policy stated by United Nations (UN) as follow:

- There are three objectives for the implementation of Agenda 21 as follows: (i) to establish measurement objectives for concerning financial activities, (ii) to create new and additional financial resources, which are sufficient and predictable, (iii) to seek qualitative improvement of funding mechanism to carry out the goals (United Nations 1992).
- The UN Monterrey Conference has considerably become a reference point for economic development cooperation with six main areas of financing for the development as follows: (i) mobilization of domestic financial resources for the

development, (ii) mobilization of international financial resources for the development, (iii) international trade for the development, (iv) increase in international cooperation of finance and technology for the development, (v) decrease in external and unsustainable debt, (vi) improving the coherence and consistency of the international monetary, financial and trading systems (United Nations 2003).

- In Future We Want (United Nations 2012), mobilization of domestic capital and effective use of financing are emphasized including the international projections of capital mobilization for achieving sustainable development goals.
- Sustainable infrastructure investments were addressed in the 2030 Agenda for sustainable development under sustainable development goal (SDG) #9 by building resilient infrastructure, promoting sustainable industrialization and fostering innovation, as well as under each of the other goals such as alleviating poverty, eradicating hunger, supplying energy access for all, providing health care and education for all in a quality, promoting social equity, and propelling fair economy (United Nations 2015b).

Public investment has a prominent role in global infrastructure (such as energy generation and distribution, water supply and sanitation facilities, transport networks, as well as social infrastructure) to meet the profound social and environmental challenges of this century, such as alleviating poverty, operating natural resources sustainably and mitigating dangerous climate change (United Nations 2015b). Societies and investors (i.e. institutional and/or individual), along with their governments, benefit from sustainable infrastructure investment due to fact that they have a common interest in well-governed and well-functioning economic, social, and environmental systems. Societies benefit because they rely on public infrastructure affecting their quality of life, reducing economic inequity in a society, and propelling economic growth (Calderón and Servén 2004). Individual and/or institutional investors benefit from public infrastructure investments, which usually have inherent-low debt default rates that provide a stable long-term return (Moody's 2017).

Public infrastructure's quantity and quality have a positive influence on the competitiveness (Turok 2004), attractiveness (Khadaroo and Seetanah 2008), sustainability (Sahely, Kennedy, and Adams 2005), and the economic growth of a country (Munnell and Cook 1990). Public investment brings further business opportunities by promoting trade as well as the growth of existing economic activity (Martin et al. 1995). Moreover, public infrastructure also improves the standard of living for all by giving public access to indispensable resources and facilities, such as water and electricity, schools and hospitals (Fay et al. 2010; Calderón and Servén 2004). This is even further true if the infrastructure investment is developed in a sustainable fiscal policy (O. Blanchard et al. 1990).

Sustainable development vision will significantly depend on the development of sustainable infrastructure, which is mainly provided by public investment, such as public schools, hospitals, utilities, roads, communication systems, etc. (Weber, Staub-Bisang, and Alfen 2016). The U.N. report (2017) estimates that the world population will reach to 8.5 billion in 2030 and 9.8 billion by 2050 (United Nations 2017). By 2030, the *middle class* will reach to some 5.5 billion people (more than 70% of today's global population – 7.5 billion) accounting one-third of the global economy by adding up 2.5 billion newcomers on 3 billion existing members (Kharas 2017). This increase will result in a substantial demand for economic and social infrastructure. In this regard, the OECD estimates that infrastructure development in business-as-usual approach will cause the unsustainable rise in both energy demand (85%) and water consumption (55%) resulting in a potential shortage of the global energy and water supply (OECD 2012). Furthermore, financial gap for the necessary development (Woetzel et al. 2016), global population growth (Damania et al. 2017), resource scarcity (Korhonen 2018), and climate change (Forzieri et al. 2016) will require a paradigm shift towards consequent development of sustainable infrastructure (Weber, Staub-Bisang, and Alfen 2016). To this end, alternative financial models and mobilizing domestic resources are required to support sustainable infrastructure development (OECD 2015b; OECD 2014)

4.2.2. Infrastructure Investments in The Past

Public investment for infrastructure in OECD countries accounted for 2.2% of GNP between 1997 and 2002, compared with 2.6% from 1991 to 1997 (OECD 2007; OECD 2006). A more recent 2015 report shows that the downward trend in government spending on infrastructure continued for the EU countries from 2010 to 2013 reduced by a further 11% (Ammermann 2015). Furthermore, infrastructure investment has declined to different percentages of GNP for 11 countries of the G20 economies due to the global economic crisis in 2008 (Woetzel et al. 2016). These cutbacks have been apparently observed in the United States, EU, Mexico, and Russia, while Turkey, Canada, and South Africa has increased their infrastructure spending.

4.2.3. Infrastructure Investments in The Future

From 2016 to 2040, the world is predicted to invest about 3.0% (business-as-usual current trend) to 3.6% (the need for global infrastructure investment, which is 20% more than the current trend) of GDP, or an approximate average of US$3-3.7 trillion a year, for new and existing economic infrastructure: energy (US$1 trillion a year), water (US$230 billion a year), telecommunication (US$300 billion a year) and transportation (US$1.5 trillion in a year) sectors in the current trend (Global Infrastucture Hub 2017). Electricity and roads account for more than two-thirds of global needs on infrastructure while meeting the SDGs for universal access to drinking water, sanitation and electricity increasing the need for the global spending on public infrastructure by a further US$3.5 trillion by 2030 (Global Infrastucture Hub 2017). Not only cost of infrastructure investment itself but also project designing and arranging financial support cost significant amount by constituting up to 10 % of total project costs (Suzuki, Miyaki, and Pace 2016).

4.2.4. Financial Gap for Public Infrastructure

There is a gap widening throughout the world between the need for financing infrastructure and the capacity of national budgets to meet this demand. The amount of this gap triples by considering the further investment required to meet SDGs (Woetzel et al. 2016). The global shortfall in infrastructure investment is estimated to be at least US$1 trillion per annum (WEF 2014). The public sector, which is conventionally responsible for the infrastructure, often claims to have many other priorities preventing the government from closing this gap with necessary funds, which is indispensable for societies in terms of boosting development and prosperity (Weber, Staub-Bisang, and Alfen 2016).

Not only emerging or developing countries have a financial gap for infrastructure, but also the industrialized and developed countries have a larger gap to fill in with different financing models and resources for upgrading and maintenance. However, among these countries, there exist substantial differences in terms of the political (Alesina and Tabellini 1990) and economic positions (C. M. Reinhart and Rogoff 2011) and requirements for closing this gap with the contribution of private capital (PWC/GIIA

2017; Yildiz 2014; Rizzi 2009). For example, economic fluctuations combined with the sovereign debt (Diamond 1965; Bulow and Rogoff 1988; C. Reinhart and Trebesch 2015) and existing tax regulations (Glomm and Ravikumar 1994) have a substantial influence on decisions for financing infrastructure. In the countries that impose high-tax, such as Germany or Nordic countries in particular, further tax increase is not a feasible solution for financing infrastructure assets (Weber, Staub-Bisang, and Alfen 2016). Moreover, fixed-income securities have a negative impact on the national budget and the financial/credit rating of the country in addition to financing only a limited number of projects (Hariton 1993; Weber, Staub-Bisang, and Alfen 2016). These imply that equity-based financing and private investment has a crucial role to play for public infrastructure.

There is a growing interest of private investments for infrastructure. Private investments in listed infrastructure assets showed a considerable performance for accumulating the total stock by increasing some four-fold from US$600 billion in 2002 to US$2.3 trillion in 2013 (AMP CAPITAL 2014). Furthermore, unlisted infrastructure funds exhibit more ambitious growth in the market. A five-fold increase was recorded from US$11 billion in 2006 to US$55 billion approximately in 2016, with a drop to US$6.5 billion in 2009 due to the financial crisis (PWC/GIIA 2017). Since the economic and financial crises in 2008, annual investing on infrastructure has recovered rapidly. For instance, foreign investors increase their investment activities in European infrastructure for four-times more from 2010 to 2013 (particularly investors from the Gulf Cooperation Council (GCC), China/Hong Kong, Canada, Japan, and South Korea) (Linklaters 2014). This report also notes that Europeans' share in a global infrastructure financing has reduced more than half in 2013 compared with 2006.

4.2.5. *Public Debt Sustainability*

Minea and Villieu (2009) provide an evidence to support that excessive public debt incurs a shortage of public investment, and does not ensure to fill in a gap in public investment (Heinemann 2002; Minea and Villieu 2009). Public debt has soared for the advanced and emerging countries as a result of the financial crisis of 2008-2009. Reinhart and Rogoff (2010) showed that an increase in public debt persists for a long time following the financial crises. In this regard, the levels of public debt have been unsustainable for a number of countries from 2010 to 2040 according to the projections of public debt-to-GDP ratio (Cecchetti, Mohanty, and Zampolli 2011). In addition, there are many studies on debt/GDP thresholds from sustainable to unsustainable public debt, with respect to different aspects such as economic growth, primary surplus, private savings and public investment, ranging from 60% to 90% (Caner, Grennes, and Köhler-Geib 2010; B. C. M. Reinhart and Rogoff 2010; Checherita-Westphal and Rother 2012; Cecchetti, Mohanty, and Zampolli 2011). In contrast, Panizza and Presbitero (2014) found that there is no evidence that public debt has a causal effect on economic growth, although there exist a negative correlation between them.

There are many studies have been investigated the sustainability of public debt in different countries from different aspects with different methodology. For instance, Bohn (1998) proposed a new method for sustainability of public debt in the United States by analyzing whether primary surplus with respect to GDP is a linear function of debt-to-GDP ratio, if so, public debt is considered sustainable. Although this is widely used alone in the literature for different countries, this has been complemented by additional tests such as stationary test with respect to the real deficit of interest payments (Fincke and Greiner 2012). For Germany, along with other European countries, following sustainable debt policies has been investigated by testing public debt to GDP ratio with different technics against economic growth with a number of channels (i.e., private saving, public investment and total factor productivity) (Checherita-Westphal and Rother 2012; Gong, Greiner, and Semmler 2001) and primary surplus (Greiner, Köllert, and Semmler 2007; Fincke and Greiner 2012). Many scholars have extensively studied Japanese fiscal policy and debt sustainability (Ihori, Doi, and Kondo 2001; Broda and Weinstein 2004; Greiner 2007; Hoshi, Kashyap, and Scharfstein 1993; Shirasu and Xu 2007), because it requires a thorough research due to the fact that Japan has much higher gross public debt than the other developed countries. Fincke and Greiner (2011) have also conducted a comparative study of public debt sustainability in the United States, Germany and Japan. As for China, there exist several studies showing that sustainable debt policies still have been followed by the central government, but it needs to develop and enhance existing policies for the local (city) governments due to the shortage of land finance, which is considerable financing tool for public investment (Tu and Padovani 2018).

There are different definitions for external and domestic debt as follows. If debt holder is a resident of the country, or debt is issued in domestic currency, then this is called as domestic debt, otherwise called as external debt (Panizza 2008). So far most of the existing researches only consider public debt as an aggregated value of domestic and external public debt. In this research, public debt is decomposed into domestic and external debt to gain more insight into the vulnerabilities of sustainability with respect to public investment. In terms of foreign currency, excessive external debt may lead to severe debt crises faster than domestic borrowing because governments can interfere in domestic debt when it reaches to sustainability thresholds by increasing inflation, but external debt has much narrower options (C. M. Reinhart and Rogoff 2013). However, the United States is less prone to external debt crises because external borrowing of the US is a large stock of domestic currency, which is in US dollars (Panizza 2008). There exist a couple of reasons for that: the largest share of global external debt is denominated in US dollar, and the world trade is commonly in US dollars, which is main reserve currency in the world (K. Reinhart et al. 2002).

Countries that have a high level of public debt, such as Japan, present a low level of public investment in OECD countries (Heinemann 2002). Japanese fiscal policy is a unique case in which external and private debt has been transferred to domestic public debt, for example, more than 90% of private debt of public companies in 1975 declined to below 50% in 1992 by shifting private and mostly external debt into domestic public debt (Hoshi, Kashyap, and Scharfstein 1993). In this regard, Japan sustained net public debt, which was around 90% in 2007, by increasing primary surplus up to the financial crises of 2008-2009 (Broda and Weinstein 2004; Fincke and Greiner 2011). However, Fincke and Greiner (2011) showed that there is no evidence that Japan followed sustainable debt policies in terms of gross public debt, which was around 185% in 2007 and this is much higher than net public debt, even though they found weak net public debt sustainability at the 10% level of significance over the period from 1970 to 2007 by including the high level of assets. Broda and Weinstein (2004) stated that Japan's sustainability problem of public debt is the level of future liabilities, not current debt-to-GDP ratio, after demonstrating that the current debt burden of Japan is less heavy than reported in the literature because net public debt was only half of the gross public debt. In the same paper, the analysis showed that unsustainability takes over due to the political reasons for default and self-fulfilling prophecies.

There exist a number of studies have been conducted on the fiscal policies of public debt sustainability for European countries in different contexts, namely, with respect to economic growth, primary surplus, private savings, total factor productivity, and public investment (Gong, Greiner, and Semmler 2001; Greiner 2007; Greiner, Köllert, and Semmler 2007; Fincke and Greiner 2011; Fincke and Greiner 2012; Checherita-Westphal and Rother 2012). Germany has followed a sustainable debt policy over the period from 1961 to 2008, even though the debt-to-GDP ratio soared after the German Reunification in 1989/ 1990 (Fincke and Greiner 2011; Fincke and Greiner 2012; Checherita-Westphal and Rother 2012). This increase in the debt-to-GDP ratio has been well managed by taking corrective actions with dynamic decision making strategy, which are to increase primary surplus and decrease government expenditure (Greiner 2007; Greiner, Köllert, and Semmler 2007). In this regard, public investment is a kind of expenditure that can be reduced whenever public debt increases; thereby the decline of public investment in Germany due to the increase in public debt is proven in the literature to provide public debt sustainability (Heinemann 2002; Gong, Greiner, and Semmler 2001).

4.3. Methodology

In this section, we explain our approach and criteria to choose countries to be included for further analysis in this study as well as describe an overall framework for data analysis and data-gathering process. Next, we present unit root tests, along with structural breaks, confirmatory analysis, and cointegration test to analyze how the data becomes stationary and to investigate long-run relationship by sharing common trends between the datasets for each country considered in this research before providing insights into the causality.

In this regard, two criteria were employed for choosing countries:

(i) Twenty countries with the largest GDP were taken into consideration as the potential candidates for the analysis due to fact that they constitute a significant amount of economic activity in the World, which are consisting of around 80% of global GDP (see Appendix A1). The debt-to-GDP ratios of these countries are ordered according to the size of their GDP (see Figure 4.3). They comprise about 60% of total world population (7,523,997,000) in 2017, which is a meaningful domain for our study (see Appendix A2).

(ii) These countries were divided into three groups according to their debt-to-GDP ratios. We assumed that there were two sustainability thresholds for sovereign debt-to-GDP ratio as reported in the literature. First, the Treaty on the European Union (i.e. Maastricht Treaty) states in the second criteria of article 121 that, as a reference point, the ratio of gross government debt must not exceed 60% of their GDP at the end of each fiscal year (European Communities 1992). Second, Cecchetti, Mohanty, and Zampolli (2011) reported according to their empirical results that gross government debt should not exceed 85% of the GDP for sustainable economic growth. In this regard, this study assumes that countries fall into three debt zones, which are (a) sustainable (lower than 60% debt/GDP ratio), (b) quasi-sustainable (between 60-85% debt/GDP), and (c) unsustainable (higher than 85% debt/GDP) (see Figure 4.2).

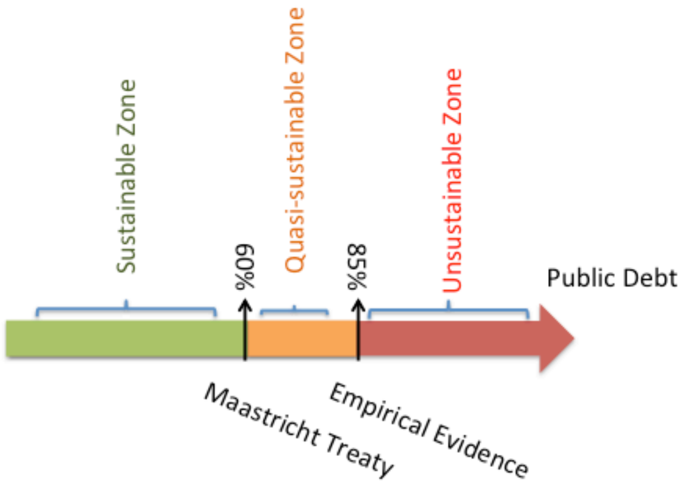


Figure 4.2. Sustainable debt thresholds for gross government debt to GDP.

After dividing these countries with highest GDP into the *public-debt sustainability zones* (henceforth called as *debt sustainability zones* and *sustainable debt zones*) according to the second criterion, the United States, China, Japan, and Germany were selected to analyze their external and domestic public debt effects on financing public infrastructure depending on their gross government debt to GDP ratio (see Figure 4.3). China (43%), Germany (71%), and the United States (105%) fall respectively into the sustainable, quasi-sustainable, and unsustainable debt zone according to their debt-to-GDP ratios. Furthermore, Japan (248%) is also included into the study due to fact that it falls definitely into the unsustainable debt zone because of its excessive gross government debt. These are the four pioneer countries in sustainable energy by building more than half of the global renewable power capacity (REN 21 2017) and good representatives for the global economy because they constitute approximately half of the world's GDP (see Appendix A2).

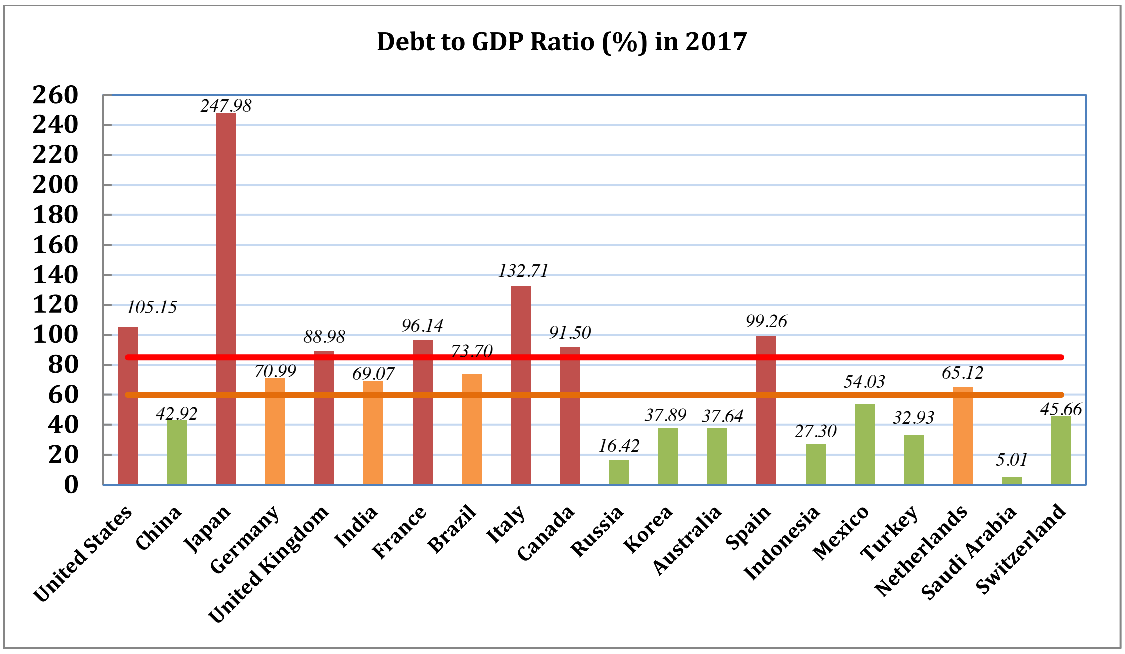


Figure 4.3. Debt-to-GDP ratios of top 20 countries in 2017 ordered by GDP and two thresholds for debt sustainability, 60% and 85%. The green, orange, and red columns represent respectively sustainable, quasi-sustainable, and unsustainable debt zones.

4.3.1. Data Gathering

This study empirically analyses how external and domestic public debt influences public infrastructure investments with respect to debt sustainability zones in the selected countries: China, Germany, USA, and Japan. In this regard, panel data involves public investment, external public debt, and domestic public debt spanning 2000-2015 time period for each country, except for China (1980-2015 for external, and 1995-2015 for domestic public debt, see Appendix A3). Public investment is a key input in the creation of physical assets including economic infrastructure (highways, airports, seaports, energy utilities, etc.) and social infrastructure (public schools, universities, hospitals, etc.). The data for public investment was gathered from IMF Fiscal Affairs Department based on annual data for the time period of 1960-2015, which is why our analysis is limited up to 2015 (IMF 2017b; IMF 2017a). External public debt was collected from the World Bank (World Bank 2017) based on quarterly data considering the last quarter of each year as annual data. Domestic public debt was obtained by subtracting the external public debt from gross government debt (IMF 2017c) , thereby domestic public debt data is limited to the time period starting from 2000 (except for China), during which external public debt data is available.

4.3.2. Framework for Causality

After collecting the data, this study follows the framework as outlined in Figure 4.4. This framework enables us a holistic approach to analyze the data for causality between public investment and debt for a country by comprising three parts with color-coded representation as shown in Figure 4.4:

Preparation: In the orange-colored column, the data is prepared for conducting statistical analysis and tests with correlations between the datasets, cleaning the data (i.e., removing outlier and replacing missing values (if there is) with sample mean), and forecasting some missing data points at the beginning or end of the time series in case of the need for having consistent time periods with the same interval for all datasets.

Pretesting: In the blue-colored column, unit root and co-integration tests are performed as a pretest for Granger causality. First, augmented Dickey-Fuller (ADF) (Dickey and Fuller 1981) and Zivot-Andrew tests (Zivot and Andrews 1992) are selected as the unit root tests for obtaining integration number of the time series, namely public investment, external public debt, and domestic public debt. Furthermore, Zivot-Andrew (ZA) test also gives us structural breaks in the datasets. Following ADF and ZA tests, integration numbers are investigated pairwise whether they are equal by confirmatory analysis. Second, Johansen test is chosen as the co-integration test to evaluate the long-run relationship by sharing common trend between datasets and countries chosen for this the study.

Causality: In the green-colored column, Granger (1969) or Toda-Yamamoto Granger causality (Toda and Yamamoto 1995) is applied on the datasets by considering the results in pretesting. If the integration numbers of related datasets are the same with each other and there is no co-integration between them, then conventional Granger causality can be performed, otherwise Toda-Yamamoto Granger causality has to be conducted.

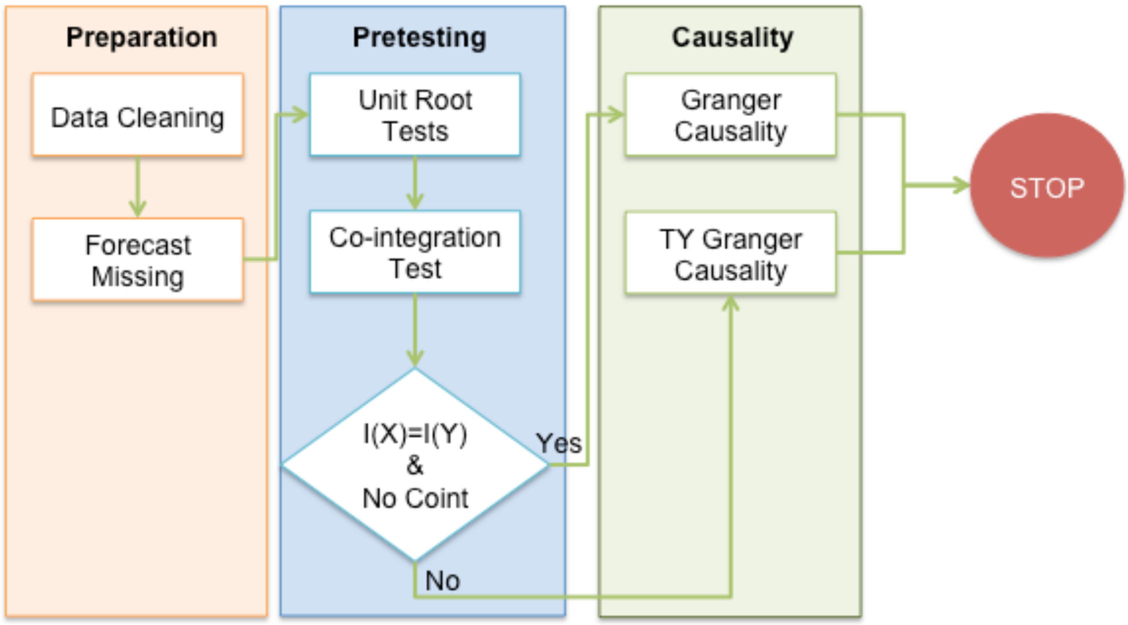


Figure 4.4. Framework for testing causality.

4.3.3. Unit Root Tests

Granger causality, first, requires pretest for the datasets whether they are stationary or not. In the case of non-stationary, there are two main techniques to make the datasets stationary, namely taking difference and transforming the data. To this end, all variables are transformed to their conjugate symmetry and were differenced as two times. Afterwards, the augmented Dickey-Fuller (Dickey and Fuller 1981) and Zivot-Andrew (Zivot and Andrews 1992) tests, along with endogenous structural breaks, were conducted for a unit root with respect to level, first, and second difference of the data.

4.3.4. Confirmatory Analysis

With the methodology followed, we are able to make stronger inferences about the status of the datasets whether they are stationary or not by confirmatory analysis. In this analysis, the integration orders (i.e., I(0), I(1), and I(2) shows the status of being stationary of time series in level, 1st difference, and 2nd difference, respectively) obtained by ADF and ZA test were consolidated into a table to assess each time series whether they are stationary in both tests with the same integration number. In this sense, the datasets for each country may become stationary in different integration orders according to ADF and ZA unit root tests. Approaching this discrepancy from two different angles, the results were taken into consideration by confirmatory analysis. First, the integration orders were compared with both unit root tests (i.e., ADF and ZA) by taking into account the results where the variables appeared to be stationary at the first time without looking their significance level. Then, this variable treated as a stationary at the integration order specified by the tests, if the number of integration is the same with both unit root tests, otherwise the result of confirmatory analysis considered inconclusive. Second, the integration orders were compared with both unit root tests (i.e., ADF and ZA) by selecting the results where the variables were stationary with the highest significance level. For confirming, the same technique with the first methodology applied to determine in which order whether or not the variables were integrated. These methods are called as *first appearance* and *strong stationary*, respectively.

4.3.5. Cointegration Test

Existing cointegration requires a long-run relationship among the datasets implying that the deviations from the equilibrium state for a co-integrated vector are stationary with finite variance, even if each data set is nonstationary with infinite variance (Engle and Granger 1987). In case of the existence of a co-integration, there exists at least a unidirectional, might be also bidirectional, Granger causality as another important implication of the long-run relationship. Engle and Granger (1987), however, demonstrated that a vector autoregression (VAR) model in differences would be spurious due to fact that the datasets in difference have no longer an invertible moving average if the datasets are co-integrated. Therefore, it is important to determine if the nonstationary datasets share a common trend (i.e., having co-integration) in a level before performing a VAR model for Granger causality. In the existence of co-integration among variables in levels, VAR model cannot be used for a conventional Granger causality. In this sense, VAR model must be replaced by either error-correction model (ECM) or augmented VAR model (see section 3.6.) with Wald test for a Granger causality (Toda and Yamamoto 1995; Engle and Granger 1987). For this reason, Johansen (1992) test was applied to determine the existence of the long-run equilibrium relationships between the datasets. In this study, the maximum eigenvalue (λ_{max}) and trace (λ_{trace}) statistics were employed to obtain the cointegration rank (r) which is equivalent to the number of independent cointegrating vector. The equations for these tests are given as follows:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln(1-\lambda_i) \quad (1)$$

$$\lambda_{max}(r, r+1) = -T \ln(1-\lambda_{r+1}) \quad (2)$$

where λ_i and λ_{r+1} are the estimated values of eigenvalue ($\lambda_1 > \cdots > \lambda_r > 0$ associated with eigenvectors $\beta = (v_1, \dots, v_r)$) and T is the number of observations.

4.3.6. Toda-Yamamota (TY) Granger Causality

In economics, the conventional Granger causality (hereafter Granger causality is considered as the conventional one unless otherwise stated) is the most common method to test for causal relationship between two time series (Granger 1969). This test requires estimating the following basic VAR(p):

$$Y_t = \gamma + C_1 Y_{t-1} + \cdots + C_p Y_{t-p} + u_t \quad (3)$$

where Y_t and γ are n-dimensional vectors (i.e., each element corresponds to a variable in the datasets), and u_t represents to n-dimensional vector for white noise innovation assuming that there is no correlation between them, and C_k denotes an $n \, x \, n$ matrix of estimated parameters for lag k. The Granger causality has a prominent role to obtain meaningful results in terms of relationship, along with its direction, between time series for many applications in economics although it has few limitations.

There are two main preconditions to apply Granger causality for bivariate time series as follows. First, the integration orders of the time series must be the same with each other in the confirmatory analysis. Second, co-integration among the time series must be absent to avoid spurious results; even this implies that there exists at least unidirectional Granger causality. When one of these conditions is not satisfied, Granger (1969) causality should not be performed on the time series (there are some exceptions see Enders 2014). Toda and Phillips (1994) discussed further about other limitations of the conventional Granger causality.

Toda and Yamamoto (1995) propose a powerful, yet simple, method requiring the estimation of modified Wald test (i.e., called modified because of the modified VAR model) based on an augmented VAR(p+d_{max}) model, where d_{max} is a maximum integration order among the variables. This test is proven that the modified Wald statistic performed in this setting converges through the asymptotic χ^2 random variable without depending on neither the integration number nor co-integration results (Toda and Yamamoto 1995). In this regard, the co-integration and unit root tests become only informative form, rather than a pretest for the Granger causality, to avoid the spurious results of pretest. To implement the TY Granger causality test, estimation of augmented VAR(p+d_{max}) model to be utilized as follows:

$$Y_t = \hat{\gamma} + \widehat{C_1}Y_{t-1} + \cdots + \widehat{C_p}Y_{t-p} + \widehat{C_{p+d_{max}}}Y_{t-p-d_{max}} + \widehat{u_t} \quad (4)$$

where the circumflex over a variable denotes the estimation of its ordinary least squares; and d_{max} represents the maximum integration number; C_k corresponds to the $n\ x\ n$ matrix of the parameters for lag k. In this study, lag order p is selected by SIC technique due to fact that true lag order is challenging to know a priori in practice. As for the null hypothesis that is tested with modified Wald test, the j^{th} element of Y_t does Granger-cause the i^{th} element of Y_t, if the following null hypothesis H_0 is rejected:

H_0: The (i, j) element of C_k is equal to zero for $k = 1, \dots, p$.

TY Granger causality stipulates that the maximum integration order d_{max} must be less than or equal to the lag order p. If the variables, however, are cointegrated, then d_{max} can be greater than p (Toda and Yamamoto 1995).

4.4. Empirical Results and Discussions

4.4.1. Unit Root Tests

To avoid the problem of spurious results, unit root tests were performed for the panel data to ensure that they were stationary in some integration orders before selecting which test (i.e., Toda-Yamamoto Granger causality or the conventional one) was more suitable for the causality. Table 4.1 reports the results of ADF test for the panel data consisting of public investment, external public debt, and domestic public debt. The hypothesis of a unit root (i.e., non-stationary time series) for almost all datasets in levels cannot be rejected significantly. This result provides the evidence that these datasets are nonstationary except for Japan's domestic public debt with a 1% significance level. However, all panel data in the first difference seem to be stationary at least at a 10% level of significance.

Table 4.1. ADF unit root tests (with SC criteria)

	Level		First Difference		Second Difference	
	Test value		Test value		Test value	
China						
Public investment	-0.9904	(3)	-7.4292	(2)***	-6.0432	(4)***
External public d.	-2.3867	(3)	-4.2700	(1)**	-8.4869	(1)***
Domestic public d.	-0.5915	(1)	-5.0591	(1)***	-8.6524	(1)***
Germany						
Public investment	-2.4393	(1)	-6.0077	(3)***	-6.6063	(3)***
External public d.	-0.8817	(3)	-3.5374	(2)*	-4.3529	(2)***
Domestic public d.	0.6708	(3)	-4.0497	(1)**	-1.8462	(2)
The United States						
Public investment	-2.3269	(3)	-3.8656	(2)**	-5.8578	(1)***
External public d.	-1.6351	(4)	-5.6789	(3)***	-3.0068	(3)**
Domestic public d.	-2.0224	(1)	-3.7465	(1)**	-5.8283	(1)***
Japan						
Public investment	-1.1309	(2)	-3.8626	(1)**	-6.9769	(1)***
External public d.	-0.8817	(1)	-3.5374	(2)*	-4.3529	(2)***
Domestic public d.	-4.5353	(3)***	-4.6473	(4)***	-2.8852	(1)

*Notes: 1. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.*
2. The numbers in parentheses are the lag orders which are selected based on the SIC.
3. The cells of stronger stationary position are colored.

Further, the study also investigates the panel data in the second difference to check if there exists a stronger stationary state, particularly for the weaker ones (i.e., a 10% level of significance). Except for the domestic public debt of Germany and Japan, the hypothesis of a unit root for most of the datasets in the second difference can be rejected more significantly than the order of first difference (if a test statistic in second difference is less than first difference, then it is stronger than first difference, and vice versa). However, the public investment for China and the external public debt for the United States have weaker stationary in second difference.

Zivot and Andrews (ZA) unit root test allowing for an endogenous structural break was also employed to detect the possible shift in regime on the unit root test. Table 4.2 shows some differences against ADF test results for external public debt of China and public investment of USA and Japan that are stationary in second difference rather than first.

Furthermore, the public investment for Germany and the external public debt for the United States have a weak stationary state level. Remaining results are the same with ADF test. We also conducted ZA test up to second difference in line with ADF test to investigate for stronger stationary.

The structural breaks in the external and domestic public debt for the stronger stationary position have mainly occurred around the economic crisis of 2008. Moreover, the results for stronger stationary reveal significantly that the domestic public debt always precedes the external public debt in terms of structural breaks during the economic crises.

Table 4.2. ZA (1992) unit root tests (with SC criteria)

	Level			First Difference			Second Difference		
	Test value		Break (year)	Test value		Break (year)	Test value		Break (year)
China									
Public investment	-2.6895	(3)	1983	-9.2542	(2)***	2007	-7.5548	(4)***	1967
External public d.	-3.0694	(3)	1992	-4.2371	(2)	1999	-9.5815	(1)***	2009
Domestic public d.	-2.5909	(1)	2004	-10.551	(1)***	2005	-8.8986	(1)***	2004
Germany									
Public investment	-4.1358	(1)*	2011	-6.6330	(3)***	2008	-7.2544	(3)***	1966
External public d.	-2.5177	(3)	2012	-5.7735	(2)***	2008	-8.0384	(2)***	2009
Domestic public d.	-4.6097	(1)	2014	-5.3308	(1)***	2008	-3.3025	(2)	2012
The United States									
Public investment	-3.4527	(3)	1979	-4.3296	(2)	1965	-6.6625	(3)***	1969
External public d.	-4.8631	(4)*	2009	-5.8205	(3)***	2010	-3.6977	(3)	2007
Domestic public d.	-3.3242	(1)	2006	-5.2408	(1)**	2006	-9.0244	(3)***	2007
Japan									
Public investment	-2.6868	(2)	1974	-4.3277	(1)	1995	-6.1771	(3)***	1983
External public d.	-4.6290	(3)	2010	-5.7735	(2)***	2008	-8.0384	(2)***	2009
Domestic public d.	-6.9301	(3)***	2012	-11.119	(4)***	2007	-3.9054	(1)	2005

*Notes: 1. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.*
2. The numbers in parentheses are the lag orders which are selected based on the SIC.
3. The cells of stronger stationary position are colored.

As shown in Table 4.3, there exist relatively many inconclusive results in the *first appearance* technique of the confirmatory analysis. Each country has an inconclusive result for confirming stationary at least a variable. For the *strong stationary* technique, however, there exists only one variable, domestic public debt for China, which is inconclusive. Therefore, the integration orders were used in the study as in the *strong* *stationary* afterwards. The inconclusive value was replaced with the integration order in the first appearance since it is conclusive in that technique at I(1).

Table 4.3. Confirmatory analysis of integration orders

	First Appearance			Strong Stationary		
	ADF	ZA	Result	ADF	ZA	Result
China						
PI	I(1)	I(1)	I(1)	I(1)	I(1)	**I(1)**
ED	I(1)	I(2)	X	I(2)	I(2)	**I(2)**
DD	I(1)	I(1)	I(1)	I(2)	I(1)	**X**
Germany						
PI	I(1)	I(0)	X	I(2)	I(2)	**I(2)**
ED	I(1)	I(1)	I(1)	I(2)	I(2)	**I(2)**
DD	I(1)	I(1)	I(1)	I(1)	I(1)	**I(1)**
United S.						
PI	I(1)	I(2)	X	I(2)	I(2)	**I(2)**
ED	I(1)	I(0)	X	I(1)	I(1)	**I(1)**
DD	I(1)	I(1)	I(1)	I(2)	I(2)	**I(2)**
Japan						
PI	I(1)	I(2)	X	I(2)	I(2)	**I(2)**
ED	I(1)	I(1)	I(1)	I(2)	I(2)	**I(2)**
DD	I(0)	I(0)	I(0)	I(1)	I(1)	**I(1)**

Notes: 1. PI, ED, and DD stand for public investment, external public debt, and domestic public debt, respectively.
2. The X represents inconclusive results.
3. I(0), I(1), and I(2) corresponds the integration orders in level, 1st difference, and 2nd difference, respectively.

4.4.2. Cointegration Test

Engle and Granger (1987) showed that a VAR model in differences will lead spurious results if the variables in levels are co-integrated. Therefore, the study requires performing co-integration test if the nonstationary variables in level share common trends before proceeding to VAR model. In this regard, VAR(p) model should be replaced either by an error-correction representation (ECM) or augmented VAR($p + d_{max}$) model when there exists a linear combination among nonstationary variables in levels (Engle and Granger 1987; Toda and Yamamoto 1995). Accordingly, Johansen and Juselius (1990) co-integration tests (i.e., maximum eigenvalue and trace test) were conducted to test the long-run equilibrium relationships among the variables. Table 4.4 reports the cointegration results for both maximal eigenvalue and trace test. For China, there is no cointegration for the external public debt meaning that the long-run relationship may not exist for the same variable at all. Germany has a weak cointegration at 10% significance level for the external public debt. However, remaining datasets for all countries specify a strong cointegration at 1% significance level. These results indicate that all datasets, except for external public debt of China, are required to present at least unidirectional causality.

Table 4.4. Co-integration test results

		Maximal eigenvalue test		Trace test	
		r=0	r=1	r=0	r=1
External Public D.	China	11.3023	3.0403	14.3425	3.0403
	Germany	18.4107*	9.2747	27.6854**	9.2748
	The United States	58.8384***	18.0798***	76.9182***	18.0798***
	Japan	67.3582***	25.4211***	92.7793***	25.4211***
Domestic Public D.	China	56.7342***	9.2878	66.0220***	9.2878
	Germany	49.9115***	11.776*	61.6873***	11.7758*
	The United States	48.4706***	14.3789**	62.8495***	14.3789**
	Japan	51.1412***	22.2432***	73.3844***	22.2432***

Notes: 1. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.
2. The lag orders are selected based on the SIC.

4.4.3. TY Granger Causality Test

Using the time series in level, TY Granger causality tests were performed between sovereign debt (explicitly, external and domestic public) and financing public infrastructure for China, Germany, the United States, and Japan after the VAR($p+d_{max}$) models had been constructed for related datasets. As shown in Table 4.5, the results indicate that there exists at least a unidirectional causality for almost all datasets, conforming to the long-run relationship in the co-integration test. However, the external public debt for China is the only dataset having no causality in any direction, which is consistent with the co-integration. For China, furthermore, there exists a unidirectional causality running from public investment to domestic public debt, implying that financing for public infrastructure leads to domestic public debt. In other words, China is less debt-dependent on public infrastructure because neither external nor domestic public debt does not Granger-cause public investment.

Table 4.5. Results for TY Granger causality test (with SC criteria)

	Period	d_{max}	k	Null hypothesis	Chi2	P-value
China	1981-2015	2	4	PI ≠> ED	0.46530	0.976789
		2	4	ED ≠> PI	0.91197	0.922836
	1995-2015	1	4	PI ≠> DD	13.5981***	0.008694
		1	4	DD ≠> PI	0.82009	0.935734
Germany	2000-2015	2	3	PI ≠> ED	2.59962	0.457556
		2	3	ED ≠> PI	7.09099*	0.069053
	2000-2015	2	4	PI ≠> DD	16.7617***	0.002150
		2	4	DD ≠> PI	33.3380***	0.000001
US	2000-2015	2	4	PI ≠> ED	7.37871	0.117178
		2	4	ED ≠> PI	80.4153***	1.11E-16
	2000-2015	2	4	PI ≠> DD	12.1089**	0.016559
		2	4	DD ≠> PI	34.8940***	4.88E-07
Japan	2000-2015	2	4	PI ≠> ED	21.9875***	0.000202
		2	4	ED ≠> PI	14.8829***	0.004950
	2000-2015	2	3	PI ≠> DD	1.85243	0.603592
		2	3	DD ≠> PI	9.62984**	0.021989

Notes: 1. PI, ED, and DD stand for public investment, external public debt, and domestic public debt, respectively.

2. The augmented lag order k equals d_{max}+ p. Except for PI ≠> DD and DD ≠> PI for China, the lag parameters p are selected based on SIC. The study employed Akaike information criterion for related dataset, namely PI ≠> DD and DD ≠> PI (Akaike 1974).

*3. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.*

4. The null hypothesis X≠>Y means variable X does not Granger cause variable Y.

5. The condition $d_{max} \leq p$ must be satisfied only for external public debt of China due to the cointegration results.

6. The maximum integration numbers (d_{max}) are taken from a stronger stationary state in the confirmatory analysis.

A weak unidirectional causality running from external public debt to public investment can be found at a 10% significance level for Germany, which is consistent with the cointegration results. For Germany, strong bidirectional causality exists between financing for public infrastructure and domestic public debt. In this regard, public investment affects domestic public debt, and this debt has also a direct impact on public investment.

The United States and Japan has strong bidirectional causality between both components of sovereign debt (i.e., external and domestic) and financing for public infrastructure at 1% significance level. In these countries, external part of sovereign debt comes into play for spending on public infrastructure. In other words, public investment has considerable amount of influence over external public debt, and this debt has also a direct response on public investment.

4.4.4. Key Findings

To the best of our knowledge, this is the first attempt to decipher causal relationships between sovereign (explicitly, external and domestic) debt and public investment approaching from debt sustainability perspective. In this regard, the key findings in this study can be summarized as follows:

(i) The integration orders show a discrepancy between ADF and ZA tests for the same time series. This study eliminates these differences by performing the *strong stationary* technique of confirmatory analysis. These results are used to determine d_{max} in TY Granger causality.

(ii) Two salient features are observed for the structural breaks of external and domestic public debts for all countries of interest in this study, which are China, Germany, Japan, and the United States (see Appendix A3 for the time periods). First, all structural breaks for external public debt and domestic public debt occur around 2008 global economic crisis. Second, domestic public debt is always occupied structural time breaks before external public debt in a strong stationary state. Moreover, the breaks for domestic public debt are detected in 2005, 2008, 2007, and 2007, respectively, for China, Germany, the US, Japan, just before the global financial crises. Therefore, this result implies that monitoring for domestic public debt may help the governments to predict possible global economic crisis since GDP of our sample comprises about 50% of the global GDP. Furthermore, the United States, China, and Japan are the top three of heavily indebted countries in the world[1].

(iii) This study finds that almost all the datasets share a common stochastic trend in level variables by conducting Johansen (1992) cointegration test, even Germany has a weak cointegration at 10% significance level. As an exception, the external public debt of China shows no cointegration over the period considered.

(iv) This study deciphers the causal relationships, along with the directions, by performing TY Granger causality between external-domestic public debt and public investment for China, Germany, US, and Japan (see Appendix A3 for the time periods). China presents only unidirectional TY Granger-causality running from public investment to domestic public debt. For Germany, there exists weak unidirectional TY Granger causality running from external public debt to public investment in addition to strong bidirectional causality between pubic investment and domestic public debt. There is strong unidirectional causality from external public debt to public investment in the US. In Japan, there exists strong unidirectional causality running from domestic public debt to public investment. The findings are quite consistent with both the cointegration results and the country segmentation for debt sustainability (i.e., sustainable, quasi-sustainable, and unsustainable debt zones)

(v) The assumptions based on debt sustainability zones (i.e., sustainable, quasi-sustainable, and unsustainable debt zones) are confirmed by the results obtained from TY Granger causality. These zones are separated with two thresholds 60% and 85% obtained from the Treaty on European Communities (1992) and empirical studies of

[1] This data is gathered from The World Economic Outlook (WEO) database that was published by IMF on 10th of October 2017

Cecchetti, Mohanty, and Zampolli (2011), respectively. The findings with respect to the sustainability zones can be summarized as follows:

- *Sustainable debt (less than 60%):* China has only strong unidirectional causality running from public investment to domestic public debt. This indicates that public investment, which is one of the channels of economic growth, leads to domestic public debt, and thereby it is less domestic debt-dependent country with respect to the investment, but vice versa is not true. Therefore, this causal relationship supports that of Tu and Padovani (2018), who demonstrate that sustainable debt policies still have been followed by the central government, but it needs to develop and enhance existing policies for the local (city) governments due to the shortage of land finance, which is considerable financing tool for public investment. Furthermore, there is no evidence for a causal relationship between public investment and external public debt. This is parallel with the findings of Panizza and Presbitero (2014) that there is no evidence for a causal effect between public debt and economic growth in which public investment is a channel of the growth.

- *Quasi-sustainable debt (between 60% and 85%):* For Germany, there exists strong bidirectional causality between public investment and domestic public debt. This indicates that financing for public investment affects domestic debt, and vice versa. In other words, this may be considered as a push-and-pull strategy by dynamic decision-making for the fiscal policies of domestic public debt, along with public investment (i.e., government expenditure). This includes corrective actions such as to increase primary surplus demonstrated by Bohn (1998), Greiner et al. (2007), Fincke and Greiner (2011), and to decrease public investment showed by Gong et al. (2001), Heinemann (2002), and Greiner (2007). However, there exists a weak unidirectional causality running from external public debt to public investment. Put differently, external public debt has appeared to lead public investment but only at a 10% significance level. This delicate situation for Germany requires some policy regulations to take corrective actions as stated in the domestic public debt and alternative financing systems to eliminate external-debt dependency on public infrastructure. Nevertheless, Germany still can be considered as near to sustainable zone with a caution, which is quasi-sustainable zone. This finding is also consistent with Fincke and Greiner (2011) and Fincke and Greiner (2012), and Checherita-Westphal and Rother (2012).

- *Unsustainable debt (more than 85%):* The United States has strong bidirectional causality between domestic public debt and public investment. On the one hand, this finding supports that the US has followed sustainable debt policies (Fincke and Greiner 2011) in terms of domestic public debt by corrective actions including the increase in primary surplus showed by Bohn (1998), and the decrease in public investment showed by Heinemann (2002). On the other hand, we obtain evidence on unsustainable debt policies in terms of external public debt by strong unidirectional causality running from external public debt to public investment. However, this unsustainability has incurred less vulnerability to external debt crises than the other countries due to the fact that external borrowing of the US is a large stock of domestic currency, which is in US dollars (Panizza 2008). Furthermore, global external debt is mainly denominated in the US dollar, and the world trade is commonly in US dollars, which is main reserve currency in the world (Reinhart et al. 2002). Therefore, the US can tolerate more external public debt than other advanced countries because of the unique status of the US dollar stated above.

As for Japan, there is strong bidirectional causality between external public debt and public investment. This finding provides an evidence that Japan has followed sustainable fiscal policies in terms of the net public debt once the high level of assets are taken into account by corrective actions, implied by bidirectional causality, including the increase in primary surplus showed by Bohn (1998), and the decrease in public investment showed by Heinemann (2002). Although gross public debt of Japan is excessive, Japanese fiscal policy is a unique case in which external and private debt has been shifted successfully to domestic public debt since mid-1970s (Hoshi, Kashyap, and Scharfstein 1993; Broda and Weinstein 2004). On the other hand, this study supports unsustainable fiscal policies in terms of domestic public debt by strong unidirectional causality running from domestic public debt to public investment. This is parallel with the findings of Fincke and Greiner (2011) that there is no evidence that Japanese fiscal policy considers gross public debt sustainability.

4.4.5. Discussions and Recommendations

As in the case of sustainable debt zone, China with a relatively low public debt/GDP ratio (less than 60%) should take necessary precautions such as avoiding excessive and misguided public investment, preventing corruption, which is shown that the effect of public debt on economic growth is a function of corruption (Kim, Ha, and Kim 2017), and balancing public and private infrastructure investments by collaborating with private wealth through different financial and business models) to keep its sovereign debt level in this zone before becoming one of the highly indebted countries. The countries in a quasi-sustainable debt zone have dynamic decision-making policies for corrective actions on domestic-external public debt and public investment to offset sovereign debt to GDP ratio to keep it in a certain and safe interval. However, in this sensitive case, countries reach, but not breach yet, the second sustainability limit (85%) and may even start to show weak unidirectional causality (at 10% significant level) running from public debt to public investment while struggling to keep the balance between the debt and public investment. This delicate situation, as for Germany, requires some policy regulations and alternative financing systems, rather than pure debt-based financing, to reduce debt dependency on public investment to be on the safe side of debt sustainability and to eliminate weak debt dependency, if exist, on public investment.

A clear implication of unsustainable external debt results for the United States provide evidence to support recommendations in the literature to reduce unsustainable-external public debt by mobilizing domestic savings through public investment via fiscal policies to achieve the sustainable development goals (IMF 2001; United Nations 2003; Agénor and Moreno-Dodson 2006; Berg et al. 2012; UNEP 2016a). For Japan, unsustainable domestic debt zone indicates a need for innovating alternative financial models against pure debt-based financing (i.e. equity based financing or mixture of debt and equity) to ensure sustainable-domestic public debt by attracting mattress money and foreign direct investment to the domestic market, particularly for the public investment to promote sustainable economic growth; and by transferring domestic resources from nonmonetary financial stocks to monetary financial system (Cecchetti, Mohanty, and Zampolli 2011; Abbas and Christensen 2010; OECD 2015a; United Nations 2012; Berg et al. 2012; United Nations 2003). In these cases, shifting sovereign debt towards more sustainable-private debt (either, domestic or external) might be an alternative solution to reduce debt-burden on the countries by creating alternative financial models for financing public infrastructure.

So far we have discussed the public debt sustainability with respect to the public investment on four countries with the highest GDP, which are the four pioneer countries in sustainable energy by building renewable power capacity more than half of the global capacity (REN 21 2017) and consisting of around 50% of global GDP (see Appendix A2), to investigate how they perform in financing for sustainable development. In what follows, we propose several directions as a future research. In this work, we only analyze the four counties those are good at sustainable development with the highest GDP. To make a more comprehensive comparison and to reach a broader perspective, we plan to expand this research into the countries with lower GDP in which sustainable development is hindered by public debt. In this study, we only focus on the public debt sustainability by exploring the interrelations between public investment and public debt. Therefore, further research is needed to investigate the private investment and private debt in terms of debt sustainability, which are out of the scope of this research.

Another point to note is that the data coverage of public debt (external and domestic) provided by the World Bank and IMF is limited to around 15 years starting from 2000 for the countries of the United States, China, Germany and Japan (World Bank 2017). On the other hand, the data coverage of public investment spans up to 2015 -even it is available since 1960 (IMF 2017b; IMF 2017a). This limits our analysis for 15 years because the intersection of public debt and investment is between 2000 and 2015.

4.5. Conclusion

Although the economic and fiscal policies along with geography, population, and ageing have a broad range of discrepancies in the countries under consideration, they have followed a similar pattern on public investment in terms of sovereign debt. Put differently, either external or domestic public debt becomes considerably influential on public investment when public debt to GDP ratio rises up through unsustainable debt zone. In this regard, sovereign debt is harmful to financing on public infrastructure if it breaches the certain thresholds through unsustainable debt zone. In other words, public borrowing can be beneficial in the beginning to promote economic growth by building public infrastructures until public debt leads to debt trap and corruption. Therefore, this paper states that the countries with high public debt should take an immediate action decisively to address their fiscal problems, and the countries with moderate (or low) public debt should take necessary precautions to sustain their debt level before becoming one of the highly indebted countries. In short, this paper concludes that performing a project for sustainable development by implementing unsustainable financing models will always end up with unsustainable economic outcomes.

CHAPTER 5: PUBLIC AND PRIVATE INVESTMENT IN THE HYDROCARBON-BASED RENTIER ECONOMIES: A CASE STUDY FOR THE GCC COUNTRIES*

Chapter 5, which is Phase 2 of the dissertation, investigates the causal relationship between public and private investments from 1960 to 2015 in the GCC countries (i.e., Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) which are known as hydrocarbon-based rentier states striving significant policy changes to diversify their economies. This research shows that there exists a non-linear dependency on public and private investments, and thereby non-linear causality is conducted to extract accurate information behind the scene, beyond the linear causality. In this regard, Saudi Arabia and the United Arab Emirates performed superior to other GCC countries in terms of nonlinear causality that shows bidirectional causality between public and private investment. In addition, structural time breaks reveal that these countries should be still considered as the rentier economies away from economic diversification. In short, the findings provide quantitative evidence about the need for public participation in public infrastructure through private investment, which is a base for Phase 3 in Chapter 6.

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5.1. Introduction

Public and private investment, along with the interrelations in between, have been studied and reported largely in the literature since the 1980s due to the paradigm shifts in global economics and the change in the economic dynamics, particularly, in developing countries. Public sector investments can be considered as the creation of physical assets including economic infrastructure (roads, railways, highways, airports, seaports, power plants, energy network, and so on) and social infrastructure (universities, hospitals, nursing homes, public schools, and so on) to develop a society and country. On the other hand, private investments are mostly considered as profit-driven businesses to generate income on capital assets and financed by non-governmental organizations, institutions, private entities, and individuals in order to maximize their own benefits. They can promote or crowd out each other depending on the quality and quantity of human capital, geographic and cultural circumstances, natural resources, and policies of the countries. For instance, public investment promotes human resource development that has a positive impact on private investment by increasing productivity and overall innovation capacity in a country. However, the unbalanced public investment may also crowd out private investment by wasting scarce resources, thereby reducing economic growth (Khan and Kumar 1997). In this regard, this study has examined the crowding out and promoting effects of public and private investment for rentier economies in the case of the GCC countries.

There is a serious challenge faced by hydrocarbon-based rentier states that is not only stimulating private investments for a non-oil based services or manufacturing, but also innovating alternative investment policies for a sustainable economic diversification. In this sense, all the GCC countries have developed their national visions around the nexus of economic diversification, transitioning to the knowledge-based economy and sustainable development for the post-petroleum era (Economic Development Board of Bahrain 2008; Supreme Council for Planning and Development of Kuwait 2015; Supreme Council for Planning of Oman 2016; Ministry of Development Planning and Statistics of Qatar 2008; Council of Economic and Development Affairs (CEDA) of KSA 2017; The Government of Abu Dhabi 2008). They recognize that public and private investments play a profound role in economic development. In the GCC countries, Figure 5.1 represents the fluctuations and the overall increase in public and private investment per capita for the period of 1960-2015 (IMF 2017b; IMF 2015). As can be seen, public and private investment has been sharply increased or decreased in these countries accompanied by the fluctuations in oil prices. Moreover, it should be noted that there is a visible increase in both of public and private investment from 2000 to 2014 for almost all of the GCC countries, except the UAE, mainly due to the increase in oil and natural gas extraction and their global prices. The UAE has shown a different characteristic in both public and private investment, which is a steady stream of the investments about US$ 10,000 per capita after the mid-1980s.

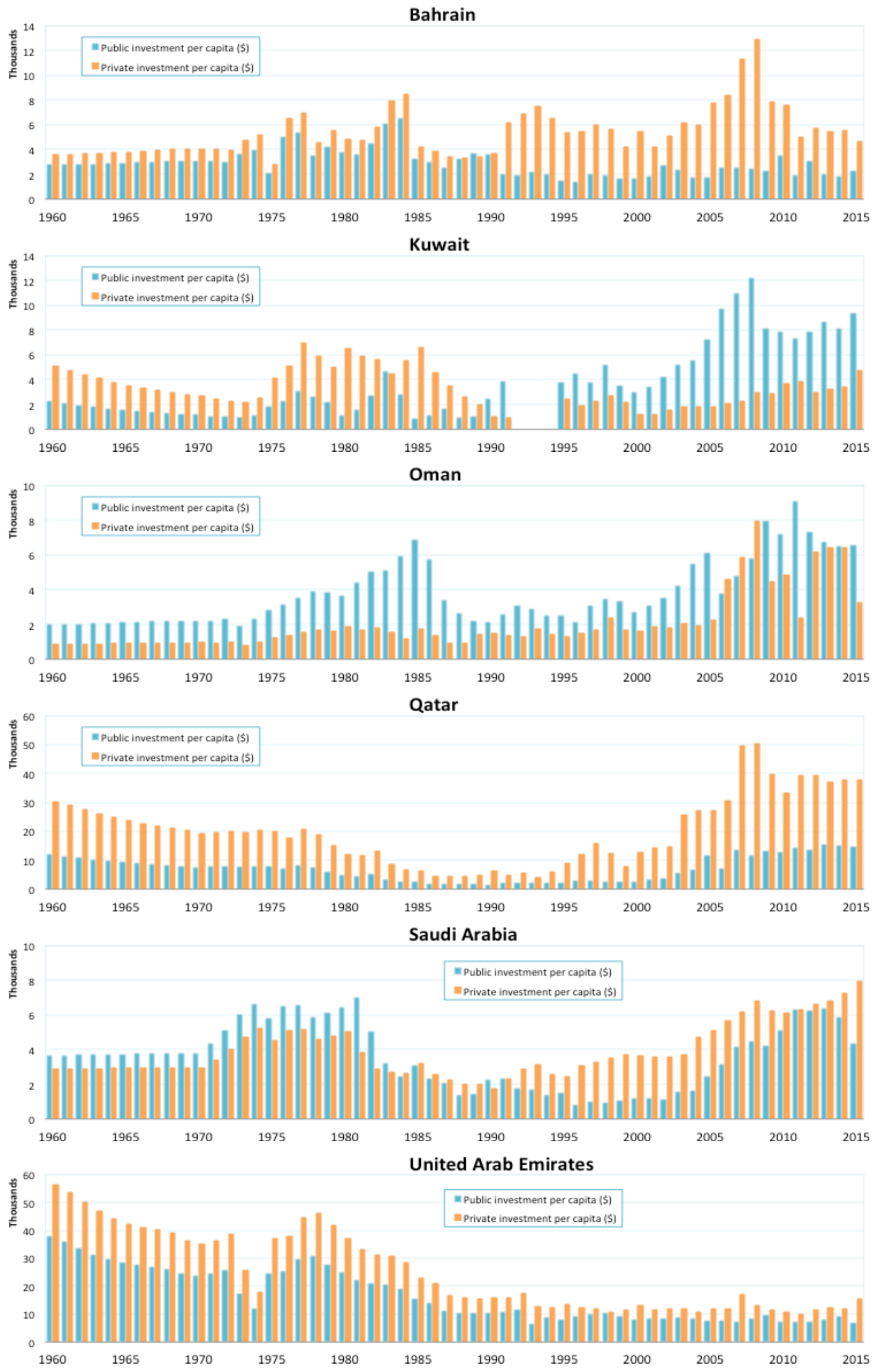

Figure 5.1. Public and Private Investment in the GCC Countries from 1960 to 2015 (see (IMF 2015) for the data source).

This study aims to investigate the claims that, first, oil-based rentier economies rely on public investment, and second, economic diversification is limited in these countries. To this end, this paper provides a different perspective from existing literature on economic diversification and sustainable development by investigating the quantitative relationships (structural time breaks, linear and nonlinear causality) between public and private investments in the GCC countries, which are the hydrocarbon-based rentier states. Therefore, the empirical analysis conducted in this research should be considered as a contribution to filling a gap in the development of the GCC countries.

5.2. Literature Review

5.2.1. Public-Private Investments in Rentier States

There always exists a constant risk of decreasing oil prices and diminishing hydrocarbon reserves that applies pressure on the governments of oil-based rentier states (henceforth interchangeable with the GCC countries) to bring alternative economic and financial policies into effect to promote investments generating non-oil/gas-based revenue. The state budgets in the GCC, which is a primary source of public investment, consists of mainly hydrocarbon-based revenue changing in different, but high, levels, from 77 to 93 percent in 2011 (Hvidt 2013). Put differently, public investment, which heavily relies on natural resources, is considerably higher than private investment, and thereby developments of the countries are strongly dependent on oil and natural gas (Basher and Fachin 2013).

Private investment, along with public investment, not only has a direct influence on economic growth in different scales (Khan and Kumar, 1997; Khan and Reinhart, 1990) but also plays a prominent role in social development and institutional quality by providing economic diversification (Busse and Gröning 2012). Furthermore, balancing the public and private investment by collaborating public decision-makers with private wealth holds the sovereign debt in a sustainable public debt level (Ari and Koc 2018). In the literature, there exists, however, a controversial discussion on positive effects (Aschauer 1989; Blejer and Khan 1984; Erden and Holcombe 2005; Ramirez 1994; Odedokun 1997) and adverse effects (Nazmi and Ramirez 1997; Everhart and Sumlinski 2001; Cavallo and Daude 2011) of the public investment's impact on private investment. This discrepancy between positive and negative effects is originated from institutional quality and financial development, but not directly caused by scarce physical resources in the oil-based rentier states (Haber and Menaldo 2011; Radetzki 2012; Moradbeigi and Law 2016). This is because natural resource abundance adversely affects financial development depending on institutional quality in many oil-based countries (Busse and Gröning 2012). In this regard, Bazhanov (2015) stated that the enhancement of the institutions for sustainable economic development might be more important than the investments. Furthermore, Cavallo and Daude (2011) discussed a positive effect of public investment on private investment when developing countries have strong institutions promoting marginal productivity of public investments; otherwise it would be *vice versa*.

5.2.2. The Influence of Public-Private Investments on Economic Growth and Diversification in the GCC Countries

The GCC countries are vulnerable to the fluctuations in hydrocarbon revenues because their national income comes from a sizeable amount of the world's oil and gas production (Flamos, Roupas, and Psarras 2013). In this regard, public and private investments are derived from hydrocarbon revenues without depending on the causal relationship in between (Basher and Fachin 2013; Cavallo and Daude 2011; Dhumale 2000). This leads a failure on economic diversification in the region. Therefore, economic diversification in such countries requires to reduce the dependency on hydrocarbons in both the public and private sector by domestic products from non-oil tradable sectors that contribute added value to the economic growth; and these products are such as manufacturing spare parts, home appliances, electronics, and other technology-based products (Kaya et al. 2019).

In the GCC countries, the public sector leaves small room for the private sector investments (Albassam 2015). This is because the national visions of these countries are not only driven but also performed by government investments in large projects, such as the Education City in Qatar and Masdar City in the UAE (Knight 2015), to achieve economic diversification. Moreover, Saudi Arabia allocated US$ 261 billion in 2018 for the national budget, which is the largest in its history, to achieve the goals of Vision 2030 (Saudi Vision 2030 2018). To diversify their economy, this budget, apart from Public Investment Fund (US$ 22 billion) and National Development Fund (US$ 13.3 billion), was used for the public investment in the non-oil sectors such as education, healthcare, infrastructure, defense, housing, industrial, and mining projects (Saudi Vision 2030 2018). Therefore, Cherif and Hasanov (2014) argue that market collision has more impact than the state failure on the breakdown of economic diversification from oil-based sectors. To mitigate and prevent market failures, governments should regulate macroeconomic policies to enhance financial market by diversifying the economy and including more private sector (Moradbeigi and Law 2016). Such policies should encourage the development of private sector, particularly non-oil tradable sector, by aligning it with public sector (Cherif and Hasanov 2014). Therefore, the core step towards economic diversification in the GCC is to increase the private sector's share in total investment and reduce their share in the tradable hydrocarbon sector.

After all, economic diversification and sustainable development requires two main conditions as follows; (i) public and private investment should move up together by triggering and reinforcing each other towards sustainable, balanced and growing economics as well as social and environmental development (Mallick, Mahalik, and Sahoo 2018; Cherif and Hasanov 2014; Erenburg and Wohar 1995); and (ii) hydrocarbon resource-based revenues should be considerably decreased in the share of state budget by increasing revenues from manufacturing, services, construction and other sectors mainly stimulated by private investments (Albassam 2015; Alsharif, Bhattacharyya, and Intartaglia 2017; Flamos, Roupas, and Psarras 2013). This study focuses on the first condition to investigate the investment behavior and make recommendations by exploring the following objectives: (i) to investigate the structural time breaks of public and private investment to discuss the effect of oil crises, (ii) to explore the linear causality, along with the direction, between public and private investment for the GCC countries, (iii) to examine the nonlinear causality between public and private investment for the GCC countries, if there exists nonlinearity in public investment data.

In summary, there are a few studies in the literature discussing the causal relationship impact between public and private investment for the GCC countries (Basher and Fachin 2013; Dhumale 2000) although the dynamics between public and private investments have been extensively studied from different angles and under different country contexts. According to the literature, private investment is necessary to boost economic growth and development by branching out into diverse and sophisticated sectors. To this end, it requires robust and reliable physical (such as energy, transportation, communication), social (such as education and health) and financial infrastructure (such as banking regulations), which are mainly developed by public investments. Furthermore, the relationship between public and private investments become positively impactful on the overall economic development if the right policies and institutions are put together to stimulate each other by bidirectional causality, not to crowd out each other or not to present unidirectional causality. In short, this study investigates how public and private investment affects each other in oil-based rentier economies, in the case of the GCC countries, by performing linear and nonlinear Granger causality.

5.3. Methodology

In this part, we explain the country selection and data-gathering process for the case study of rentier economies to analyze causal relationship between public and private investment. Next, a unified framework showing a general concept (Figure 5.2) and detailed approach are presented with the steps including unit root tests, along with structural breaks, confirmatory analysis, co-integration test, linear and nonlinear causality. Unit root tests analyze the time series whether they are stationary or not, and examine whether both public and private investment data for the same country have the same order of integration or not. Afterward, co-integration test investigates the long-run relationship by sharing common trends between time series for each country before giving insights into the causality. In the following step, linear and nonlinear causality is performed to understand the causal relationship and its direction between public and private investment. In this regard, panel data involves public and private investment spanning the period of 1960-2015 for each country. This annual data for public and private investment was gathered from the International Monetary Fund (IMF) Fiscal Affairs Department (IMF 2017b; IMF 2017a; IMF 2015).

5.3.1. Framework for Causality

This study follows a framework, as depicted in Figure 5.2, that presents a systematic approach enabling us to analyze the time series of public and private investment for structural time breaks, linear and nonlinear Granger causality. The holistic framework consists of three parts represented by color-coded columns in Figure 5.2.

Pretesting: In the orange-colored column, two unit root tests, Augmented Dickey-Fuller (ADF) (Dickey and Fuller 1981) and Zivot-Andrew (ZA) (Zivot and Andrews 1992) tests, were chosen to investigate the integration orders of public and private investment for each country considered in this study. Meanwhile, the ZA test provides structural time breaks of the datasets. Next, the integration orders of public and private investment obtained from ADF and ZA tests were examined pairwise to check whether the results from both are matched by confirmatory analysis. If public and private investment for the same country meet the same integration order and not to have a cointegration in between them, then standard Granger (1969) causality is performed to investigate causality. Otherwise, Toda-Yamamoto Granger causality (Toda and Yamamoto 1995) is conducted (see Figure 5.2).

Linear Causality: In the blue-colored column, Granger (1969) or Toda-Yamamoto Granger (Toda and Yamamoto 1995) causality test, both are a linear model, is employed on the datasets for further analysis. The selection, which one of the causality tests will be used, depends on the pretests. These pretest results enable to perform Granger causality if and only if the integration numbers of the time series are equal, and there exists no cointegration between them. Otherwise Toda-Yamamoto Granger causality (see Figure 5.2).

Nonlinear Causality: In the green-colored column, this study performs the BDS to ascertain nonlinearity of the public investment. The BDS computes the test statistic for the null hypothesis that public investment is a series of *independent and identically distributed* (i.i.d.) random variables (Brock, Dechert, and Scheinkman 1987). Next, nonlinear Granger causality proposed by Diks and Panchenko (2006) is conducted to investigate nonlinear causality between public and private investment if the BDS test confirms that there exists a nonlinearity in one of the time series (see Figure 5.2).

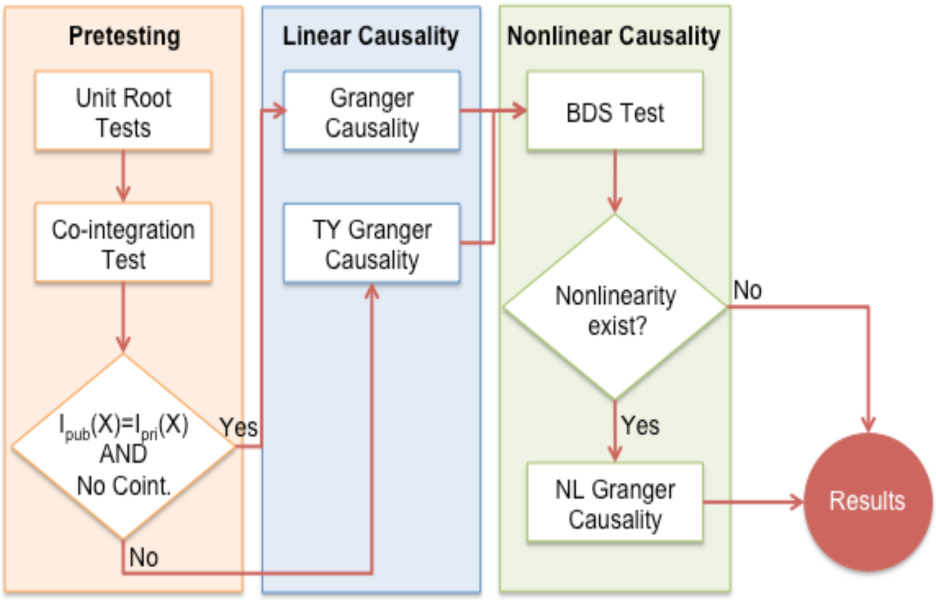

Figure 5.2. Framework for testing causality.

5.3.2. Confirmatory Analysis

The confirmatory analysis is a control mechanism for the accuracy of unit root tests. This study employs the ADF and ZA tests to examine the integration orders of the time series. Although these tests perform for the common purpose, finding the integration order, they might show different results from each other. Therefore, we conducted a confirmatory analysis to enhance the accuracy of the test results. To this end, we, first, compare the results from both tests for each time series. If the integration orders are identical for the same time series, then the result is considered as a true integration number. Second, we examine pairwise comparison for the integration order of the time series, which are subjected to the pairwise causality test. If both time series have true integration orders and these numbers are identical, then they have common and true integration order; otherwise, the result is inconclusive.

5.3.3. Toda-Yamamoto (TY) Granger Causality

In finance, the standard Granger causality (henceforth the *standard* Granger causality called as only *Granger causality*) stands for many applications examining the causal relationships between the time series (Granger 1969). This technique estimates the basic VAR(p) model as follows:

$$Y_t = \gamma + C_1 Y_{t-1} + \cdots + C_p Y_{t-p} + u_t \tag{5}$$

where Y_t is measured as a vector of time series variables in time *t,* and γ is a vector of constants. Here, Y_t and γ are n-dimensional vectors, and u_t denotes to the n-dimensional vector of white noise, and C_k represents an $n \ x \ n$ matrix of parameters for lag k.

The Granger causality plays a profound role in obtaining relationships, along with the direction of causality, among time series for many applications in economics, although this test has some limitations under certain conditions. There exist two primary preconditions to be able to apply the Granger causality. First, the integration orders of the time series associated with the same test have to be identical with each other. Second, there has to be no co-integration between the time series for conducting the Granger causality to avoid spurious results. To be able to employ the standard Granger causality, these two conditions must be fulfilled in associated time series (there exist few exceptions, see Enders 2014). Toda and Phillips (1994) discussed the limitations of Granger causality.

Toda and Yamamoto (1995) proposed a robust, yet simple, approach depending on modified Wald test (this is called as *modified* test due to the *augmented (modified)* VAR model) that is based on augmented VAR(p+d_{max}) model, wherein d_{max} is the maximum integration order of datasets associated together in investigating the causality in between. In this setting, modified Wald statistic converges toward asymptotic χ^2 random variable without depending on neither co-integration nor integration order (Toda and Yamamoto 1995). Therefore, Toda-Yamamoto (TY) Granger causality test does not require a unit root and cointegration test, thus preventing biased results of the pretest. To perform the TY Granger causality, the augmented VAR(p+d_{max}) model is shown as follows:

$$Y_t = \hat{\gamma} + \widehat{C_1} Y_{t-1} + \cdots + \widehat{C_p} Y_{t-p} + \widehat{C_{p+d_{max}}} Y_{t-p-d_{max}} + \widehat{u_t} \qquad (6)$$

where the circumflex over C_k, γ, and u_t denotes the estimation of ordinary least squares; C_k represents to the $n \; x \; n$ matrix of the parameters for lag k; d_{max} corresponds to the maximum integration order of the datasets associated together in conducting the causality. There are a couple of techniques to determine the true lag order p, which is challenging to know a priori, such as Schwarz Information Criterion (SIC), Akaike Information Criterion (AIC), and so on (Akaike 1974; Schwarz 1978). By employing the *modified* Wald test on the augmented VAR(p+d_{max}) model, the j^{th} element of Y_t does Granger-cause the i^{th} element of Y_t, if the following null hypothesis H_0 is rejected:

H_0: The (i, j) element of C_k is equal to zero for $k = 1, \ldots, p$.

TY Granger causality requires that the true lag order p must be greater than or equal to maximum integration order d_{max} of the datasets. However, if the time series are cointegrated, then p can be less than d_{max} (Toda and Yamamoto 1995).

5.3.4. BDS Test

Brock et al. (1987) proposed the BDS test utilizing the concept of correlation integral (Grassberger and Procaccia 1982) to investigate the identically and independently distributed (henceforth, called as i.i.d.) assumption on the error term of a time series by developing and employing an estimator of spatial probabilities over time (Brock et al. 1996). Consider an m-dimensional time series X_t, m is called an *embedding dimension*, with its observations $(X_t, X_{t+1}, \ldots, X_{t+m-1})$, then the correlation integral can be defined as follows (Chiou-Wei, Chen, and Zhu 2008):

$$C_m(T,\epsilon) = \frac{2}{T_m(T_{m-1})} \times \sum_{t=1}^{T_m - 1} \sum_{s=t+1}^{T_m} I(X_t^m, X_s^m, \epsilon) \tag{7}$$

where $I(X_t^m, X_s^m, \epsilon)$ denotes an indicator function that is equivalent to

$$I(X_t^m, X_s^m, \epsilon) = \begin{cases} 1, & if \ \|X_t^m, X_s^m\| < \epsilon \\ 0, & otherwise \end{cases} \tag{8}$$

here $\|X_t^m, X_s^m\|$ represents the Euclidian distance between X_t^m and X_s^m. T corresponds to the sample size, and T_m is the sub-sample size of the m-embedding dimensions. Brock et al. (1996) defined the BDS statistic with given an m-embedding dimension and a bandwidth of the radius ϵ as follows:

$$W_m(T,\epsilon) = \frac{\sqrt{T}(C_m(T,\epsilon) - C_1(T,\epsilon)^m)}{\sigma_m(\epsilon)} \tag{9}$$

where $\sigma_m(\epsilon)$ is the standard deviation of the m-embedding dimensional sample. This statistic asymptotically follows a standard normal limiting distribution. As a result of this test, there exists a nonlinear relationship between time series if the null hypothesis can be rejected.

5.3.5. Nonlinear Granger Causality

Granger (1969) causality plays a profound role in discovering the linear relations, along with the direction, between the financial time series. However, most of the time series includes many sophisticated components and features that cannot be detected in a linear setting. Therefore, Baek and Brock (1992) (BB) proposed a nonlinear Granger causality after showing that the standard Granger causality has limitations on detecting nonlinearity. Afterward, Hiemstra and Jones (1994) (HJ) proposed a modified version of the BB test by decreasing nuisance-parameter problems and enhancing the finite-sample size and power properties against a nonlinear Granger causality. Diks and Panchenko (2006) demonstrated that the HJ test tends to over-reject the null hypothesis. To solve this problem, they proposed a nonparametric test (henceforth, this test called as DP test) for nonlinear Granger causality by replacing the test statistic of the HJ test with a weighted average of local contributions. The null hypothesis of the DP test, which is X_t does not Granger-cause Y_t, was reformulated by the local conditional mean as follows:

$$H_0: E\left[f_{X,Y,Z}(X,Y,Z)f_Y(Y) - f_{X,Y}(X,Y)f_{Y,Z}(Y,Z)\right] = 0 \qquad (10)$$

A natural estimator of H_0 based on indicator function, which is defined in the subsection of the BDS test, can be stated as:

$$T_n(\epsilon_n) = \frac{(2\epsilon)^{-d_x-2d_y-d_z}}{n(n-1)(n-2)} \sum_i \left[\sum_{k,k\neq i} \sum_{j,j\neq i} I_{ik}^{XYZ} I_{ij}^{Y} - I_{ik}^{XY} I_{ij}^{YZ} \right] \qquad (11)$$

This statistic can also be interpreted as an average value over the local BDS test for the conditional distribution of X and Z, given $Y \neq y_i$ (see for details Brock et al., (1996)).

Simply, the null hypothesis is presented as the invariant distribution of $W_t = (X_t^{l_x}, Y_t^{l_y}, Y_{t+1})$, considering $l_x = l_y = 1$ and dropping time index t, then it becomes $W = (X, Y, Z)$, which is assumed as a continuous random variable. Afterward, the local density function of a d_W-variate random vector W at W_i can be stated as

$$\widehat{f_W}(W_i) = \frac{(2\epsilon)^{-d_W}}{n-1} \sum_{j,j\neq i} I_{ij}^{W} \qquad (12)$$

then the test statistic with this estimator becomes as follows:

$$T_n(\epsilon_n) = \frac{n-1}{n(n-2)} \sum_i \left(\widehat{f_{X,Y,Z}}(X_i, Y_i, Z_i) \widehat{f_Y}(Y_i) - \widehat{f_{X,Y}}(X_i, Y_i) \widehat{f_{Y,Z}}(Y_i, Z_i) \right) \quad (13)$$

Diks and Panchenko (2006) proved that the test statistic $T_n(\epsilon_n)$ fulfills Eq.(12) under a sequence of bandwidths ϵ_n

$$\frac{\sqrt{n}(T_n(\epsilon_n) - q)}{S_n} \xrightarrow{converges} N(0,1) \quad (14)$$

where S_n represents the estimator of the asymptotic standard deviation of $\sqrt{n}(T_n(\epsilon_n) - q)$. We followed the DP test statistic to examine the null hypothesis of nonlinear Granger causality.

5.4. Empirical Results and Discussions

5.4.1. Unit Root Tests

The unit root tests were conducted on the panel data to analyze the stationary status of the time series in level, 1st, and 2nd difference. We performed the ADF and ZA test, along with structural time breaks, to determine that which Granger causality (i.e., Toda-Yamamoto Granger causality or the standard one) is suitable for investigating causal relationship. Table 5.1 reports the results of the ADF test for the panel data consisting of public and private investment. The null hypothesis of the non-stationary time series cannot be rejected in levels for almost all datasets, except for public investment in Qatar.

This result provides evidence that public and private investment datasets for Bahrain, Kuwait, Oman, Saudi Arabia, and the United Arab Emirates are non-stationary in level. In the 1st difference, the findings reveal that both time series are stationary at least at a 5% level of significance, except for public investment in Qatar and Saudi Arabia. In the 2nd difference, we were able to reject the null hypothesis of non-stationary at a 1%

significance level for public investment of Saudi Arabia.

Zivot and Andrews (ZA) test was performed to examine the endogenous structural breaks by analyzing the possible shifts in the regime of the unit root test. Table 5.2 shows consistency with the results of the ADF test, given in Table 5.1, except for private investment in Kuwait. This provides strong evidence that both time series for each country becomes stationary in the same order. Saudi Arabia and U.A.E., which are the countries with the highest oil production in the GCC countries (BP 2017), present the structural time break for private investment around 1979, which is matching with the large oil shock starting in 1979 (O. J. Blanchard and Gali 2007). Public investment in Qatar had a unique structural time break in 1998 when oil prices plummeted to around $10/barrel (Kohl 2002). ZA test reveals that public and private investment for Bahrain and Oman has the structural break around 2005. Moreover, recent oil shocks between 2004 and 2008 caused the structural breaks for private investment in Kuwait and Qatar, and public investment in Saudi Arabia and U.A.E. (Kilian and Hicks 2013).

Table 5.1 ADF unit root test

	Level		First Difference		Second Difference	
	Test value		Test value		Test value	
Bahrain						
Public investment	-2.1460	(2)	-6.7826	(1)***	-6.2760	(4)***
Private investment	-2.6105	(1)	-4.4369	(1)***	-7.3021	(1)***
Kuwait						
Public investment	-0.4498	(1)	-4.2321	(1)***	-3.7466	(4)***
Private investment	-0.7504	(1)	-5.0339	(1)***	-3.9930	(4)***
Oman						
Public investment	-0.8853	(1)	-4.8808	(1)***	-5.0165	(3)***
Private investment	0.1935	(4)	-6.6408	(3)***	-5.6037	(4)***
Qatar						
Public investment	-4.3327	(4)***	-1.7094	(4)	-3.2015	(3)
Private investment	0.4259	(3)	-3.9615	(2)**	-4.9046	(3)***
Saudi Arabia						
Public investment	-2.1731	(2)	-2.9592	(1)	-6.2995	(1)***
Private investment	1.1314	(1)	-4.2688	(1)***	-4.3769	(3)***
United Arab Emirates						
Public investment	-1.8776	(1)	-5.3081	(1)***	-5.2857	(4)***
Private investment	0.1782	(1)	-4.7435	(1)***	-5.7923	(2)***

*Notes: 1. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.*
2. The numbers in parentheses are the lag orders which are selected based on the SIC.

Table 5.2. ZA unit root tests

	Level			First Difference			Second Difference		
	Test value		Break (year)	Test value		Break (year)	Test value		Break (year)
Bahrain									
Public investment	-4.1197	(2)	1990	-7.6011	(1)***	2004	-7.0203	(4)***	2008
Private investment	-5.3148	(1)**	2006	-6.3679	(1)***	2007	-9.7615	(1)***	2006
Kuwait									
Public investment	-2.0798	(1)	2007	-6.3987	(1)***	1984	-4.5469	(4)	1988
Private investment	-5.0848	(1)**	2004	-6.7665	(1)***	2007	-7.8361	(4)***	2006
Oman									
Public investment	-3.9203	(1)	1999	-6.0938	(1)***	2006	-6.0225	(3)***	2009
Private investment	-3.9675	(4)	2001	-15.821	(3)***	2004	-7.8177	(4)***	2003
Qatar									
Public investment	-6.5521	(4)***	1998	-2.1818	(4)	1982	-6.9484	(3)***	2002
Private investment	-4.7291	(3)	2000	-7.4723	(2)***	2005	-6.5352	(3)***	2006
Saudi Arabia									
Public investment	-3.1775	(2)	1990	-4.4153	(1)	2011	-8.7963	(1)***	2008
Private investment	-3.4467	(1)	1999	-5.4753	(1)**	1979	-6.7178	(3)***	2006
United Arab Emirates									
Public investment	-3.4455	(1)	1992	-6.2640	(1)***	2006	-7.2571	(4)***	2005
Private investment	-2.9230	(1)	2004	-5.5799	(1)***	1978	-7.2489	(2)***	2005

*Notes: 1. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.*
2. The numbers in parentheses are the lag orders which are selected based on the SIC.

As shown in Table 5.3, the ADF and ZA test results were consolidated to confirm whether both public and private investment become stationary in the same integration order. There exists an inconclusive finding for Kuwait because the ADF and ZA test results for private investment do not match with each other. Therefore, common integration order for public and private investment is inconclusive. This means that TY Granger causality is more appropriate than the standard procedure for investigating the causal relations between the datasets. For Saudi Arabia and Qatar, public and private investments have a discrepancy in the integration orders of the ADF and ZA test, thereby confirmatory analysis shows that standard Granger causality is not suitable as much as TY Granger causality. Apart from these, standard Granger causality can be conducted for Bahrain, Oman, and U.A.E. according to the confirmatory analysis if public and private investments do not have co-integration in between for these countries.

Table 5.3. Confirmatory analysis of integration orders

	ADF	ZA	Result	Conclusion
Bahrain				$I_{pub}(1) = I_{pri}(1) = I(1)$
Public investment	$I_{pub}(1)$	$I_{pub}(1)$	$I_{pub}(1)$	
Private investment	$I_{pri}(1)$	$I_{pri}(0)$	X	
Kuwait				Inconclusive
Public investment	$I_{pub}(1)$	$I_{pub}(1)$	$I_{pub}(1)$	
Private investment	$I_{pri}(1)$	$I_{pri}(0)$	X	
Oman				$I_{pub}(1) = I_{pri}(1) = I(1)$
Public investment	$I_{pub}(1)$	$I_{pub}(1)$	$I_{pub}(1)$	
Private investment	$I_{pri}(1)$	$I_{pri}(1)$	$I_{pri}(1)$	
Qatar				$I_{pub}(0) \neq I_{pri}(1) = NA$
Public investment	$I_{pub}(0)$	$I_{pub}(0)$	$I_{pub}(0)$	
Private investment	$I_{pri}(1)$	$I_{pri}(1)$	$I_{pri}(1)$	
Saudi Arabia				$I_{pub}(2) \neq I_{pri}(1) = NA$
Public investment	$I_{pub}(2)$	$I_{pub}(2)$	$I_{pub}(2)$	
Private investment	$I_{pri}(1)$	$I_{pri}(1)$	$I_{pri}(1)$	
United Arab Emirates				$I_{pub}(1) = I_{pri}(1) = I(1)$
Public investment	$I_{pub}(1)$	$I_{pub}(1)$	$I_{pub}(1)$	
Private investment	$I_{pri}(1)$	$I_{pri}(1)$	$I_{pri}(1)$	

Notes: 1. The X represents inconclusive results.
2. I(0), I(1), and I(2) corresponds the integration orders in level, 1st difference, and 2nd difference, respectively.
3. The conclusion is obtained by comparing the results of unit root tests (ADF and ZA) for each country.
4. NA stands for Not Applicable meaning that public and private investment are not in the same integration number for the same country. This prevents us from employing standard Granger causality.

5.4.2. Cointegration Test

Engle and Granger (1987) demonstrated that a VAR model in differences would lead spurious results in standard Granger causality if the variables in levels were cointegrated. Therefore, we performed Johansen and Juselius (1990) co-integration tests (i.e., maximum eigenvalue and trace test) to investigate whether public and private investment for each country in level share common trends, meaning that they are cointegrated or not. In the existence of co-integration, VAR(p) model should be replaced either by an error-correction representation (ECM) or augmented VAR($p + d_{max}$) model to avoid spurious results (Engle and Granger 1987; Toda and Yamamoto 1995). Apart from that, there exists a long-run causal relationship at least in one direction if the co-integration exists between the time series.

Table 5.4 reports the cointegration results in both maximal eigenvalue and trace test for the GCC countries. Except for Kuwait and Saudi Arabia, all other countries in the GCC showed apparent co-integration between public and private investment, and hence this indicates that there is at least unidirectional causality for these countries. As a result of this and the confirmatory analysis in the previous subsection, we conducted TY Granger causality in the GCC countries by employing augmented VAR($p + d_{max}$) model to avoid spurious results.

Table 5.4. Co-integration test results between public and private investment

	Maximal eigenvalue test		Trace test	
	r=0	r=1	r=0	r=1
Bahrain	18.8789*	7.1215	26.0004**	7.1215
Kuwait	15.8748	4.5081	20.3829	4.5081
Oman	32.2065***	4.3605	36.5670***	4.3605
Qatar	45.8807***	5.7912	51.6722***	5.7912
Saudi Arabia	10.8369	8.0927	18.9297	8.0927
United Arab Emir.	33.7321***	3.8732	37.6052***	3.8732

*Notes: 1. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.*
2. The lag orders are selected based on the SIC.

5.4.3. *TY Granger Causality Test*

TY Granger causality test was conducted in the level of public and private investment for the GCC countries after the VAR($p+d_{max}$) model had been implemented for associated time series. As shown in Table 5.5, there is at least a unidirectional causality in almost all GCC countries, except for Saudi Arabia. These results are also compatible with the co-integration test, except for Kuwait. There exist two mainstream of the nation's behavior on the causal relations between public and private investment, which are (i) a unidirectional causality running from private to public, and (ii) a bidirectional causality between them. For Bahrain and Kuwait, there is a unidirectional causality running from private to public, implying that private investment leads to public investment. In these countries, private investment surprisingly plays a dominant role in spending on public investment. In other words, private investment has a considerable amount of influence over public investment, but not vice versa.

Table 5.5. Results for TY Granger causality test

	Period	d_{max}	*k*	Null hypothesis	Chi2	P-value
Bahrain	1960-2015	1	3	Public ≠> Private	0.47976	0.923315
		1	3	Private ≠> Public	17.1164***	0.000669
Kuwait	1960-2015	1	2	Public ≠> Private	1.08909	0.580104
		1	2	Private ≠> Public	13.7845***	0.001016
Oman	1960-2015	2	9	Public ≠> Private	37.9161***	1.80×10^{-5}
		2	9	Private ≠> Public	57.0551***	4.93×10^{-9}
Qatar	1960-2015	1	8	Public ≠> Private	126.383***	0.000000
		1	8	Private ≠> Public	144.041***	0.000000
Saudi Arabia	1960-2015	2	4^{+}	Public ≠> Private	1.65884	0.798181
		2	4^{+}	Private ≠> Public	5.14638	0.272605
United Arab Emirates	1960-2015	1	2	Public ≠> Private	6.00460**	0.049673
		1	2	Private ≠> Public	39.8118***	2.26×10^{-9}

Notes: 1. "Public" and "private" stand for public investment and private investment, respectively.
2. The augmented lag order k equals $d_{max}+p$. The lag parameters p are chosen based on SIC.
*3. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.*
4. The null hypothesis X≠>Y means variable X does not Granger cause variable Y.
5. The condition $d_{max} \leq p, (p = k - d_{max})$, must be satisfied only for Kuwait and Saudi Arabia due to the cointegration results (Toda and Yamamoto 1995)*. Therefore, Saudi Arabia's lag was taken as two, instead of one according to the SIC, resulting in that k = 4.*
6. The maximum integration numbers (d_{max}) are taken from the ADF test results in the confirmatory analysis.

For Oman, Qatar, and the U.A.E., strong bidirectional causality exists between public and private investment at 1% significance level. In this regard, public investment leads to private investment, and vice versa is also true. This might be a push-and-pull strategy for public and private investment in order to implement dynamic decision-making policy and practice. Finally, Saudi Arabia does not show any causal relationship with the associated time series. We also concern about the nonlinear relationship for the GCC countries, and thereby we performed the BDS test to investigate nonlinearity in the time series. In this regard, the nonlinear Granger causality test would provide more favorable results than the TY Granger causality if there were nonlinearity.

5.4.4. BDS Test

The BDS test was conducted on the residual series of VAR models to test for nonlinearity of the time series (Brock, Dechert, and Scheinkman 1987). BDS test statistic for the null hypothesis states that public investment is a series of *independent and identically distributed* (i.i.d.) random variables. This means that if the assumption of the null hypothesis is rejected, then the time series can be considered that nonlinearity may be embedded in the series. In that case, the nonlinear Granger causality test would give us more convenient results than the TY Granger causality. We performed the BDS test for only public investment data in order to understand the nonlinear interrelationship between public and private investment. Because if there is a nonlinearity in only one of the time series, then this is enough to conclude that there may be a nonlinear interrelationship in between them.

Table 5.6 shows the BDS test results on the residuals of the VAR model for public investment. In almost all cases, the null hypothesis can be rejected for the entire GCC countries under the different orders of embedded dimensions. This suggests that nonlinear interrelationship between public and private investment is likely to exist in the residuals. Therefore, nonlinear Granger causality test to investigate the causal relationship between public and private investment yields more favorable results than linear Granger causality. In this regard, we performed the nonlinear Granger causality proposed by Diks and Panchenko (2006) to complement our analysis on causal relationship.

Table 5.6. BDS statistic for the public investment series

Length in S.D.	Embedding Dimensions	W statistic Bahrain	Kuwait	Oman	Qatar	K.S.A.	U.A.E.
0.5	2	2.78248***	0.83846	5.36964***	2.44914**	2.24649**	4.74586***
0.5	3	3.07014***	1.85043*	5.03935***	2.26905**	2.92643***	4.39337***
0.5	4	2.75033***	1.78958*	5.19269***	2.61925***	2.50354**	4.14690***
0.5	5	2.38618**	1.32547	4.65201***	2.58726***	2.15344**	3.65640***
0.5	6	1.84697*	2.46942**	5.45884***	2.27830**	1.26069	3.69832***
0.5	7	1.86065*	2.07967**	5.11319***	2.56343**	0.17106	3.30850***
0.5	8	3.42418***	1.65216*	4.58990***	2.47087**	-0.23927	2.83797***
0.5	9	3.13429***	2.70747***	5.74194***	2.75582***	1.04559	2.32509**
0.5	10	2.60421***	2.56403**	5.31515***	2.64060***	-0.51584	3.77136***

Notes: 1. Test results are based on the residuals of a VAR model.
*2. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.*

5.4.5. Nonlinear Granger Causality

The nonlinear interrelationship between public and private investment was investigated by conducting nonlinear Granger causality test (Diks and Panchenko 2006) on the residuals of VAR model of associated time series (public and private investment for a particular country). According to Diks and Panchenko (2006), we set optimal bandwidth to 1.5 because the number of observation is less than 500. The number of lags is set to $L_{public}=L_{private}=1, 2, 3, 4, 5, 6, 7$, and 8. Table 5.7 reveals the results of nonlinear Granger causality for GCC countries and Table 5.8 demonstrates an overview of the results for linear and nonlinear Granger causality tests.

Table 5.7. Results for nonlinear Granger causality test

L_x=L_y	H_0: Public ≠> Private	P-value	H_0: Private ≠> Public	P-value
Bahrain				
1	1.42604*	0.07693	0.79193	0.21420
2	2.03257**	0.02105	1.02824	0.15191
3	1.85603**	0.03172	1.02600	0.15245
4	1.76017**	0.03919	1.02925	0.15168
5	1.68949**	0.04556	0.66269	0.25376
6	1.31254*	0.09467	0.31656	0.37579
7	1.32863*	0.09199	-0.05129	0.52045
8	1.12776	0.12971	-0.20485	0.58116
Kuwait				
1	-1.16116	0.87721	0.87857	0.18981
2	-1.73829	0.95892	0.51873	0.30197
3	-0.68683	0.75390	1.00849	0.15661
4	-0.65888	0.74501	0.94917	0.17127
5	-0.47068	0.68107	0.40624	0.34228
6	-1.25644	0.89552	-0.20161	0.57989
7	0.97957	0.16365	-0.31524	0.62371
8	0.90415	0.18296	-0.23966	0.59470
Oman				
1	1.64204*	0.05029	-1.01698	0.84541
2	1.73133**	0.04170	0.37697	0.35310
3	1.94863**	0.02567	0.44201	0.32924
4	1.75062**	0.04000	0.28869	0.38641
5	1.57884*	0.05719	0.47826	0.31623
6	1.24456	0.10665	0.82308	0.20523
7	0.93569	0.17472	0.82100	0.20582
8	0.86732	0.19288	-0.05887	0.52347
Qatar				
1	0.57394	0.28300	0.49825	0.30915
2	1.90341**	0.02849	0.73222	0.23202
3	1.20351	0.11439	-1.23867	0.89227
4	1.04722	0.14750	0.38878	0.34872
5	0.75313	0.22569	0.41828	0.33787
6	0.88521	0.18802	0.43446	0.33198
7	1.04875	0.14715	0.40674	0.34210
8	0.36795	0.35645	0.34018	0.36686
Saudi Arabia				
1	-0.56766	0.71487	1.07935	0.14021
2	1.06907	0.14252	1.45642*	0.07264
3	1.40325*	0.08027	2.24684**	0.01233
4	1.49451*	0.06752	2.61029***	0.00452
5	0.95941	0.16868	2.14409**	0.01601
6	0.44051	0.32978	1.99860**	0.02283
7	-0.75307	0.77430	1.89071**	0.02933
8	-0.24238	0.59576	1.66281**	0.04817
U.A.E.				
1	1.45767*	0.07247	0.75549	0.22498
2	1.33045*	0.09169	1.39443*	0.08159
3	0.51318	0.30391	1.36100*	0.08676
4	0.29664	0.38337	1.61404*	0.05326
5	-1.17425	0.87985	1.14768	0.12555
6	-1.23142	0.89092	1.04759	0.14741

7	-1.00724	0.84309	1.07289	0.14166
8	-0.87390	0.80891	1.05358	0.14604

Notes: 1. Test results are based on the residuals of a VAR model.
2. Lx = Ly denotes the number of lags on the residuals series used in the test.
3. In all cases, optimal bandwidth is set to 1.5 due to the relatively small sized sample according to Diks and Panchenko (2006).
*4. *, ** and *** indicate significance level at the 10%, 5% and 1%, respectively.*
5. The null hypothesis X≠>Y means variable X does not Granger cause variable Y.

A nonlinear Granger causality interrelationship between public and private investment was found to exist in five countries, namely Bahrain, Oman, Qatar, Saudi Arabia, and the UAE., except for Kuwait. For Bahrain, there is weak but significant bidirectional nonlinear Granger causality between public and private investment while having a strong unidirectional linear Granger causality running only from private to public investment. For Kuwait, there is no any nonlinear Granger causality between associated time series whereas private investment strongly and significantly Granges causes public investment in linear Granger causality. For Oman, Qatar, and the UAE, the nonlinear Granger causality from the public to private investment is significant but inconsistent with the result of bidirectional causality from the linear model. This provides strong evidence that the causation from the public to private exists for these three countries in both linear and nonlinear model. Saudi Arabia has a bidirectional nonlinear Granger causality between public and private investment in contrast to the linear model with the nonexistence of causality.

Table 5.8. Overview of causality test results

		H_0: Public ≠> Private	H_0: Private ≠> Public
Bahrain	Linear Granger causality	✗	✓
	Nonlinear Granger causality	✓	✗
Kuwait	Linear Granger causality	✗	✓
	Nonlinear Granger causality	✗	✗
Oman	Linear Granger causality	✓	✓
	Nonlinear Granger causality	✓	✗
Qatar	Linear Granger causality	✓	✓
	Nonlinear Granger causality	✓	✗
Saudi Arabia	Linear Granger causality	✗	✗
	Nonlinear Granger causality	✓	✓
United Arab	Linear Granger causality	✓	✓
Emirates	Nonlinear Granger causality	✓	✓

Notes: 1. The null hypothesis X≠>Y means variable X does not Granger cause variable Y.

5.4.6. Key Findings and Discussions

Bahrain is considered relatively more diversified economy than other GCC countries, except for the UAE, because of having considerably less oil and natural gas reserves. This diversification has taken place in the financial services by the private sector since 1973 with the launch of offshore banking units. The development of the financial market is a primary ingredient of the economy in Bahrain, rather than hydrocarbon-based revenues. Furthermore, Bahrain has been desperately seeking foreign direct investment and attracting some as well due to the lack of enough natural resources to grow its economy. Because of these reasons, it is possible to justify that private investment leads to public investment in the linear settings of Granger causality. However, this finding may be spurious because of the nonlinearity in the datasets according to the BDS test. Indeed, there exists only unidirectional causality running from public investment to private investment in the nonlinear settings. This provides evidence to support the claim in the literature that Bahrain is still dependent on the oil-based economy (Flamos, Roupas, and Psarras 2013), although it struggles to diversify the economy through the financial sector.

Kuwait has shown a similar trend with Bahrain in the linear settings that is a significant linear Granger causality running from private to public investment. However, the results from linear causality cannot represent a true relationship between public and private investment because there exists nonlinearity in the datasets according to the BDS test. In other words, the results are biased towards private investment in the linear settings while expecting more accurate results from nonlinear causality. In the manner of nonlinear Granger causality, Kuwait has not any nonlinear relations between public and private, even though there exists nonlinearity in the datasets. This provides evidence supporting the neutrality hypothesis, which means that public investment may not affect private investment, and vice versa. This result implies that public and private investments are separately caused by other factors, thereby the common association among these time series is provided by other factors.

Oman and Qatar presented enthusiastic objectives in their national visions indicating strong desires for economic diversification and knowledge-based economy (ONV 2020, 2013; QNV 2030, 2008). In this regard, these countries have been trying to promote private participation in the economy, but still, public investment leads to private investment as evidenced by both linear and nonlinear settings. Although Qatar has exhibited rapid economic development during recent years that brought a population boom through expatriates and the investments from public and the private sector in the linear settings, it is still heavily reliant on public investment for attracting further private investment in terms of nonlinear settings. As for Oman, it has the lowest hydrocarbon revenue with respect to the earnings from export (65%) and the second lowest concerning the share of GDP (41%) (Hvidt 2013). These statistics have exerted a need to improve the investment structure and alternative revenue streams rather than natural resources.

Fortunately, Oman has located in a geographically strategic point of the region and exploited this feature as leverage by being a port country for international trade. For this reason, Oman presents bidirectional linear causality between private and public investment in linear settings, but these trading and re-export facilities require a substantial public investment that governs private investment in nonlinear settings.

Saudi Arabia has a more complex economy because it has a higher GDP, greater population, and larger land than the other GCC countries. The linear causality cannot reveal the complex relationships that are concealed by the nonlinearity of the datasets. Therefore, the linear Granger causality test does not show any relationship between public and private investment. However, there is nonlinearity in the datasets according to the BDS test in Saudi Arabia, and thereby this study conducted nonlinear Granger causality. As a result of this test, Saudi Arabia shows bidirectional causality between public and private investment. This result is inconsistent with the majority of the literature regarding economic diversification and healthier economies. This is because Saudi Arabia presents the highest dependence, compared to the GCC countries, in three economic indicators that are (i) oil sector as a percentage of GDP, (ii) oil revenue as a percentage of total revenue, and (iii) oil export as a percentage of total export (Albassam 2015). Therefore, Saudi Arabia does not satisfy the condition that is reducing hydrocarbon-based revenues in the share of the state budget, although it fulfills a weak bidirectional causality between public and private investment. Furthermore, public and private investment datasets might not be the highest quality that makes our results spurious and biased towards the healthier economics.

The U.A.E. also presents bidirectional causality for the same datasets in both linear and nonlinear settings, which is the only country in this study demonstrating the consistent results in both tests. The UAE has shown a different characteristic in both public and private investment per capita, which is a steady stream of the investments about US$ 10,000 per capita after the mid-1980s (see Figure 5.1), that is consistent with the literature in terms of decreasing oil-share in GDP from around 65% in 1980 to 30% in 2007 (Alsharif, Bhattacharyya, and Intartaglia 2017; Flamos, Roupas, and Psarras 2013). This implies that the UAE have spent considerable time and effort for diversifying the economy by applying dynamic-decision making strategies to keep the public and private investment in balance and stable. The U.A.E became the financial hub and business center in the region by attracting private sector by providing appropriate policies and environment (Alsharif, Bhattacharyya, and Intartaglia 2017). Besides, the tourism industry has also been promoted in the country by the government to diversify the economy (Mansfeld and Winckler 2008) that also attracts a considerable amount of capital. Although the results for the U.A.E represent weak bidirectional causality at a 10% significance level, this provides evidence that the country is a thriving economy by triggering each other of public and private investment.

These findings reveal mostly unidirectional nonlinear causality running from public to private investment in almost all GCC countries. However, Saudi Arabia and the UAE have a weak bidirectional causality at a 10% significance level that implies a limited achievement in economic balance. Therefore, these oil-based rentier states still rely on public investment. Furthermore, the structural time breaks show that these states are still rentier economies, and could not achieve economic diversification as yet, although all of the GCC countries have a national vision emphasizing economic diversification. Because these countries are still heavily dependent on oil and natural gas resources, and thereby all of the breakpoints have occurred at the time of oil crises that can be considered as one of the indicators of limited economic diversification. Put differently, economic development, along with the growth, in the GCC heavily relies on the natural resources, thereby the developments and growths are strongly dependent on the price fluctuations of oil and natural gas resources. In summary, this study provides evidence from a different perspective to support the claims that, first, oil-based rentier economies still rely on public investment, and second, economic diversification is limited in these countries.

Thus far we have discussed the causal relationship between public and private investment in the GCC countries to provide evidence for the dependency on public investments and hydrocarbon-based revenues. In what follows, we propose several directions as future research. We plan to expand this research into the investment law and foreign direct investment (FDI) to evaluate the reasons and potential solutions for public investment dependency. Furthermore, there are also several directions towards follow-up studies based on the effects of education and culture. In the education part, future research will investigate the impact of providing access to quality education and relevant skills-based training for the entire society, local people in particular. This might increase labor productivity and flexibility and develop a social and cultural awareness for establishing and running technology-oriented high-quality entrepreneurial activities. In a cultural aspect, future study will explore the economic and financial opportunities for the GCC countries to diversify their economies by utilizing their specific conditions in terms of their geography, climate, population, language, and even religion.

5.5. Conclusion

The GCC countries should take action to escape from being rentier states by diversifying their economies according to their national visions. They might achieve economic diversification from hydrocarbon dependency to the non-oil-based sector through the knowledge-based economy. To this end, the public participation through private sector plays a prominent role in promoting non-oil-based business. In this regard, the government needs to establish institutional and relational trust between the state, ruling elite(s) and the private sector based on a larger portion of their population. The private sector should feel secure regarding calculative risks and investment failures. Therefore, the oil-based rentier states should establish strong institutions with higher quality and apply dynamic decision-making structure on the investments to benefit from the feedback effect of public and private investment.

This study investigates the causal relationship between public and private investments from 1960 to 2015 in the GCC countries (i.e., Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) which are known as hydrocarbon-based rentier states striving significant policy changes to diversify their economies. This research shows that there exists a non-linear dependency on public and private investments, and thereby non-linear causality is conducted to extract accurate information behind the scene, beyond the linear causality. In this regard, Saudi Arabia and the United Arab Emirates performed superior to other GCC countries in terms of nonlinear causality that shows bidirectional causality between public and private investment. In addition, structural time breaks reveal that these countries should be still considered as the rentier economies away from economic diversification. In short, the findings provide quantitative evidence to support the claim that, first, oil-based rentier economies strongly rely upon public investment, and second, economic diversification is limited in these countries.

CHAPTER 6: SUSTAINABLE FINANCING FOR SUSTAINABLE DEVELOPMENT: AGENT-BASED MODELING OF ALTERNATIVE FINANCING MODELS FOR CLEAN ENERGY INVESTMENTS*

Renewable energy investments require a substantial amount of capital to provide affordable and accessible energy for everyone in the world and finding the required capital is one of the greatest challenges faced by governments and private entities. In a macroeconomic perspective, national budget deficits and inadequate policy designs hinder public and private investments in renewable projects. These problems lead governments to borrow a considerable amount of money for sustainable development, although such excessive debt-based financing pushes them through unsustainable economic development. This substantial amount of borrowing makes a negative contribution to high global debt concentration putting countries' economic and social development at risk. In line with this, excessive debt-based financing causes an increase in wealth inequality and when wealth inequality reaches to a dramatic level, then wars and many other social problems are triggered to correct the course of wealth inequality. In this regard, the motivation behind Chapter 6, which is Phase 3 of the dissertation, is to develop a set of policy guidelines for sustainable financing models as a solution for these intertwined problems which are (i) financial gap in energy investments, (ii) excessive global debt concentration, and (iii) dramatic increase in wealth inequality. To this end, this study presents a quantitative and comparative proof of concept analysis on alternative financing models for a solar farm investment to investigate the change in wealth

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* Ari, Ibrahim, and Muammer Koc. 2019. "Sustainable Financing for Sustainable Development: Agent-Based Modeling of Alternative Financing Models for Clean Energy." *Sustainability*, 11, 1967.

inequality and social welfare by reducing debt-based financing and increasing the public participation. There are many studies in the literature investigating the evolution of wealth inequality throughout the history. However, there is a gap in the literature which is investigating the effects of various policy rules on the evolution of wealth inequality in a future time frame to discuss the possible policy implications beforehand. In this respect, Phase 3 contributes to the literature by developing simulation models for conventional and alternative financing systems that enables to investigate the change in wealth inequality and social welfare as a result of various policy implications throughout the simulation time.

6.1. Introduction

Energy investments have a significant influence on economic growth and development as widely discussed in the literature (Samouilidis and Mitropoulos 1983; Munnell 1992). Global energy investment accounted US$ 1.8 trillion in 2017 and power sector took the largest portion, which was about US$ 750 billion (IEA 2018). Electricity investment in the power sector has shifted towards renewables, networks, and efficiency. In line with this, renewable power valued US$ 300 billion in 2017, accounted for two-thirds of power generation investments, and hit record levels of spending on solar photovoltaic (PV) (IEA 2018). Despite such considerable amount of current investments, renewables require an annual increase of at least 150% from the current trend between 2015 and 2050, although the rapid advancements in technology reduce significantly the cost of harnessing clean energy (OECD/IEA and IRENA 2017). These investments have crucial importance in truly providing affordable and accessible clean energy globally in order to achieve the Paris Agreement target, which is a promise to hold temperature rise below 2°C by 2050 (UNFCCC 2015).

Renewable energy investment plays a critical role in building a sustainable future and a better planet for everyone. Renewables mitigate greenhouse gas (GHG) emissions and provide alternatives resources, rather than fossil fuels, for harnessing energy which is a necessity for economic and social development. However, there was a substantial gap nearly of US$ 1.7 trillion in 2017 for financing energy infrastructure including renewables (IEA 2018; OECD/IEA and IRENA 2017). This statistic shows that finding the required capital is one of the greatest challenges for clean energy investment faced by governments and private entities. In a macroeconomic perspective, national budget deficits and inadequate policy designs hinder public and private investments in renewable projects. These problems lead governments to borrow a considerable amount of money for sustainable development, although such excessive debt-based financing pushes them through unsustainable debt zone (Ari and Koc 2018) and into unsustainable economic development. In a business-as-usual case, renewable energy projects were funded about 90% by debt-based financing from 2009 to 2017 (IRENA 2017). This substantial amount of borrowing makes a negative contribution to high global debt concentration putting countries' economic and social development at risk. In line with this, excessive debt-based financing causes an increase in wealth and income inequality. Piketty advocates that when wealth inequality reaches to a dramatic level, then wars and many other social problems are triggered to correct the course of wealth inequality (Piketty and Zucman 2014; Piketty 2014).

The motivation behind the study is to develop a set of policy guidelines for alternative and sustainable financing models as a solution for these intertwined problems which are (i) financial gap in energy investments, (ii) excessive global debt concentration, and (iii) dramatic increase in wealth inequality resulting economic and social crises. In other words, this paper is motivated by finding a solution for the triangle of unsustainability illustrated in Figure 3. In this regard, the objective of the study is to develop the policy framework in the financing system for a substantial decrease in wealth inequality without decreasing total wealth by reducing debt-burden on society and including public participation through private investments. In line with the objective, this study attempts to provide evidence for the following questions. First, if renewable projects are financed excessively by debt-based financing, either from domestic or external creditors, how it may affect the long-term sustainable economic and social development for the benefit of the public? Second, the critical question to be answered eventually is: what kind of policy applications for sustainable financing should be developed for renewables, and other public infrastructures, without damaging the long-term sustainable economic and social development? In this regard, this study provides a quantitative and comparative proof of concept analysis on alternative and sustainable financings for solar farm investments to investigate their long-term impact on the change in wealth inequality, total wealth accumulation in the economy, and social welfare. To this end, an equity and foundation (not-for-profit)-based financial intermediary (EBIN) is designed in an agent-based model with simple, yet powerful, policy rules and regulations, and also a banking system is developed to compare the proposed models with conventional financing. The proposed policy framework, which is open to further improvements, encompasses four main components as follows. First, the proposed policy prioritizes individuals in society over large enterprises to participate in solar farm investments as much as their savings. Second, to prioritize individuals, the study limits the investment share in power plants for each shareholder (except for individuals) which are divided into individuals, large enterprises, banks, and equity-based financial intermediaries. Next, the EBIN is designed to become a self-sufficient along with the individuals in society after a certain time. Last, the proposed model requires a foundation share from the profit of the EBIN, and thereby this increases the social welfare and equity by spending the money accumulated in the foundation pool for the benefits of the public.

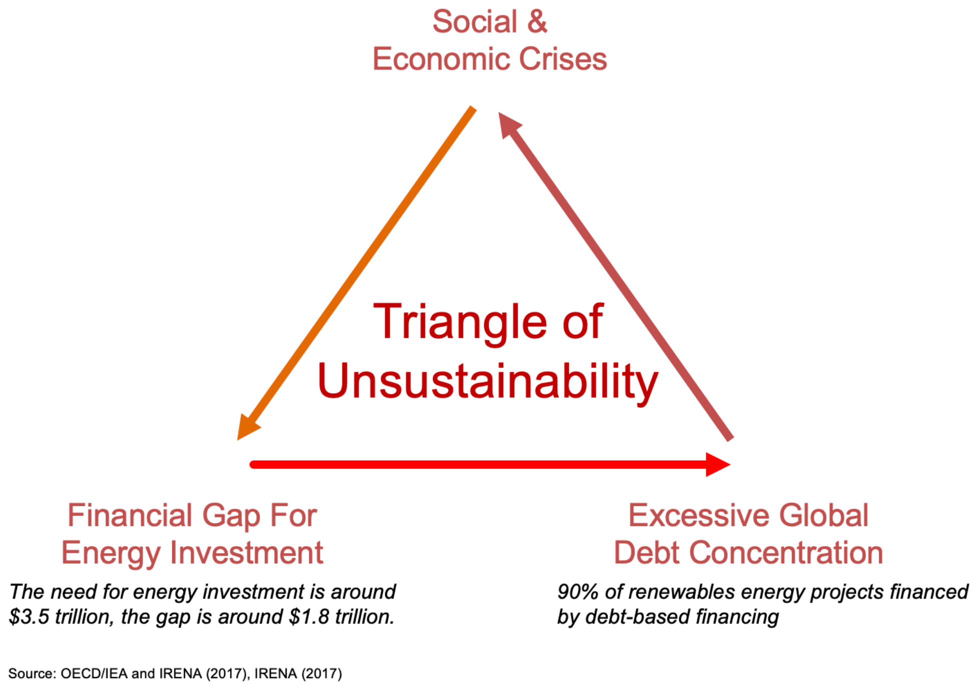


Figure 3. Problem Statement.

There are many studies in the literature investigating the evolution of wealth inequality throughout the history. However, there is a gap in the literature which is investigating the effects of various policy rules on the evolution of wealth inequality in a future time frame to discuss the possible policy implications beforehand. In this respect, the most important contribution of the study to the literature by developing simulation models for conventional and alternative financing systems that enables to evaluate the change in wealth inequality and social welfare as a result of various policy implications throughout the simulation time. In line with this, this study implements the proposed policy regulations resulting in a dramatic decrease in wealth inequality (Gini index) throughout simulation time. The resulting value is less than the lowest Gini coefficient among 174 countries reported in Global Wealth Databook 2018 (Credit Suisse 2018).

6.2. Literature Review

6.2.1. Sustainable Development and Global Debt Concentration

The global economy requires notable transformation and thinking to prevent a desertification, deforestation, land degradation, biodiversity loss, climate change, air pollution, waste of water, over-consumption, and over-production. To this end, the United Nations (UN) commits economic growth in harmony with nature for both individual and national prosperity towards sustainable development (United Nations 2012; United Nations 2015b). In this context, the economic transformation requires to innovate inclusive and productive financing policies, and also ensure that existing financing models become environment-friendly by promoting greener production behavior within individuals, firms, organizations, societies, and governments (UNEP 2016b; UNEP 2015; Gambetta et al. 2019). However, high global debt concentration retards this inclusive and productive financing and also has a significant negative impact on sustainable development (PWC 2017; Ari and Koc 2018). The global debt-to-GDP ratio rose dramatically from 269 percent in 2007 to 325 percent in 2016 (MGI 2015; Tiftik et al. 2017). This increase has an adverse effect on economic growth and financial stability because severe economic and financial crises are expected to happen when the debt ratios exceed a certain limit (C. M. Reinhart and Rogoff 2009). Therefore, Ari and Koc recommend to innovate equity-based financing models, rather than pure debt-based financing, to maintain debt sustainability (Ari and Koc 2018). However, this study investigates sustainable financing models by not only reducing debt-burden on society, but also preventing social stress and redistributing the wealth more equitable.

6.2.2. Wealth Inequality and Social Inequity

The wealth inequality has influenced significantly, much more than the income inequality, in governing the countries throughout the history as Wilford Isbell King wrote in his book "Whoever controls the property of a nation becomes thereby the virtual ruler thereof."[2]. Wealth distribution, in contrast to income, is best employed as an indicator of the possessing economic power in society rather than as a measure of the living standards enjoyed by the public (Shammas 1993). Therefore, the intimidating power of wealth leads many policy-makers to advocate redistribution of resources by the state through progressive income taxation, which is a good way to increase the material well-being of a society. However, progressive income taxation does not redistribute the economic power, which enables to rule the countries, from a few people to society. For instance, the Nordic countries (Finland, Norway, and Sweden) hit low records of income inequality in the world (UNU-WIDER 2018), whereas they have significantly high levels of wealth inequality in the world (Credit Suisse 2018) (see Table 6.1). There are many studies in the literature investigating the evolution of wealth inequality throughout the history and economic models which have been able to explain this inequality so far (Shammas 1993; Cagetti and De Nardi 2008; A. Smith 1981; Azzimonti, Francisco, and Quadrini 2014; Röhrs and Winter 2017). However, there is a gap in the literature which is investigating the effects of various policy rules on the evolutions of wealth inequality in a future time frame by a computer simulation. This research aims to reach to near of the lowest wealth inequality, 0.498, among 174 countries in the report (Credit Suisse 2018).

Table 6.1. Wealth and Income Inequality in Nordic countries.

	Date (income inequality)	Income inequality	Date (wealth inequality)	Wealth inequality
Norway	2015	23.9	2018	79.1
Finland	2015	25.2	2018	76.7
Sweden	2015	26.7	2018	86.5

[2] Wilford Isbell King, The Wealth and Income of the People of the United States (1915; repeated edition, New York, 1969), 53.

Thomas Piketty advocates throughout his book, Capital in the twenty-first century, that wars, or social unrests, happen to correct the course of history when wealth inequality reaches at significantly high levels (Piketty 2014). Then, the critical question is: what is the global status of wealth inequality? Global Wealth Databook 2018 reported the regional Gini indexes of wealth inequality at dramatically high levels, such as 89.7, 90.1, 71.4, 83.6, 85.4, 81.9, 84.3, and 90.4, respectively, in Africa, Asia-Pacific, China, Europe, India, Latin America, North America, and the World (Credit Suisse 2018). These numbers indicate that capital has been concentrated and centralized in a few hands who are the shadows rulers of the countries by steering economic power. Therefore, policy-makers should innovate different redistribution mechanisms to reduce wealth inequality to acceptable levels. This study focuses on new policies to decrease wealth inequality to these levels.

6.2.3. Financial Localization

Many studies discuss the financial localization and not-for-profit community banking for healthier economy (Werner 2012; Lee and Werner 2018; Werner 2014; Werner 2016). Richard Werner advocates that monetary reform should be implemented realistically by establishing many small, local, not-for-profit community banks, such as in the success story of the German economy over the past 170 years (Werner 2014). This is because there is an inverse relationship between bank size and the tendency of banks to lend to micro and small enterprises (SMEs), thereby this propensity limits the growth of SMEs (Mkhaiber and Werner 2018). In other words, large enterprises and banks grow together in a significant level without individuals and SMEs, and this leads to capital concentration and centralization in a few hands, which causes social problems as mentioned in the sub-section of 'Wealth inequality and social equity'. In line with this, SMEs in the UK experience the shortage of funding because of a highly concentrated banking system in which five banks account for more than 90% of deposits (Werner 2012). On the other hand, Germany has more than 1,700 locally-headquartered, small savings and cooperative banks that account for around 70% of deposits (Werner 2012). In the meantime, this might be one of the reasons that Germany is only one that achieves sustainable public debt level among top three developed countries by the GDP (Ari and Koc 2018). In short, financial localization plays a crucial role in providing an adequate amount of funds for all and thereby balancing wealth inequality. However, there is a gap in the literature that is planning on when many small, local, and not-for-profit financial intermediaries should be established. In this regard, this study investigates the potential time-schedules to create a bank or another type of financial intermediaries.

6.2.4. Agent-Based Modeling

Agent-based (AB) modeling is a powerful scientific toolset for solving complex real-world problems in many research fields including economic (Tesfatsion 2001; Tesfatsion 2002; Tesfatsion 2006) and social design (Epstein 2006; Bonabeau 2002). AB model adopts a bottom-up approach by designing heterogeneous agents (i.e., people, sector, market, financial intermediaries, and so on) with low abstraction, more details, and micro level interactions. This study employs a sub-field of AB modeling that is called agent-based computational economics (ACE) motivated in the economic and financial systems (Tesfatsion 2001; Chen, Chang, and Du 2012). In economy and finance, ACE not only brings the solutions for complex systems by heterogeneity and adaptivity, beyond equilibrium and rational behavior, but also giving an opportunity to examine difficult questions about human and environmental interactions such as agency problem, asymmetric information, collective learning, and imperfect competition (Tesfatsion 2006). Therefore, ACE is not limited to uniform-symmetric identities or other constraints arising from analytical models.

Furthermore, ACE facilitates the aggregation of values over heterogenous agents (i.e., individuals, power plants, sectors, banks, and so on) while their composition is changing dynamically, which is a challenging subject (Stoker 1993; Gallegati et al. 2006). This dynamic interdependency of economic agents regarding their behaviors and actions constitutes microeconomics, and the collective behaviors and actions of the agents form a macroeconomic system. In this study, we considerably exploit the aggregation property of the ACE in the deterministic model of financing clean energy by incorporating not only funding and carbon intensity, but also incorporating income inequity.

ACE is a relatively new research paradigm, thereby there exist a limited number of academic papers in the vertical dimension of a specific field under the economy although there are many in a horizontal perspective diversified in economics and finance with a growing number of researchers. In energy economics and finance, this study's focal point, ACE has largely employed in electricity market regulations (Rahimiyan and Mashhadi 2010; Ringler, Keles, and Fichtner 2016) and energy efficiency models (Wu, Mohamed, and Wang 2017; Liang et al. 2019) (see (Weidlich and Veit 2008) for critical literature review on ACE based electricity sector). However, there is a gap in the literature which is the modeling in evaluating wealth inequality by funding the recurring projects by different segments of the population and different financial instruments. In this regard, this study addresses this gap by designing agent-based modeling on investigating the wealth inequality in a society consisting of large enterprises and individuals by funding solar farms with various agent types.

6.3. Methodology

6.3.1. Project Finance

Public infrastructures require a substantial amount of upfront funds in the beginning and pay back in a longer period. In this regard, project finance is employed commonly for funding public infrastructures such as power plants, airports, seaports, bridges, and many other areas. This is because project finance is a risk-averse and long-term financing model for the project owner and developer, but not for the investors, because it puts only future cash flows, along with the project's assets, up as collateral, but not owner's or developer's assets. This study focuses on project financing approach, particularly investor's side (see Figure 6.4c), that employs two common techniques to raise the required amount of money which are debt-based and equity-based financing (see Figure 6.4a and Figure 6.4b).

This study proposes policy regulations on alternative financing models for a solar farm with a power purchasing agreement to investigate the change in wealth inequality and social welfare. These policy rules are as follows (see Figure 6.4b and Figure 6.4c).

vi. The individuals are prioritized to invest in a power plant as much as they have savings.

vii. There are four types of shareholders that are individuals, large enterprises, a bank, and an equity-based financial intermediary. The shareholders are listed in a given order to participate in a power plant depending on the savings. For example, assuming that the potential shareholders are listed in order as the individuals and large enterprises if the individuals do not have enough money for the entire investment, the remaining amount is provided by the large enterprises.

viii. The shareholders have an upper bound to join in a solar farm. This upper bound is usually a hundred percent for individuals. In other words, the individuals can invest up to 100 percent of the total investment of a power plant.

ix. The equity-based financial intermediary (EBIN) is designed to be a self-sufficient financial intermediary up to a certain limit according to the upper bound.

x. There is a foundation share out of the EBIN's profit (see Figure 6.4c). The foundation share is accumulated in the foundation pool to support the public infrastructure. In this regard, the proposed policy can rise social welfare.

6.3.1.1. Relations between the stakeholders of project finance

The project owner is a private or public entity that owns the project's assets (henceforth the project is interchangeable with the solar farm) and future cash flows eventually. Project owner puts the solar farm on auction for constructing, operating, and maintaining, in brief, from the very beginning to the end. In this stage, project developer, who is a private or public entity, wins the auction for the solar farm (arrow 1 in Figure 6.4a and Figure 6.4b, henceforth only arrow number will be specified inside the parentheses). Next, project developer establishes Special Purpose Vehicle (SPV) that is a project company to protect the developer from possible failure of the solar farm by signing all contracts on behalf of the developer (arrow 2). SPV signs a financial contract, debt-based or equity-based, with investors to collect the required funds by using only future cash as collateral (arrow 3). The investors also become a shareholder of the solar farm (arrow 4) if the investment is funded by equity-based financing.

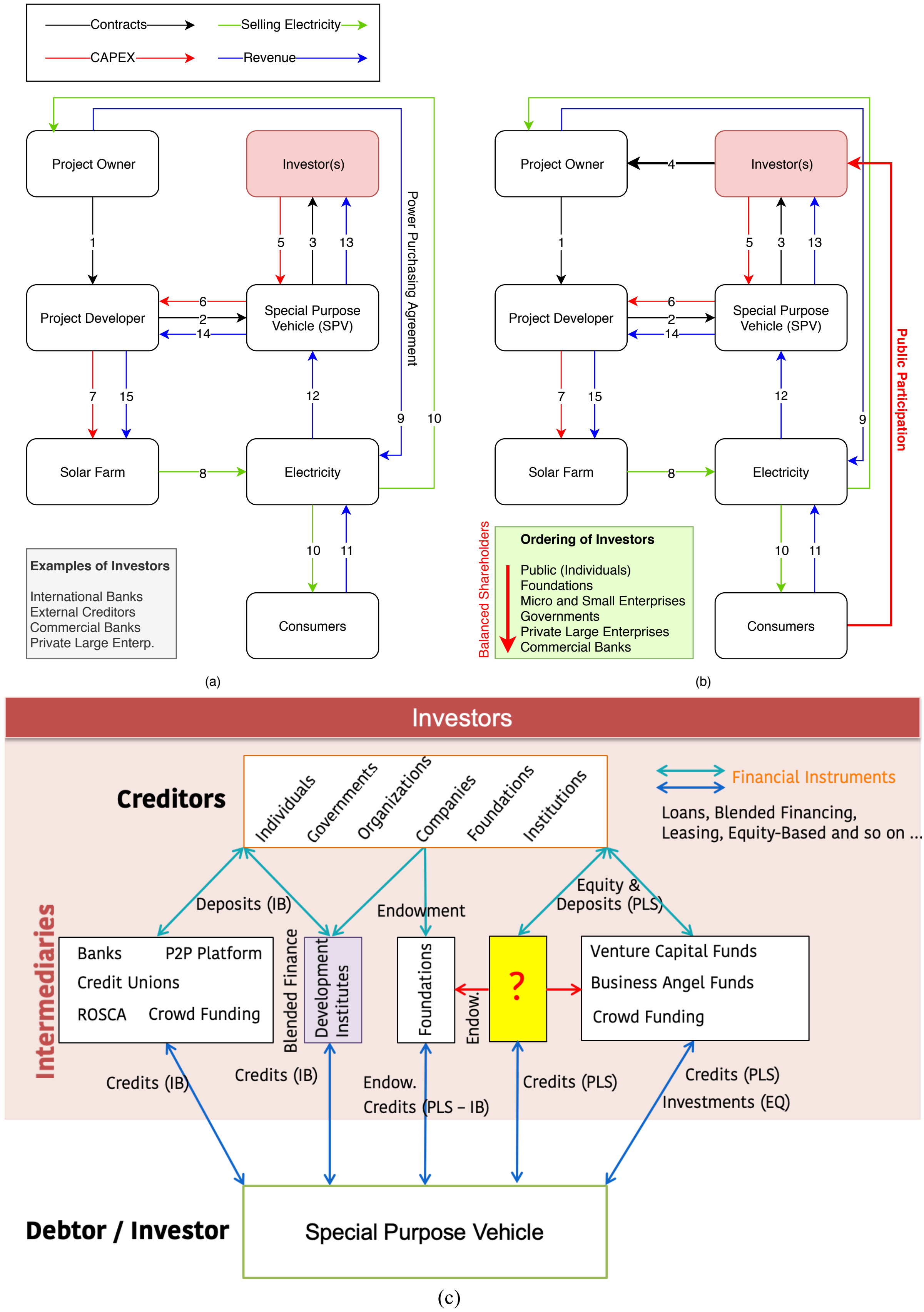


Figure 6.4. (a) Debt-based project financing, (b) debt and equity-based financing with some of the proposed policies, and (c) investors part in (a) and (b).

6.3.1.2. Project finance cash flows

Money transactions between investors and the SPV constitute an essential part of the project finance. To maximize profit, investors invest on the solar farm (arrow 5) in return of dividends or debt contracts backed by the SPV relying on the future cash flows. The project developer is responsible for designing, building, operating and maintaining of the solar farm by funding the required capital from investors through SPV (arrow 6 and 7). Next, the solar farm generates electricity (arrow 8) and sells this (arrow 10) to the public. Thus, the SPV collects the earnings from the customers (arrow 11 and 12). In the meantime, there exists a cash flow coming from project owner (arrow 9) to the SPV because the owner sings power purchase agreement (PPA) with the developer in the very beginning of the project to attract more project developers to bid on the auction. This contract is a guarantee for the developer. Last, the SPV distributes the generated revenue to the investors and project developer accordingly (arrow 13 and 14).

6.3.2. Agent-Based Model

This study provides an agent-based model on alternative financing models for a solar farm to investigate the change in wealth inequality and social welfare. In the following part, the agent-based model is described for financing the solar farm. This model considers seven agent-types as follows.

6.3.2.1. Power plant (PP) agent-type

Power plant plays a critical role in generating *revenue* by producing electricity. This plant requires upfront financing for the initial capital expenditure, which is the *overnight capital cost (OCC),* to become operational. Before generating electricity, there is a *construction period (CP)* to build a power plant. Producing energy (electricity) is subjected to the operational cost during the *lifetime*. This study assumes that the PP generates electricity for the period of *lifetime (LT)*. In addition to net energy output, operational cost, and revenue, PP calculates the carbon intensity of the production and the mitigation levels of carbon emissions. To this end, PP stores the carbon intensity constants for the energy plants powered by natural gas and solar to evaluate *carbon emission* and mitigation level over the lifetime, this part is explained in the model implementation section.

The *Special Purpose Vehicle (SPV)*, inside the *PP*, plays a central role in managing the financial activities of the power plant by borrowing and fundraising for the capital expenditures, paying back loan installments, expensing for the operational cost, distributing the net profit to the shareholders. Therefore, the SPV has a fundamental responsibility which is communicating with external agent-types by message-passing algorithms. It communicates with the *bank* (conventional financial intermediary) agent-type through *loan* agent-type and *equity-based financial intermediary* through *equity-based instrument* agent-type. Put this simply, SPV calculates the cash inflow (capital expenditures) and outflow of the project by exploiting the other three functions, namely net energy output, revenue, and operational expenses. These functions are explained in detail by the next sub-section.

6.3.2.1.1. Functions of power plant

Net energy output (NEO). The NEO is a key function of the PP that calculates available net energy output for each year as shown in Equation 1:

$$NEO_t = (CAP) * (EY) * (RPA) * (ED)_t, \qquad (t = 1, \dots, LT) \tag{15}$$

where CAP is a constant for *power plant capacity*, and EY represents specific *energy yield* which is calculated for a solar farm by geographic conditions. RPA denotes the *rate* *of power plant availability* providing the percentage of running time over total possible run-time annually. This constant considers possible power cut due to general maintenance or extraordinary conditions such as natural disasters. ED shows *efficiency degradation* that is the intrinsic value of solar farm changing by geographic conditions, photovoltaic (PV) materials, and time.

Operational expenses (OPEX). OPEX consists of land lease (*LL*), asset management (*AM*), insurance (*INS*), other expenses (*OE),* and operations and management (*OM*). This function is shown as shown in Equation 2:

$$OPEX_t = LL_t + AM + INS + OE + OM_t\,, \qquad (t = 3, \dots, LT) \tag{16}$$

where LL_t is the annual cost defined by a landowner, which is usually the government. *AM* is equal to $\mathrm{AM} = \mathrm{OCC} \times \mathrm{RAM}$, where RAM represents the *rate of asset management* cost. *INS* is denoted by $\mathrm{INS} = \mathrm{OCC} \times \mathrm{RIN}$, where RIN indicates the rate of insurance cost. *OE* is defined as $\mathrm{OE} = \mathrm{OCC} \times \mathrm{ROE}$, where ROE is the rate of other expenses. As can be seen, the AM, INS, and OE are the fixed cost as a share of the overnight capital cost. On the other hand, the OPEX shows different characteristic in the second year, thereby $OM_{1,2}$ along with OM_t are explicitly given as shown in Equation 3, 4, and 5:

$$OM_1 = PPC \ \times OMC(\$/kW/year) \tag{17}$$

$$OM_2 = OM_1 \times DOM_1 \tag{18}$$

$$OM_t = OM_{t-1} \times INF \tag{19}$$

where OMC represents *estimated operation and management cost* per kilowatt per year. Second year, operation and management costs reduce by the factor of *DOM*, which is the *decrease rate* on OM_1. Following years, OM_t only depends on the inflation rate (*INF)*.

Revenue (REV). The revenue function has a profound role in generating money from productive use of renewable resources by utilizing *levelized cost of electricity* (LCOE), *weighted average cost of capital* (WACC), and *marginal profit* (MP) table. First, LCOE, sub-function of REV, is the sum of the net present values of $OPEX_t$ over the lifetime divided by the sum of the net present values of NEO_t over the *lifetime*. This equation is given as shown in Equation 6:

$$LCOE = \frac{\left(\sum_{c=0}^{m} \frac{CAPEX_c}{(1+WACC)^c} + \sum_{t=0}^{n} \frac{OPEX_t}{(1+WACC)^t}\right)}{\sum_{t=0}^{n} \frac{NEO_t}{(1+WACC)^t}} \tag{20}$$

where m is equal to *construction period – 1*, and n represents the lifetime of PP. WACC denotes the weighted average costs of *loan share (LS)* times interest rate (cost of debt) and *equity share (ES)* times the *cost of equity (CE)*. This cost ratio is defined as shown in Equation 7:

$$WACC = LS \times LIR + ES \times CE \tag{21}$$

where *LIR* indicates the interest rate of the financing power plant. The sum of *LS* and *ES* is equal to 1, and they cannot be less than zero.

After calculating WACC and LCOE, the REV can be computed as shown in Equation 8:

$$REV_t = LCOE \times MP_t \times NEO_t \ , \qquad t = 1, \ldots, lifetime \tag{22}$$

where MP_t represents the values of the marginal profit table for each year.

6.3.2.2. Depositor/Investor (DI) agent-type

The depositor/investor plays a crucial role in providing capital resources. This study designs two agent population from DI agent-type namely *individuals* and *large enterprises*. We assume that the individuals (IN) consist of 100 thousand agent population from people, micro and small enterprises governed and owned independently by the citizens. The large enterprises (LE) comprise a ten-agent population from large corporate and private entities. These agents from IN and LE population can deposit their savings into the bank agent, or invest through *equity-based financial intermediary (EBI)* agent. They can perform both actions at the same time, or keep their money in their safe. Therefore, LE and IN have three time-dependent variables, in which they can save their money, namely *bank pool (BP), EBI pool (EBIP),* and *safe pool (SP)* of the related agent. The bank pool represents the savings deposited in the bank, EBI pool stores the capital resources in EBI for future investments, and safe pool keeps the money as the mattress money. For the sake of simplicity, we assume that these saving pools (i.e., bank, EBI, and safe) in each population (IN and LE populations separately) has a uniform distribution in each time step. For example, if the total bank pool of *IN* population stores $100 000, then each has $1 in his bank pool due to uniform distribution and 100 thousand population. As a proof of concept, this assumption enables the calculation of wealth inequity by Gini index over simulation time.

6.3.2.3. Loan agent-type

The loan agent-type plays a profound role in financing the power plants. While creating a PP agent, in the initial stage, PP communicates with the *bank* agent to be financed by a *loan* agent. This stage is called agreement between the bank and powerplant to create loan agent with the *loan amount (LA)*, *loan interest rate (LIR)*, and *loan period (LP)*. The LA denotes the loan demand defined by the *loan share (LS)* of the *overnight capital cost (OCC) as in the equation, LA=OCC×LS*. The OCC is a constant value of the PP, and LS represents the environmental constant.

6.3.2.3.1. Functions of loan agent

Set lending. The loan agent lends the required amount for the construction during each year of the construction period (CP) of the PP agent (see Equation 9). In this period, the loan agent shifts the installments to the initial year of the electricity generation; thereby this time interval is called the grace period. Afterward, the loan initiates the payback period of installments until the end of the loan period.

$$Lending_t = \begin{cases} \frac{LA}{CP}, & t = 1, \dots, CP \\ 0\ , & otherwise \end{cases} \tag{23}$$

Calculate installment amount. This function calculates the *annual installment payment (PMT)* as shown in Equation 10:

$$PMT = \frac{LIR}{1 - (1 + LIR)^{-LP}} \times LA \tag{24}$$

Calculate future value. This function computes *the future values (FV)* of the outstanding debt amount for each year. The outstanding debt denotes the subtraction of paid installments from the total loan amount. The FV is shown as shown in Equation 11:

$$FV_t = LA \times (1 + LIR)^t - PMT \times \frac{((1 + LIR)^t - 1)}{LIR}, t = 0, \dots, LP - 1 \tag{25}$$

Calculate interest collection. The *interest payments (IPMT)* designate the interest earning over the future values of the outstanding debt for each year during the loan period, which is shown as shown in Equation 12:

$$IPMT_t = FV_t \times LIR, \qquad t = 0, \dots, LP - 1 \tag{26}$$

Calculate principal collection. The *principal payments (PPMT)* is obtained by the subtraction of the IPMT from PMT, which is shown as shown in Equation 13:

$$PPMT_t = PMT_t - IPMT_t, \qquad t = 0, \dots, LP - 1 \tag{27}$$

Set payback. This function communicates with the power plant and the *bank* agent (explained in the following subsection) to collect PMT amount from the PP agent and deposit this payment back to the bank by decomposing it to the IPMT and PPMT.

6.3.2.4. Bank agent-type

The bank has a significant role in evaluating a conventional financial system. This study assumes that the bank agent is a simple financial intermediary according to the theories of banking structure. The financial intermediation theory (FIT) considers a bank just as a non-bank financial institution, the only difference is the main activity of banking that is the depositing and lending business. Therefore, the banks in the FIT differ from the banks in the fractional reserve theory and the credit creation theory by having no power to create money out of nothing (Werner 2016).

This study assumes that there is only one bank in the environment of simulation. This assumption is based on financial localization and no competition between banks. In detail, we consider a closed economic system thereby capital resources are limited to geographical location. Therefore, there is not enough resources and need to establish a second bank. In this regard, there is no competition due to the monopoly of the banking system. However, we assume that this bank can communicate with the agents out of the environment thereby it can utilize the idle cash in money pools, which is called the *bank liquidity (BL)*, by lending to the interbank lending market outside of the environment. It is worth to note that the large enterprises and individuals cannot reach out of the environment such as another bank or another agent to deposit or lend their savings.

6.3.2.4.1. Functions of bank agent

The bank operates with three stock variables namely *large enterprise money pool (LEP)*, *individual's money pool (INP)*, and the *bank profit pool (BPP)*. The LEP and INP not only store the savings of large enterprises and individuals but also deposit the interest issued by the bank for the savings. The central bank requires the reserve deposit from the bank that is the share of the bank liabilities. In return, the central bank pays interest on the reserve by the *interest of the required reserve*. The BPP represents the interest earnings from the central bank and the interbank lending market (which provides interest to the bank in return for lending idle bank liquidity). Furthermore, these money pools (LEP, INP, and BPP) can be reduced by the withdrawals for investment and be increased by profit deposits from the power plant. These actions are conducted by several functions as follows.

Set depositor interests. The bank pays interest for the savings of the large enterprises and individuals by a *prime-deposit interest rate (PDI)* and a *default-deposit interest rate (DDI)*, respectively. The reason why we distinguish the PDI and DDI is that of a common practice in the banking system because the population of the large enterprises is less and their deposits much more than individuals. Therefore, the bank might set a lower rate for the DDI since the operational cost of individuals for the bank is higher than the large enterprises.

Set bank profit. This model enables the bank to utilize the idle deposits by the interbank lending market out of the environment. This access is not possible for individuals and large enterprises because this market is outside of the environment. As a proof of concept, we assume that the bank lends the idle money to the interbank lending market annually by the *central bank rate (CBR)*. The idle money represents the *bank liquidity (BL)* which is the remaining cash after depositing the reserve amount to the central bank by *the interest of required reserves (IORR)* and providing loans to the PPs.

Set profit deposits (SPD). The power plant generates profit out of the revenue for the project developer and the shareholders. This model enables the DI agents (LE and IN agents) to store the profit value in their *bank pool (BP)*, *EBI pool (EBIP)*, or *safe pool (SP)*. This function assigns the value in the BP of the LE and IN agents to the LEP and INP of the bank agent, respectively. The project developer (DEV) is the object variable of the environment that represents which agent (the bank, LE, IN, or equity-based intermediary) is responsible for building a power plant. In return, The DEV might have a profit share in the project without any capital investment. If the DEV agent's BP pool is greater than zero for a year, then this value will also be assigned to the related money pool in the bank agent (i.e., LEP, INP, and BPP).

Set withdrawals for investment. This function enables and operates the withdrawals for the investment of the building a power plant by the LE, IN, equity-based intermediary, or the bank itself. The withdrawals indicate the subtraction of the investment amount from the related money pool. Put differently, the large enterprises and individuals can take the required amount out from their pool in the bank, when they invest for a power plant.

Set reserve amount. The bank agent has a *reserve pool (RV)* that is a stock variable to fulfill banking regulation. This regulation requires that each bank deposits the reserve amount, which is a share of the bank liabilities, to the central bank. In return, the central bank pays interest on the reserve by the *interest of the required reserve (IORR)*. The *reserve share (RS)* is a constant of the environment.

6.3.2.5. Equity-based financial instrument (EBIS) agent-type

The EBIS agent plays a central role in developing alternative financing models for the building of a power plant. Initially, a new PP agent interacts with the *equity-based financial intermediary* (EBIN), explained in Section 6.3.2.1, to make an agreement for the fundraising of the capital expenditures. If the EBIN has the liquidity, or able to fundraise from the LE and IN agents, to invest in a new power plant, then they agree with the message-passing algorithm. In this case, the EBIN creates the EBIS agent for the investment of a new power plant. The investment represents the *equity amount (EA),* $EA = OCC \times ES$, where the OCC denotes the overnight capital cost of the power plant. The ES is a constant value of the environment.

6.3.2.5.1. Functions of the EBIS agent

The investment policy, defined in the environment, forms the shareholder structure of a power plant. This structure includes the ordered list of the shareholders and the corresponding upper bounds of each one of the participants. The ordered list is a prioritized collection of the IN, LE, EBIN and the BANK agents. The *upper bound* ($UP_{IN, LE, EBIN, Bank}$) indicate that each agent in the ordered list can participate in the project of power plant up to the certain corresponding limit, even if this agent has more liquidity than the upper bound. The EBIS agents calculate the fundraising amount and the holding ratios under the investment policy. To this end, this agent-type contains the following functions, namely *"set investments"* and "*set shares"*.

Set investments (F-SI). This function consists of four stages in obtaining the investment values of the project participants. First, the EBIS interacts with the shareholder agents (i.e., the LE, IN, EBIN, and the BANK) to receive their *liquidity* ($LQ_{IN, LE, EBIN, BANK}$). In the next step, the F-SI calculates the amount of participation limit (henceforth interchangeable with the *upper limit*, $UPL_{IN, LE, EBIN, Bank}$) for each agent by the upper bound and the equity amount as shown in Equation 14:

$$UPL_{IN,LE,EBIN,Bank} = EA \times UP_{IN,LE,EBIN,Bank} \quad (28)$$

where the EA (equity amount) is the initialization value of the EBIS.

In the following stage, the investment amount for each agent is obtained by comparing the agent's liquidity with the upper limit amount (see Equation 14). If the liquidity of an agent is greater than or equal to the upper limit of the agent, then the investment amount (INV) is assigned as the UPL; otherwise is the LQ as shown in Equation 15:

$$INV_a = \begin{cases} UPL_a \ , & LQ_a \geq UPL_a \\ LQ_a \ , & otherwise \end{cases} \quad , \quad a = \{IN, LE, EBIN, BANK\} \quad (29)$$

In the last step, the F-SI divides the investment amount for each agent into the agent's money pools. In other words, an agent can invest in a power plant, as much as the level of its liquidity and the UPL, by taking this investment amount out of the EBIP, SP, and BP (i.e., EBIN, safe, and bank money pools). For instance, let us assume that the LE agent has \$10 million breaking into \$800 thousand, \$200 thousand, and \$9 million in the EBIP, SP, and BP, respectively. Also, the UPL of the LE is \$5 million according to the investment policy. In this case, the LE takes \$800 thousand, \$200 thousand, and \$4 million out of the EBIP, SP and bank pool in order, as stated by the policy.

The terminology, before the investment equations, is presented as shown in Equation 16, 17, and 18:

$$LQ_a = LQ_{a,p_1} + LQ_{a,p_2} + LQ_{a,p_3} \ , \qquad p = \{O(EBIP, SP, BP)\} \tag{30}$$

$$INV_a = INV_{a,p_1} + INV_{a,p_2} + INV_{a,p_3} \tag{31}$$

$$INV_a \leq LQ_a \tag{32}$$

where $a = \{IN, LE, EBIN, BANK\}$ represents the agents, $O()$ is the ordering function that arranges the sequence of the pools according to the policy, which is defined in the environment. In this regard, $INV_{a,p}$ denotes the investment amount from the pool p of the agent a. Also, $LQ_{a,p}$ stands for the liquidity in the pool p of the agent a. This step's equations ($INV_{a,p}$) are shown as shown in Equation 19, 20, 21:

$$INV_{a,p_1} = \begin{cases} INV_a, & INV_a \leq LQ_{a,p_1} \\ LQ_{a,p_1}, & INV_a > LQ_{a,p_1} \end{cases} \tag{33}$$

$$INV_{a,p_2} = \begin{cases} 0, & INV_a \leq LQ_{a,p_1} \\ INV_a - LQ_{a,p_1}, & LQ_{a,p_1} < INV_a \leq LQ_{a,p_1} + LQ_{a,p_2} \\ LQ_{a,p_2}, & INV_a > LQ_{a,p_1} + LQ_{a,p_2} \end{cases} \tag{34}$$

$$INV_{a,p_3} = \begin{cases} 0, & INV_a \leq LQ_{a,p_1} + LQ_{a,p_2} \\ INV_a - LQ_{a,p_1} - LQ_{a,p_2}, & LQ_{a,p_1} + LQ_{a,p_2} < INV_a \leq LQ_a \end{cases} \tag{35}$$

Set shares (F-SS). This function calculates (i) the investment share of an agent, and (ii) the investment share of an agent's money pool with respect to the agent's total investment. First, the F-SS computes the participation shares of the agents by dividing the agent's investment into the total investment in a power plant (see Equation 22). These investment shares are employed to determine the shares of profit distribution. In other words, the project participants (i.e., the IN, LE, EBIN, and BANK) earn the profit generated by the power plants according to the investment shares of the agents, $SINV_a$. This equation is shown as shown in Equation 22:

$$SINV_a = \frac{INV_a}{INV^{pp}} \ , \qquad a = \{IN, LE, EBIN, Bank\} \tag{36}$$

where INV^{pp} represents the total investment of a power plant.

Second, the F-SS obtains the investment shares of an agent's money pools by dividing the investment amount out of each money pool into the agent's total investment. For instance, the LE takes, as the same values in the example above, $800 thousand, $200 thousand, and $4 million out of the EBIP, SP, and bank pool. Then, investment shares of each pool ($SINV_{a,p}$) are 16, 4, and 80 percent, respectively. These values, as shown in Equation 22, are employed to obtain the future profit deposits in the pools.

$$SINV_{a,p} = \frac{INV_{a,p}}{INV_a}, \qquad \begin{array}{l} a = \{IN, LE, EBIN, Bank\} \\ p = \{EBIP, SP, BP\} \end{array} \tag{37}$$

6.3.2.6. Equity-based-intermediary (EBIN) agent-type

The EBIN agent-type plays a profound role in delivering policy implications for more sustainable financing. The equity-based financing balances the deb-based financing by sharing risk with the project developer instead of transferring the entire risk into the project developer, as in the conventional banking. In return, the equity-based financing offers more profit than the deposit interest in the debt-based financing because of carrying more risk. However, this study eliminates the potential risks by the government guarantee. In the initial stage of the project, the government signs *power purchasing agreement (PPA)* with the project developer, thereby the risk is removed from the project developer and transferred to the government. Therefore, the future cash flows of a power plant substitute for the potential risk of the investment. In other words, the PPA serves as collateral for the project. Meanwhile, this model implements the PPA by *the government agent (GA)*.

The conventional banks, first, evaluate the investor's financial risk status by analyzing the past credit score from the credit bureau. The individuals, micro and small enterprises show a lack of creditworthiness because they usually do not have any credit score at all, or they have poor risk scores due to the liquidity problem of the SME. Therefore, the credit score leads the banks to lend mostly to the large enterprises because they have low financial risk and high creditworthiness score. In this case, the individuals, micro and small enterprises encounter the capital resource scarcity. This fact is a problem which leads to economic inequity in the short run and social inequity in the long run. As a result, this system makes the rich richer, and the poor poorer. The ultimate consequence of economic and social inequity might be social unrest, violence, political chaos, and even war (Piketty 2014).

6.3.2.6.1. Functions of the EBIN agent

Set profit deposits (F-SPD). The shareholders receive profit over the power plants according to the investment shares of agents, $SINV_a$. There are two layers to distribute total profit ($P_t,\ t = 1 \dots Lifetime$), which is the aggregated value over the power plants annually. First, this function calculates the agent profit ($AP_{a,t},\ a = \{IN, LE, EBIN, BANK\}, t = 1 \dots Lifetime$) by multiplying the investment shares by the total profit in a year. Here, the EBIN profit, $AP_{EBIN,t}$, is the net profit that is the remaining amount of the EBIN's gross profit after transferring *the foundation's profit* (FP_t) to the foundation pool, which is explained below. The FP_t is obtained by multiplying the EBIN's gross profit by the *foundation profit share* (FPS), $FP_t = AP_{EBIN,t} \times FPS$ where FPS is the environment constant. Second, the F-SPD distributes the profit values of each agent into the corresponding money pools (see Equation 24) by multiplying the investment share of the pool, $SINV_{a,p}$, by the agent profit, $AP_{a,t}$.

$$AP_{a,p,t} = SINV_{a,p} \times AP_{a,t}\,, \qquad \begin{array}{c} a = \{IN, LE, EBIN, BANK\} \\ p = \{EBIP, SP, BP\} \\ t = 1 \ldots LT \end{array} \tag{38}$$

The foundation pool is an account to deposit the excess money of the EBIN according to the investment policy. The excess money is a surplus amount that is more than the authorized investment of the EBIN. In other words, the investment policy authorizes the EBIN to invest in a power plant up to a certain limit. Beyond this limit, the excess money is transferred to the foundation pool. Depending on the policy, this model enables to utilize the FP for the benefit of the public such as for social venture capital and public infrastructure (i.e., education and health facilities, bridges, railways, highways and so on).

Set withdrawals for investment (F-SWI). This function subtracts the necessary amount for the investment of an agent, INV_a, from the money deposit in the EBIN of the corresponding agent, $EBIP_a$. In other words, this function withdraws the necessary money for the investment of an agent and invest this amount in a power plant. In this regard, there are two cases to decide the money withdrawals for the INV_a. First, if the $EBIP_a$ is sufficient for the investment, then the F-SWI takes out the INV_a amount from the $EBIP_a$. Otherwise, if it is not sufficient, then the F-SWI withdraws the whole money from $EBIP_a$. In this case, *the fundraise function (F-F)* raises the remaining part of INV_a from agent's other money pools namely the SP and the BP.

Fundraise (F-F). This function fundraises the remaining amount out of the withdrawals from the $EBIP_a$. The F-F interacts with the other DI agents (IN, LE, BANK) to raise the necessary money from the agent's money pools, other than $EBIP_a$ pool, which are the SP and BP for the IN and LE agent, and the BPP for the BANK agent.

6.3.2.7. Government agent-type

The government plays a vital role in balancing social and economic inequity. The GA provides incentives for building a power plant by prioritizing the individuals, micro and small enterprises. This prioritization is the backbone of the model's investment policy. The government is responsible for regulating the policy by employing the environment variables.

There exist several essential incentives, along with the prioritization of the IN agent-type, that are power purchasing agreement (PPA), land concession, and tax exemption. The PPA is an agreement between the government and the project developer stating that the government purchases whole the electricity produced by power plants. The EBIN recognizes the PPA as risk protection from the electricity market turmoil, and The BANK considers the agreement as collateral. It is important to note that this study assumes that the government incentivizes equity-based financing by compensating price discrepancy in favor of equity-based funding. Under this assumption, the government always sells electricity at a fixed price, although the levelized cost of electricity changes for the government by different shares of loan and equity. In addition, this study focuses on wealth distribution under different policy settings without any intervention on income and wealth by the government, thereby income and wealth taxations are out of scope.

A land concession is a place granted for building a power plant. The tax exemption is tax relief for the investors, subject to selling electricity generated by the power plants. In return, the government can receive the following environmental, economic, and social benefits as a result of this policy implementation and incentives. First, this model, which is implemented in renewable energy plants, brings environmental benefits by reducing

CO_2 emissions. Next, economic benefits fulfill more equitable income through society, reduces debt dependency on energy security, and provides more individual participation. Last, this financing model delivers more social equity by exploiting the foundation pool to invest in human capital development, public infrastructure, and social venture capital.

6.3.2.8. Environment

The environment is a top-level agent that contains all agents explained above in the simulation. In this study, the ENV runs the agent-based model and the computer simulation by the variables and constants as follows.

Equity share (ES). Equity share indicates the investment share of capital expenditure in a power plant. The EBIN agent calculates the total investment amount by the equity share. In other words, the equity amount (henceforth interchangeable with investment amount) is $EA = OC \times ES$, where OC represents the overnight capital cost.

Loan share (LS). Loan share represents the debt percentage of the overnight capital cost that is borrowed from the BANK by the SPV of a power plant. The SPV computes the loan amount (LA) by $LA = \mathrm{OC} \times \mathrm{LS}$. It is worth to mention that the sum of equity and loan share is equal to 1, $\mathrm{ES} + \mathrm{LS} = 1$.

Initial capital (IC_a). The IC_a is a constant array that indicates the initial capital of the IN and LE agents in the simulation start, where a={IN, LE}. These agents are not only able to deposit the savings into the BANK and EBIN agent, but also can keep their money, to some extent, in the safe pool, SP.

Capital deposit share ($CDS_{a,p}$). This constant-array defines the initial deposit shares of the money pools (p={EBIP, BP, SP}) for each agent (a={IN,LE}). For instance, let us assume that $CDS_{IN,BANK} = 0.8$, then the individuals deposit the 80 percent of their initial capital into the BANK at the beginning of the simulation. In the meantime, it is worth to mention that the model establishes the BANK and EBIN at the beginning of the simulation, thereby they only have the money deposits from the IN and LE. In other words, they do not have any profit or interest earnings from the previous transactions in the beginning.

Profit deposit share ($PDS_{a,p}$). The profit deposit share denotes the profit shares of the money pools (p={EBIP, BP, SP}) for each agent (a={IN,LE}). The *profit distribution function ($F\text{-}PD_{a,p,t}$)* employs the $PDS_{a,p}$ to divide the total profit amount into the separate money pools for each agent in every year. For instance, under the assumption of $DS_{IN,BANK} = 0.8$, the individuals deposit the 80 percent of their profit income, from the power plants in a year, into the BANK.

Project developer (DEV). This model assigns one of the agents (IN, LE, EBIN, and BANK) to the DEV object-variable. Project developer might take profit share in the exchange of the responsibilities of building and managing a power plant.

Project developer share (DEVS). Project developer can participate in profit distribution as a shareholder without capital investment because the DEV is responsible for building and managing the project. The DEVS represents the project developer's profit share which is *preference share*. Preference shares are shares of a power plant with dividends that are paid out to the preferred shareholder (i.e., DEV) before common stock dividends for other agents are issued.

Equity intermediation share (EIS). In return for only raising fund, the EBIN has preference share in profit distribution that is the operating profit of the intermediary. This profit is allocated by the equity intermediation share, which corresponds to profit for the EBIN and funding cost for the shareholders. The EBIN can also receive profit apart from the intermediary share by investing in a power plant with the money it owns.

Foundation share (FS). This constant represents the foundation share of the EBIN's gross profit. The EBIN transfer the foundation amount to the foundation pool, which is calculated by multiplying the gross profit by the foundation share.

Shareholder list (SL). The shareholder list plays an important role in prioritizing the shareholders by assigning the agents (IN, LE, EBIN, BANK) in an ordered list. The EBIN decides the investment shares in order according to the shareholder list, which corresponds to the prioritization of the agents under the investment policy. For example, under the assumption of SL={O(IN,EBIN,LE,BANK)}, the EBIN raises the investment fund by collecting the money from the IN, EBIN, LE, and BANK in order.

Shareholder upper bound (SUP_a). This upper bound indicates that the shareholders can invest in a power plant up to a certain limit as a share of the overnight capital cost, which is shareholder upper bound. In other words, the EBIN collects money from the first agent in the shareholder list up to the first agent's SUP_a of the overnight capital cost. If the collected amount reaches to the limit, then the EBIN seeks the remaining amount in the second of the shareholder list, and this procedure continues up to the last agent in the list.

Carbon intensity (CI_{pp}). The CI_{pp} denotes the life cycle emissions of carbon intensity for an energy plant powered by natural gas (NG) and solar farm (SF), separately, where $pp = \{NG, SF\}$ represents the set of power plants.

6.3.2.8.1. Functions of the environment

Calculate illiquidity. The illiquidity assets play a key role in computing the wealth and thereby comparing the proposed policies with conventional financing policies. The illiquidity is equivalent to the total present value of the future profits of the remaining years from the lifetime of powerplants. However, we assume that the illiquid asset of the shareholders for each year in the construction period is assigned to a value that is the present value of the first year of operation divided by the construction years.

$$illiquidity_{p,t} = \begin{cases} \dfrac{PV_1}{CP}, & t \leq 0, \quad t = -CP + 1, \ldots, lifetime \\ \displaystyle\sum_{i=t}^{lifetime} PV_i\,, & t > 0 \end{cases} \tag{39}$$

where PV_i represents the present value of the future profit of the power plant p for year i, and CP denotes the construction period in years. In the meantime, PV_i employs the inflation rate as a discount rate for year i. The illiquidity is distributed into the agents as in Equation 10.

$$illiquidity_{a,p,t} = illiquidity_{p,t} \times SINV_a, \quad a = \{IN, LE, EBIN, BANK\} \tag{40}$$

where $SINV_a$ represents the investment share of the agent a. Henceforth, we can calculate the total illiquid assets of an agent (i.e., IN, LE, EBIN, and BANK) at time t as shown in Equation 11.

$$TILQ_{a,t} = \sum_{i=1}^{\#\ of\ power\ plants} illiquidity_{a,i,t} \quad (41)$$

where $TILQ_{a,t}$ represents the total illiquid assets of an agent a at time t.

Calculate Gini index. The Gini index plays a primary role in evaluating new policies and comparing the proposed financing models with conventional financing models in terms of wealth inequality. This study computes the Gini by taking a half of the relative mean absolute difference. The mean absolute difference represents the average absolute difference of all pairwise wealth of the entire population, and then the relative mean absolute difference is calculated as the mean absolute difference divided by the average. In this regard, the Gini is shown as follows.

$$gini = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|y_i - y_j|}{2n\sum_{i=1}^{n} y_i} \quad (42)$$

where y_i is the wealth of entity i (individual, large enterprise, bank, or EBIN), and there are n entities. This study can simplify the summation in Equation 25 because of the assumption of uniform distribution of liquidity (and thereby illiquid assets) within the populations (individuals and large enterprises). First, this uniformity enables us to calculate each entity's wealth in each group (individuals, large enterprises, bank, and EBIN) that is shown in Equation 25, 26, 27, and 28.

$$y_{IN} = \frac{TA_{IN}}{Population_{IN}} \quad (43)$$

$$y_{LE} = \frac{TA_{LE}}{Population_{LE}} \tag{44}$$

$$y_{Bank} = TA_{Bank} \tag{45}$$

$$y_{EBIN} = TA_{EBIN} \tag{46}$$

where y_{IN} and y_{LE} represents the average wealth for a person and a large enterprise as money pools (and illiquid assets accordingly) are distributed uniformly according to the assumptions. As a reminder, this model consists of two financial intermediaries namely the bank and the EBIN, thereby their average wealth, y_{Bank} and y_{EBIN}, are equal to their total assets. TA_{IN} and TA_{LE} corresponds the total assets, sum of liquid and illiquid assets, for individuals and large enterprises. Next, we calculate the pairwise absolute differences of each entity's wealth as in Equation 29, 30, 31, 32, 33 and 34.

$$b = |y_{IN} - y_{LE}| \tag{47}$$

$$c = |y_{bank} - y_{EBIN}| \tag{48}$$

$$d_1 = |y_{IN} - y_{Bank}| \tag{49}$$

$$d_2 = |y_{IN} - y_{EBIN}| \tag{50}$$

$$e_1 = |y_{LE} - y_{Bank}| \tag{51}$$

$$e_2 = |y_{LE} - y_{EBIN}| \tag{52}$$

Afterwards, we simplify Equation 25 that is shown in Equation 35, 36, and 37.

$$\begin{aligned} numerator = {} & Population_{IN} \times Population_{LE} \times b + Population_{IN} \times (d_1 + d_2) \\ & + Population_{LE} \times (e_1 + e_2) + c \end{aligned} \tag{53}$$

$$\begin{aligned} denominator = {} & (Population_{IN} + Population_{LE} + 2) \times (TA_{IN} + TA_{LE} \\ & + TA_{Bank} + TA_{EBIN}) \end{aligned} \tag{54}$$

$$gini = \frac{numerator}{denominator} \tag{55}$$

This study also investigates the scenarios based on non-profit EBIN agent which transfers all the excess money to the individuals through the foundation. In this case, the EBIN's wealth (y_{EBIN}) is employed only for the benefit of the public, thereby we extract y_{EBIN} from the related equations, and the foundation assets are added into individual's wealth as in Equation 38. This change affects the pairwise absolute differences b' and d_1' accordingly as in Equation 39 and 40.

$$y_{IN}' = \frac{TA_{IN} + TA_{FN}}{Population_{IN}} \tag{56}$$

$$b' = |y_{IN}' - y_{LE}| \tag{57}$$

$$d_1' = |y_{IN}' - y_{Bank}| \tag{58}$$

Then, the Gini index transforms into Equation 43 by following Equation 39 and 40.

$$numerator' = Population_{IN} \times Population_{LE} \times b' + Population_{IN} \times d_1' + Population_{LE} \times e_1 \tag{59}$$

$$denominator' = (Population_{IN} + Population_{LE} + 1) \times (TA_{IN} + TA_{LE} + TA_{Bank}) \tag{60}$$

$$gini' = \frac{numerator'}{denominator'} \tag{61}$$

6.3.3. Platform Description

The ACE model is implemented in AnyLogic 8.3. that is broadly employed in multimethod simulation modeling, namely agent-based modeling, system dynamics, and discrete event modeling. In a technical sense, AnyLogic can be run in any operating system supporting Java Virtual Machine (JVM), such as Linux, Windows, and MacOS. Furthermore, AnyLogic enables to embed a custom Java code in an agent-based model. Therefore, it provides a substantially flexible modeling and simulation environment without compromising the robustness and scalability level of the model (Abar et al.

2017). In the meantime, AnyLogic has a user-friendly graphical user interface for visual model development, although the development effort is relatively moderate (Abar et al. 2017).

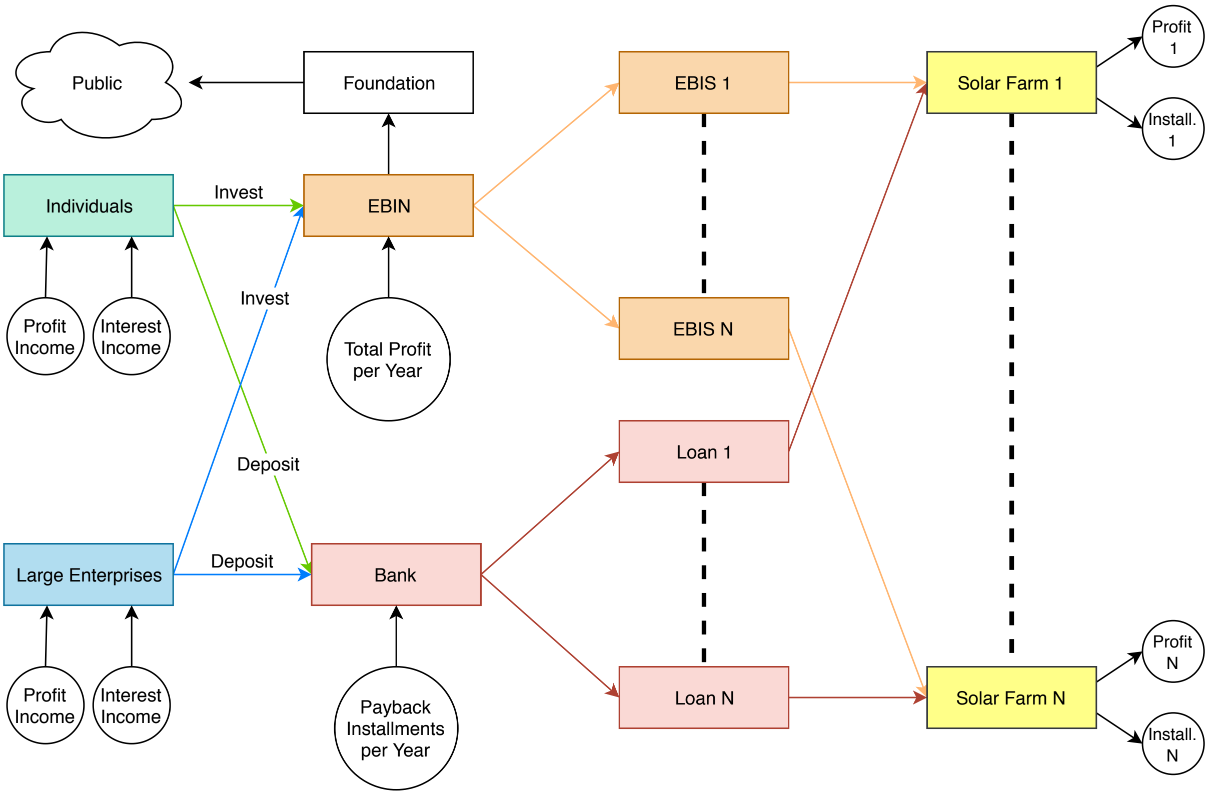


Figure 6.5. Agent-based model structure and agent interactions.

Figure 6.5 shows the agent-based model and agent interactions which represents the communications of agents with each other. The IN and LE agents can be considered as depositors or investors, or both, at the same time. The IN and LE behave as investors while communicating with the EBIN. On the other hand, the IN and LE act as depositors while interacting with the BANK. The EBIN communicates with a power plant (PP) agent through the EBIS agent if the equity share is greater than zero. The BANK interacts with a PP agent through the LOAN agent if the loan share is greater than zero. The EBIN agent communicates with the foundation pool (FP) if the foundation share is greater than zero. The FP reaches out to the public by spending money in public infrastructure, philanthropic purposes, and social venture capital. The FP also enables the proposed model to provide social impact finance.

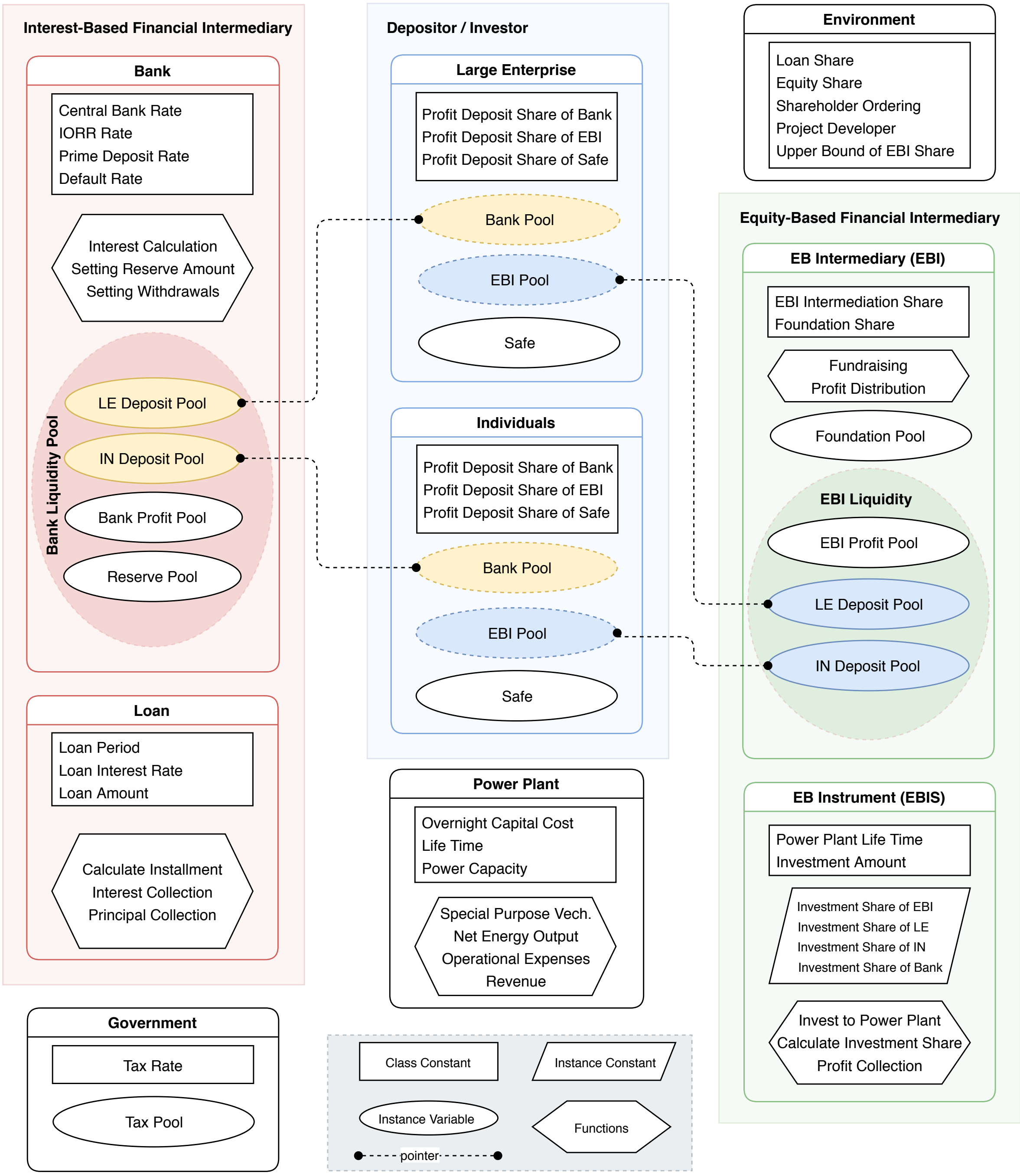


Figure 6.6. Agents along with class and instance constants, variables, and functions in the model.

Figure 6.6 shows the main constants, variables, and functions in the agent-based model of financing power plants. The class-constants represent the same value for all instances of a class during the course of the simulation, while instance-constants store the same value for an object instance, not for all instances, during the lifetime of that instance. On the other hand, agent-based models require variables and functions to evolve through behaviors and actions. The pointer in Figure 6.6 is an alias of a variable that accesses a common stack in the memory.

6.3.4. Model Implementation: A Solar Farm in Qatar

Qatar has made limited progress in renewable energy generation despite the great potential for harnessing solar power. Therefore, the current share of renewable energy over the total generation capacity, which is planned to reach 13GW by 2019 (Bayram, Saffouri, and Koc 2018), is negligible (MDPS - Ministry of Development Planning and Statistics 2018). However, the government set quite promising targets to achieve a considerable share in total power capacity and to diversify the energy mix. The targets for renewable power in the first and second-stage are 2% and 20% of total energy production by 2020 and 2030, respectively (REN 21 2017). In line with this, the Ministry of Energy and Industry is developing and implementing a strategy for utilizing renewable energy along with its policy (MDPS - Ministry of Development Planning and Statistics 2018). In addition, a group of researchers from Kahramaa, which is Qatar general electricity and water corporation, has developed a solar farm project, along with the feasibility and geographic location, with the collaboration of Hamad Bin Khalifa University (HBKU) as a capstone project (Al-Aali and Bughenaim 2018). In this study, we adopted their project's input data and assumptions for the technical part of the powerplant agent (see the powerplant part of Table 6.2). Also, Table 6.2 summarizes all the inputs and assumptions in this study. It is important to note that the project developer and the government sign a power purchasing agreement, which is a legal contract stipulating that the government buys the whole electricity generated by the powerplant during the lifetime.

Table 6.2. Configuration of the experiment on the agent-based model

Agent	Variable	Abbreviation	Unit	Value
Power Plant[1]	Overnight capital cost	OCC	QAR[2]	766,500,000.00
	Lifetime	LT	year	25
	Construction period	CP	year	2
	Power capacity	CAP	MWp	300
	Energy yield	EY	MWh/MW	1655
	Estimated O & M cost	OMC	QAR	29.2
	Decrease rate of O&M (first yr)	DOM	-	0.01
	Rate of plant availability	RPA	-	0.99
	Degradation factor (first year)	DF1	-	0.03
	Degradation factor (others)	DFX	-	0.002
	Land lease	LL	QAR	0
	Rate of asset management cost	RAM	-	0.30
	Rate of insurance cost	RIN	-	0.15
	Rate of other expenses	ROE	-	0.15
Depositor/Investor	Initial capital (IN)[3]	IC_{IN}	QAR	766,500,000.00
	Initial capital (LE)[4]	IC_{LE}	QAR	1,766,500,000.00
	Population (IN)[5]	POP_{IN}	people	100,000
	Population (LE)[6]	POP_{LE}	people	10
Loan	Interest rate	LIR	-	0.04
	Loan period	LP	year	10
	Grace period	GP	year	LT
Bank	Central bank rate	RCB	-	0.0225
	Interest of required reserves	IORR	-	0.0220
	Prime-deposit interest rate	RPD	-	0.0105
	Default-deposit interest rate	RDD	-	0.0095
Environment	Carbon intensity (NG)[7]	CI_{ND}	g CO2eq/kWh	46
	Carbon intensity (Solar)[7]	CI_{Solar}	g CO2eq/kWh	469
	Construction frequency[8]	CF	year	2

Notes: 1. The inputs of power plant agent are adopted from a capstone project conducted in HBKU (Al-Aali and Bughenaim 2018).

2. The Qatari riyal is pegged to the US dollar at a fixed exchange rate of $1 USD = 3.65 QAR.

3. This is an assumption to have this much amount of money. In this way, individuals are able to build the first powerplant by their own money.

4. This assumption enables large enterprises to build the successive powerplants by their own money (incorporating the profit earned from the installed powerplants).

5. Gini coefficient requires the population data to calculate wealth inequity in the society. We assume a closed region, which means there is no death and giving a birth during the simulation time, with a 100 thousand individuals including micro and small enterprises.

6. According to the business population estimates (Strategy Department for Business - Energy and Industrial 2017)*, large enterprises constitute 0.1 percent of the population. Therefore, we assume the population of large enterprises as a ten, accordingly.*

7. According to the Intergovernmental Panel on Climate Change (IPCC), which is the leading international body for the assessment of climate change, the median values of CO_2 emission for solar PV farm 46 g CO2eq/kWh while those for natural gas fuel is 469 g CO2eq/kWh (excluding land use change emissions) (IPCC 2012).

8. Construction frequency is the time interval between the construction of two successive powerplants.

6.3.5. *Policy Scenarios*

The simulations run under predefined inputs and assumptions in Table 6.2 and policy variables in Table 6.3. These policy variables are explained in the *Environment* sub-section (3.1.8). They have a significant influence on the simulation results because they affect the wealth accumulation in size (how much wealth will be accumulated) and place (in which agent it will be accumulated). However, this study set these policy variables constant because our goal is to evaluate how the changes in the parameters of the project developer, loan share, equity share, project shares (or shareholder limits), non-profit EBIN, and foundation share will affect the wealth accumulation and Gini index.

Table 6.3. Policy inputs, environmental configuration, of the experiment.

Variable	**Abbreviation**	**Value**
Capital deposit share (pool / IN)	$CDS_{IN,\,p}$	BANK=1.0, EBIN=0.0, SAFE=0.0
Capital deposit share (pool / LE)	$CDS_{LE,\,p}$	BANK=1.0, EBIN=0.0, SAFE=0.0
Project developer share	DEVS	0.15
Equity intermediation share	EIS	0.10

In this study, there exist seven financing scenarios to be evaluated on the solar farm project in Qatar, which are divided into two groups (see Table 6.4). First, we perform three of the scenarios for the comparison purpose against the proposed policies. Second, this study conducts the remaining four of the scenarios by adding a new policy on top of the previous simulations in each step. The comparative analysis and the performance of the policies will be discussed in Section 4. The details of each policy scenario are given as follows.

Table 6.4. Policy scenarios.

	Project Developer	Loan (%)	Equity (%)	Shareholder List [1]	Project Shares [2] [Shareholder Limits]	Non- Profit EBIN[3]	Foundation Share[4]
1	LE[5]	100	0	(LE,Bank,IN,EBIN)	(1.0, 0.0, 0.0, 0.0)	-	-
2	LE[6]	70	30	(LE,Bank,IN,EBIN)	(1.0, 1.0, 1.0, 1.0)	FALSE	0.0
3	LE[5,7]	0	100	(LE,Bank,IN,EBIN)	(1.0, 1.0, 1.0, 1.0)	FALSE	0.0
4	EBIN	0	100	(EBIN,IN,LE,Bank)	(1.0, 1.0, 1.0, 1.0)	FALSE	0.0
5	EBIN	0	100	(EBIN,IN,LE,Bank)	(0.20, 1.0, 1.0, 1.0)	FALSE	0.0
6	EBIN	0	100	(EBIN,IN,LE,Bank)	(0.20, 1.0, 1.0, 1.0)	TRUE	0.5
7	EBIN	0	100	(EBIN,IN,LE) [8]	(0.20, 1.0, 1.0)	TRUE	0.5

Notes: 1. Shareholder list implies the investor list. The shareholder list prioritizes the shareholders by assigning the agents in order (see the sub-section of Environment (3.1.8)).

2. Project shares are only valid for a 100% loan-based scenario because project shares can be only predefined in this setting. In other scenarios, project shares can be determined by the participation shares (investment) of the shareholders in each project. Therefore, shareholder limits are valid for corresponding shareholder list in the other cases (see the sub-section of Environment (3.1.8)).

3. Non-Profit EBIN defines the behavior of the foundation pool that is an account to deposit the excess money of the EBIN according to the investment policy. If it is false, then the EBIN is profit-based enterprise and does not transfer any money to the foundation.

4. The details of the foundation share can be found in the sub-section of the set-profit-deposit function of the EBIN in 3.1.6.1.

5. This scenario is designed for the comparison purposes against the proposed models and a part of sensitivity analysis of the equity and loan share parameters.

6. This scenario is taken as a business-as-usual-case because the large enterprises (project developer) usually own the project with the average of 30% capital investment (Esty 2004)*.*

7. This scenario is not a common practice because large enterprises, project developer, are not usually willing to invest in a project by putting a 100 percent of the equity. In other words, they want to employ their capital as a leverage in minimum level, thereby they usually own the project with the average of 30% capital investment (Esty 2004)*. However, we selected this case due to the comparison purposes of the 100 percent equity-based investments against the proposed policy.*

8. This scenario is a hypothetical case because there is not such a system that the banking is nonexistent. However, we chose this case to show the behavior of the wealth accumulation and Gini index in the case of absence of the banking.

Scenario 1: The policy of Scenario 1 is based on pure loan-based financing of a powerplant, which means that the debt-to-capital ratio is a hundred percent. This scenario is designed for the comparison purposes against the proposed models and a part of sensitivity analysis of the equity and loan share parameters. In this scenario, the project developer is a consortium of large enterprises in the model. Since the project fund is a hundred percent debt-based financing, the predefined project-shares are valid for the shareholders. Therefore, this feature enables us to define large enterprises with a hundred percent share of the project. In this scenario, there is no need to establish the EBIN because of the pure debt-based financing.

Scenario 2: The policy of Scenario 2 is based on a common practice that is a mixed financing of a powerplant. This study considers this case as a business-as-usual case for the comparison purposes against the proposed models because the average of the project companies has a debt-to-capital ratio of 70% and an equity-to-capital ratio of 30% (Esty 2004). In this scenario, the project developer is a consortium of large enterprises. Since the project fund is a mixed financing, the project-shares cannot be predefined as in the pure debt-based financing. This study assumes that the capital investment ratio of the shareholders dynamically determines the project shares in each power plant. In other words, the shareholders will own the powerplant as much as their equity shares that is invested in the project. This feature depends on agent's liquidity and predefined shareholder limits. The shareholder limits indicate that the shareholders can invest in a power plant up to a certain limit as a share of the overnight capital cost, even they have more liquidity. In this scenario, the shareholder limits are (LE,BANK,IN,EBIN) $\rightarrow$ (1.0, 1.0, 1.0, 1.0) that means the LE, BANK, IN, and EBIN can invest in a powerplant up to a hundred percent of the overnight capital cost. Last, there is a need to establish the equity-based financial intermediary, the EBIN, to fundraise required equity amount. This EBIN is a profit-based intermediary, thereby it does not transfer any money to the foundation pool.

Scenario 3: The policy of Scenario 3 is based on a pure equity-based financing of a powerplant, which means that the equity-to-capital ratio is a hundred percent. In this case, the project developer is a consortium of large enterprises. The shareholder list and the corresponding shareholder limits are (LE,BANK,IN,EBIN) $\rightarrow$ (1.0, 1.0, 1.0, 1.0). Since the EBIN is the profit-based financial intermediary, there is no money accumulation in the foundation pool. It is worth to note that this scenario is not a common practice because large enterprises are not usually willing to invest in a project by putting a 100 percent of the equity. However, this scenario is designed for the comparison purposes against the proposed models and a part of sensitivity analysis of the equity and loan share parameters.

Scenario 4: The policy of Scenario 4 is based on a pure equity-based financing of a project, which means that the equity-to-capital ratio is a hundred percent. This part is the same with Scenario 3. However, this study applies a new policy by changing the project developer and reordering the shareholder list. The project developer is altered from the LE to the EBIN. The shareholder list and the corresponding shareholder limits are (EBIN,IN,LE,BANK) → (1.0, 1.0, 1.0, 1.0). This change means that the project developer seeks the required fund from EBIN, IN, LE, and BANK in the order without any share limits. If the first agent does not have adequate capital to invest in total overnight capital cost, then the project developer takes the whole liquidity from the first agent and asks the remaining amount from the next agent in the list. Meanwhile, There is no money transfer from the EBIN to the foundation pool since the EBIN is still profit-based intermediary.

Scenario 5: The policy of Scenario 5 is based on a hundred percent equity-based financing of a solar farm. The project developer and the shareholder list remain the same with Scenario 4. However, the shareholder limits are changed to (EBIN,IN,LE,BANK) → (0.20, 1.0, 1.0, 1.0). This policy change means that the project developer raises the funds first from the EBIN up to the 20% of the overnight capital cost, which is a shareholder limit. Even if the EBIN has more liquidity, it cannot invest more than this limit. Therefore, excessive money, which is earned from the powerplants and intermediation shares, will be accumulated in the EBIN's money pool. Because there is no money transfer from the EBIN to the foundation pool since the EBIN is still profit-based intermediary.

Scenario 6: The policy of Scenario 6 is based on full equity-based financing of a solar powerplant. The project developer, the shareholder list, and the shareholder limits remain the same with Scenario 5. In this policy, the parameters of non-profit EBIN and the foundation share are set to "true" and 50%, respectively. This study applies these conditions in two successive stage. First, the EBIN transfers 50% of its own earnings to the foundation pool up to the reaching the shareholder limit, which is 20% of overnight capital cost. Second, beyond this limit, the whole excessive money is transferred to the foundation pool without considering the foundation share. This study assumes that foundation pool is distributed equally throughout the society in terms of public infrastructure, health centers, education facilities, and so on.

Scenario 7: The policy of Scenario 7 is based on full equity-based financing of a solar powerplant. The only difference from Scenario 6 is that we remove the banking system completely from our simulation model. This scenario is a hypothetical case because there is no such a system that the banking is nonexistent. However, this model enables us to evaluate the behavior of the wealth accumulation and Gini index in the case of absence of the banking. Thus, this case provides a few glimpses to develop a future policy and adjust the existing banking system.

6.4. Results and Discussions

The results of the seven scenarios in financing solar farms in Qatar are shown in Table 6.5, which are divided into the policies for comparison purposes and the proposed policy implications. These results indicate that the investment policy in Scenario 6 based on the proposed model has the best performance compared with the policies in the other six scenarios. This is because Scenario 6 is the optimum policy set among these scenarios in terms of the Gini index minimization and the wealth maximization simultaneously. It is worth note that Scenario 7 becomes deficient in terms of total wealth accumulation, although the Gini index is a substantial low. In environmental aspects, there is a significant decline in carbon emissions at the same level for each scenario. The mitigation of carbon emissions climbs rapidly from around 0.20 million tons to 2.56 million tons of CO_2 equivalent in a year. This much amount of carbon mitigation have obviously a positive effect on the public health and helps the fulfillment of Qatar's environmental commitments (MDPS - Ministry of Development Planning and Statistics 2018). This result shows that this study satisfies the environmental sustainability.

Table 6.5. Results of the seven policy scenarios.

	Policies for Comparison			**Proposed Policy Implications**			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
WA – Bank (QAR in Billions)	15.078	12.056	5.401	4.135	3.684	3.712	0.00
WA – EBIN (QAR in Billions)	0.00	1.792	4.318	19.346	12.296	2.636	2.636
WA – LE (QAR in Billions)	11.352	14.211	23.446	4.573	5.476	5.682	4.212
WA – IN (QAR in Billions)	1.230	1.23	1.23	4.027	10.041	10.041	9.343
WA – FND. (QAR in Billions)	0.00	0.00	0.00	0.00	0.00	9.482	9.482
WA – Total (QAR in Billions)	27.66	29.289	34.395	32.081	31.497	**31.553**	25.673
Gini Index	0.955	0.958	0.964	0.874	0.681	**0.483**	0.311

The total cash accumulations are about QAR 25.5 billion, 26 billion, and 28 billion, respectively, in Scenario 1, 2, and 3 (see Figure 6.7). In these scenarios, the project developer is a consortium of all large enterprises. Therefore, the individuals have a minimal and steady increase in the cash accumulation throughout the simulation time, because they earn only interest on their deposits in the bank. In detail, the individuals do not invest in a powerplant, as can be seen in the illiquid asset accumulation graph, because the project developer raises the required funds without demanding any amount from individuals according to the shareholder list. As for the bank, the trend of cash accumulations is the same, but they reach a peak at different levels in each scenario. The highest levels are around QAR 15 billion, 12 billion, and 5.5 billion, respectively, in Scenario 1, Scenario 2, and Scenario 3. As can be understood from this result, the liquidity accumulated in the bank decreases as the equity share increases for the powerplants. This is because the project developer withdraws more money from the bank to invest more in the powerplants, and the EBIN earns more profit as the financing is more equity-based. It is worth to note that the EBIN does not deposit its profit into the bank. If the debt-to-capital ratio is a hundred percent as in Scenario 1, then the cash accumulation for the EBIN does not occur over the simulation time.

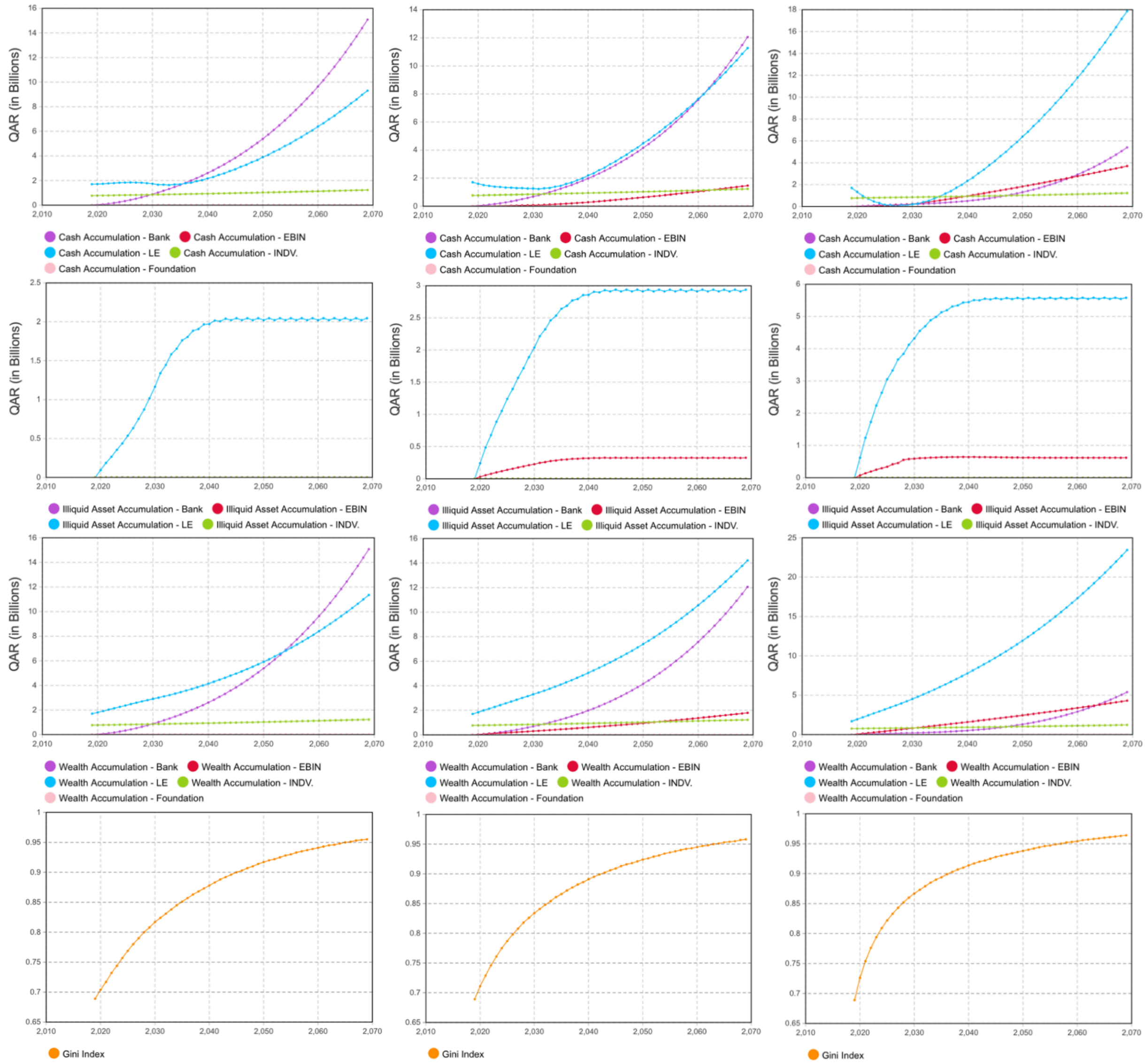
Large enterprises, on the other hand, show different behavior in the cash accumulations of Scenario 1, 2, and 3 because of being the project developer. The liquid assets of the large enterprises reach a peak at different levels in 2069 (simulation's end) as QAR 9.3 billion, 11.3 billion, and 17.9 billion, respectively, in Scenario 1, 2, and 3. This significant increase is because of that the consortium of the large enterprises invests in the powerplants with more equity rising in each successive scenario. Therefore, the illiquid asset accumulation rises according to the increase in equity in the short run, and thereby the liquid asset accumulation also increases in the long run. In Scenario 1, there is a slight fall in the cash accumulation from 2028 to 2032 following a gentle and steady increase. The reasons for this decrease are twofold as follows. First, the loan installments in debt-based financing are greater than the profit between the third and tenth year of the powerplant's operation. Second, the loan installments reach a level in 2028 in which the interest earnings from the cash deposits in the bank and positive net profits cannot compensate the deficits from the paybacks. However, the cash accumulation begins to recover in 2032 right after closing the loan for the first powerplant in Scenario 1. Afterward, the liquid asset for the large enterprises grows rapidly up to the end of the simulation. In Scenario 2 and 3, the cash accumulations again hit a low point in 2031 and 2027 respectively. This is not because of the negative net profit as in Scenario 1 (net profits are positive in these cases), but the withdrawals from the bank for the investment. In other words, this diminishing money is transformed into an illiquid asset to generate more liquid assets. In the meantime, the bank's liquid assets exceed the cash accumulations of large enterprises at 2031 and 2062, respectively, in Scenario 1 and 2. In Scenario 3, the large enterprise's curve, however, stands always higher than the bank's liquid assets.

It is worth to note that negative profits in Scenario 1 can be solved by prolonging the loan period, but this will cause less illiquid asset accumulation (also wealth accumulation), and difficult to compare the results with the other scenarios. Therefore, we set the loan period constant to eliminate discrepancies in the results. Furthermore, this is one of the reasons that the debt-to-capital ratio of 70% is more common practice in the project market (Esty 2004) because the net profit will not be negative in this case.

The results show that the illiquid asset accumulations in Scenario 1, 2, and 3 reach the equilibrium state in 2044, which is equivalent to 25 years from the simulation start. This period is the lifetime of a powerplant. Next, the illiquid asset accumulations are leveled off and remained constant at different levels until the end of the simulation time. These levels are around QAR 2 billion, 3 billion, and 5.5 billion for large enterprises, respectively, in Scenario 1, 2, and 3. There is also a small share of the EBIN in Scenario 2 (QAR 325 million), and Scenario 3 (QAR 620 million) because of the intermediation share. This finding implies that illiquid asset accumulation increases with the rise of equity-based financing, and vice versa. In return, the cash accumulation also grows in the long-run.

The wealth is the sum of the liquid and illiquid assets. The total wealth accumulations are around QAR 27.7 billion, 29.3 billion, and 34.4 billion, respectively, in Scenario 1, 2, and 3 (see Figure 6.7). This result indicates that wealth accumulation increases in each scenario as equity share rises, and vice versa. This is because the illiquid assets generating liquid assets depend on equity participation. In Scenario 1,2 and 3, the bank and individuals accumulate only cash assets throughout the simulation time as can be seen on the graphs of the illiquid asset accumulation. Therefore, the wealth accumulations of the bank and individuals are equivalent to their cash accumulations. The bank's wealth reduces respectively in Scenario 1, 2, and 3, while total wealth is rises in those cases. In Scenario 1, the bank's wealth exceeds the individuals and then large enterprise's wealth whereas it always stands at lower points than the large enterprises in Scenario 2 and 3. This is because, in Scenario 2 and 3, the potential wealth of the bank is transferred to the large enterprises and the EBIN through the investments in illiquid assets as the shares of equity increase in the powerplants. In Scenario 2, the EBIN is always lower than the bank whereas it, however, stands higher than the bank's wealth by 2063 in Scenario 3, and then the bank exceeds the EBIN from that time on.

This study measures the Gini index to evaluate the change in economic inequity and compare the proposed policies with Scenario 1, 2, and 3 (see Figure 6.7). In these scenarios, there is an upward trend in economic inequity over the simulation time. The change becomes sharper in these cases when the equity-shares gradually increase against the loans. This is because the large enterprises, whose population is a ten, accumulate more cash through more illiquid assets due to the being the project developer. In addition, they earn more interest from the bank as they collect and deposit more profit from the powerplants funded by more equity-based financing. These results show that sole equity-based financing, without any policy application, does not benefit in economic and social equity, even it harms more as can be seen in Scenario 3. As a result, the rich become richer and the poor stay poor.



(1) (2) (3)

Figure 6.7. The cash accumulation, illiquid asset accumulation, wealth accumulation and Gini index of (1) Scenario 1, (2) Scenario 2, and (3) Scenario 3.

This study introduces alternative financial models by adding a new policy on top of the previous models in each scenario. This approach forms Scenario 4, 5, and 6, as follows (see Figure 6.8). In Scenario 4, which is based on Scenario 3, there exist two policy change in the parameters of project developer and shareholder list. First, the project developer is altered from a consortium of large enterprises to the EBIN. Second, the model prioritizes the EBIN and then individuals in the shareholder list as in the order of (EBIN, IN, LE, Bank). In Scenario 5, this study applies another policy change, in addition to Scenario 4, that limits the EBIN's investment in the powerplants with 20 percent. In Scenario 6, the model incorporates the foundation pool by changing the EBIN from profit-based intermediation to non-profit-based one. This new policy is expected to reduce social and economic inequity by spending this money on the benefits of the public such as social venture capital and public infrastructure (i.e., education facilities, health centers, bridges, railways, highways and so on). Scenario 7, which is based on Scenario 6, is a hypothetical test case assuming that there is no bank in the financial system. The other parameters are entirely the same as Scenario 6. This case provides evidence to the discussions about the banking system in the literature by evaluating wealth inequity when there is no bank in the model.

In Scenario 4, 5, and 6, the EBIN, project developer, raises the required funds for a power plant by a hundred percent equity-based financing. In these scenarios, the total cash accumulations are about QAR 25.9 billion, 25.3 billion, and 25.4 billion, respectively (see Figure 6.8). There is a little fluctuation in the liquid around the average of QAR 25.5 billion. This value is very close to the liquid asset accumulations in Scenario 1 and 2. In other words, in the proposed models, the cash accumulations stay almost at the same level with the accumulations in Scenario 1 and Scenario 2. However, there is a small difference between Scenario 3 and the proposed models by around QAR 2.5 billion. This is because a consortium of the large enterprises is the project developer in Scenario 3, and the powerplant is funded by the equity-to-capital ratio of a hundred percent. Therefore, the illiquid assets are accumulated in a few hands (the large enterprises and the bank) that causes monopoly; and these much assets in the large enterprises generate more profit in the long run. In addition to this, they deposit more money into the bank because of the more profit, and thereby they also earn more interest on their profit from the powerplants.

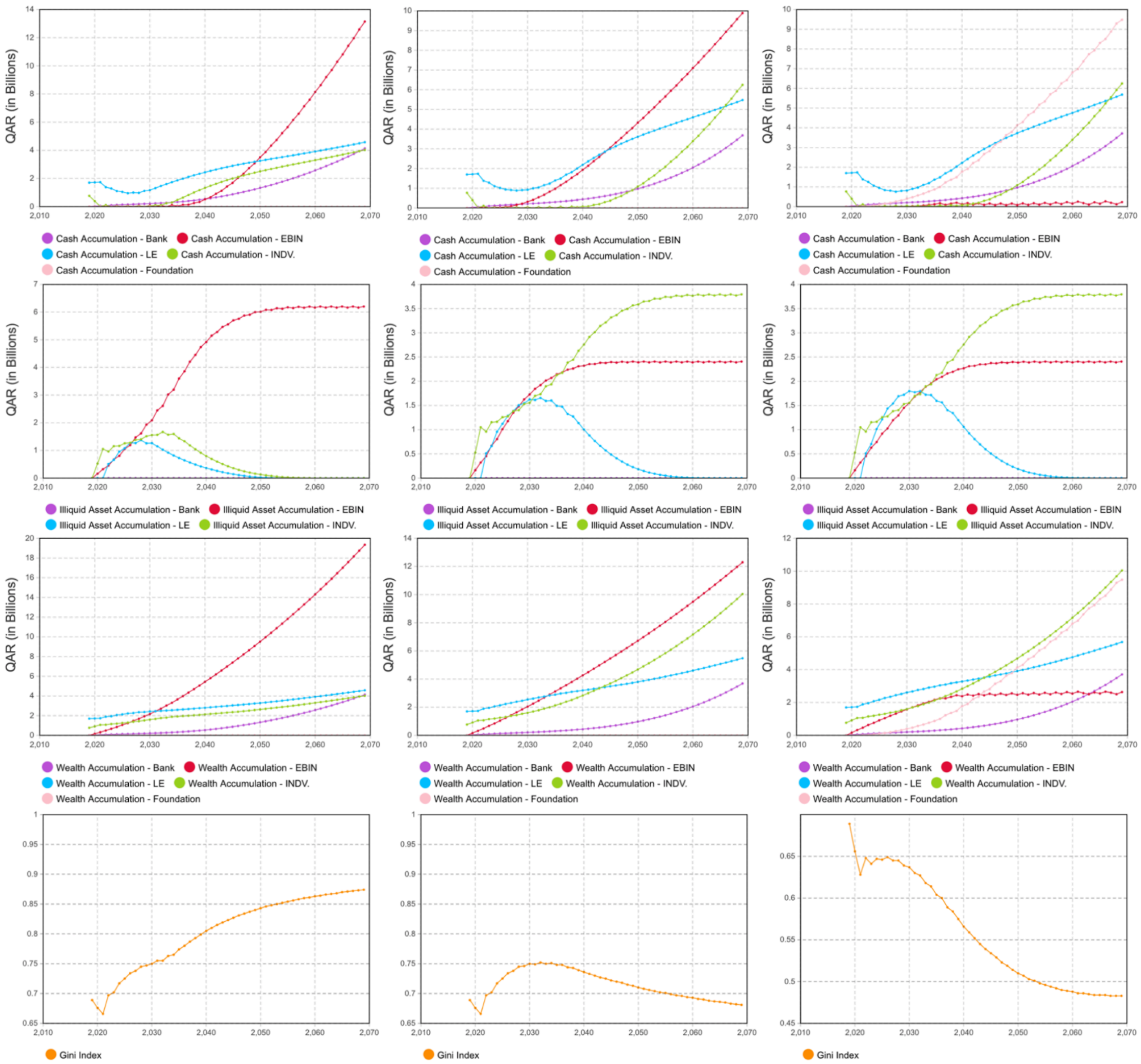
This monopoly, as can be seen in the dramatic increase in Gini index of Scenario 3, incurs an unsustainable financing model and undesired case for the public. None of the proposed models suffers from this much increase in economic inequity.

In Scenario 4, 5, and 6, the illiquid asset accumulations reach the equilibrium state, which is the state that the illiquid assets of all the shareholders remain constant at a certain level, around 2060 (see Figure 6.8). This result shows that the proposed models reach the equilibrium state about 16 years later than Scenario 1, 2, and 3. This is only because the project developer and the order of shareholder list are changed to the EBIN and (EBIN, IN, LE, Bank), respectively, in the proposed policies. The underlying reason for the delay in reaching the equilibrium state is given as follows. The EBIN does not have adequate liquidity to finance a powerplant at the beginning of the simulation, and thereby the EBIN raises the required funds by following the order in the shareholder list. Therefore, the individuals are the first in the list right after the EBIN to finance the powerplant, but they also do not have enough money to build the successive projects. Thus, the EBIN collects the remaining amount from the large enterprises. In each successive project, the EBIN earns profit not only from the intermediation share (10%) and project developer's share (15%), but also from the investment in the project, and thereby the EBIN owns more liquidity to invest in the long run. In the meantime, the individuals also earn profit from the powerplant after transforming their initial liquidity to the illiquid assets, so that they can invest more in future powerplants in the long run. It is worth to remind that the proposed policies prioritize the EBIN and individuals for the fundraising of the powerplant. Therefore, the proposed policies utilize the delay of 16 years to make the EBIN or individuals, or both, self-sufficient for building a powerplant according to the shareholder limits.

In Scenario 4, the cash accumulation of the EBIN reaches a peak at QAR 6.2 billion in 2069, the end of the simulation (see Figure 6.8). However, this liquidity remains constant at zero until 2034 because the EBIN transforms all its earnings from the previous powerplants to the illiquid assets by investing in the following powerplants. After 2034, the EBIN becomes self-sufficient to finance future power plants. Therefore, the liquidity of the individuals, second in the shareholder list, increases while decreasing its illiquidity because the power plants are entirely funded from 2034 on by the EBIN. In the meantime, the illiquidity of large enterprises, third in the shareholder list, begins to decrease in 2028, six years ago from the individuals, because the individuals, along with the EBIN, become sufficient to finance the power plants; thus, that no need to raise any money from the large enterprises. This result also reflects in Gini coefficient. As can be seen in Figure 6.8, the wealth inequity steeply reduces in the first two years of the simulation because individuals have adequate money to invest in the first power plant, which takes two years to construct it. Afterward, the individuals and the EBIN don't have any money to invest in the second powerplant, and thereby the EBIN raises the required amount from the large enterprises. Then, the Gini index begins to rise sharply because wealth again concentrates in a few hands, large enterprises. However, this rise slows down as the share of individuals in the power plants increases until 2034. From 2034 on, the Gini coefficient begins again to rise quickly from 0.765 to 0.874 because the wealth increase of the individuals slows down. Moreover, the EBIN accelerates its wealth accumulation at that period. This is not only because it is the project developer and first in the shareholder list, but also profit-based financial intermediary. This time, the EBIN causes an increase in the wealth inequity instead of the bank in Scenario 1, 2, and 3. Although this rise is not severe as much as in Scenario 1,2, 3, it harms to economy and society.

In Scenario 5, the model proposes a new policy on top of Scenario 4 that limits the share of the EBIN in the power plants at 20 percent. The remaining policy variables are the same as Scenario 4. This limit provides more investment shares than Scenario 4 in the power plants for the large enterprises in the short run and the individuals in the long run. As can be seen in Figure 6.8, the EBIN's liquidity remains constant at zero until 2026 that is a shorter time period as compared in Scenario 4. This is because the EBIN cannot invest in the power plants more than 20 percent, thereby the liquidity begins to increase while illiquidity is decreasing. Therefore, this policy enables to retard the illiquid asset accumulation after 2026 and then limits the illiquidity at QAR 2.4 billion from 2047 to 2069 (the end of the simulation). From 2026 on, the individuals and large enterprises participate more in the construction of power plants. In this scenario, the large enterprises, however, still continue to invest in the power plants from 2028 to 2032 whereas the EBIN does not require to raise any funds from the large enterprises in Scenario 4 during that period. This is because the EBIN cannot invest more than 20 percent and the individuals are not self-sufficient to invest 80 percent of a power plant until 2032. Afterward, the illiquidity of the large enterprises slows down up to 2060 and then remain constant at zero until the end of the simulation. On the other hand, the illiquidity of the individuals reaches a peak at QAR 3.7 billion in 2060, and stay at the same level up to the end of the simulation. These results also reflect the change in wealth inequity, see the Gini index in Figure 6.8. The trend of the wealth inequity is almost the same as Scenario 4 until 2030, although it deviates significantly afterward. From 2030 on, the Gini coefficient begins to decrease from 0.775 to 0.681, which is even less than the initial value of 0.689. This is because the shareholder limit for the EBIN is set to 20 percent and the individuals' liquid and illiquid assets growing faster than Scenario 4. This result gives a harm to the economy and society, although this inequity is not severe as much as in Scenario 4.

In Scenario 6, this study proposes another policy on top of Scenario 5 that sets the EBIN as a non-profit financial intermediary and thereby transfers the excessive profit to the foundation pool for the benefits of the public. It is worth to remind that the excessive profit is determined in two stages. First, the EBIN transfers 50 percent of its total profit to the foundation pool until reaching the shareholder limit of 20 percent. Second, after this limit, the EBIN only saves the adequate amount of money to be able to invest in the next power plant at 20 percent and then transfers the remaining profit to the foundation pool without considering the foundation share. Therefore, the EBIN's liquidity stays at a low level, and the foundation pool following a steady increase in the liquidity reach a peak at QAR 9.5 billion in 2069. This much money is distributed back to the society by public infrastructure and social venture capital. On the other hand, the illiquid asset accumulation of the individuals stays at the same level in each data point with Scenario 5. However, the EBIN's illiquidity increases slower than Scenario 5 because transferring 50 percent of the profit to the foundation pool causes less investment in the powerplants up to 2054. Therefore, the illiquidity of the large enterprises rises more rapidly than Scenario 5 up to 2030 because it compensates the remaining capital deficit induced by the EBIN's less investment. These results also reflect the change in wealth inequity (see the Gini index in Figure 6.8). There is a sharp decrease in the Gini index in the first two years of the simulation because the individuals have enough capital to invest in the first power plant, as in Scenario 4 and 5. Following the erratic rise of the wealth inequity from 2021 to 2026, there is a dramatic decrease from 0.649 to 0.483 over the course of 2026 and 2069. This value is less than the lowest Gini coefficient, 0.498, among 174 countries reported in Global Wealth Databook 2018 (Credit Suisse 2018). In the meantime, Qatar's Gini index in 2018 is computed as 0.615, which is much higher than 0.483 (Credit Suisse 2018). Scenario 6 is the optimum policy set among these scenarios in terms of the Gini index minimization and the wealth maximization simultaneously. As a proof of concept, this policy reduces social stress by spending on the benefit of the public through the foundation pool; and also decreases social and economic inequity by more equitable wealth distribution.



(4) (5) (6)

Figure 6.8. The cash accumulation, illiquid asset accumulation, wealth accumulation and Gini index of (4) Scenario 4, (5) Scenario 5, and (6) Scenario 6.

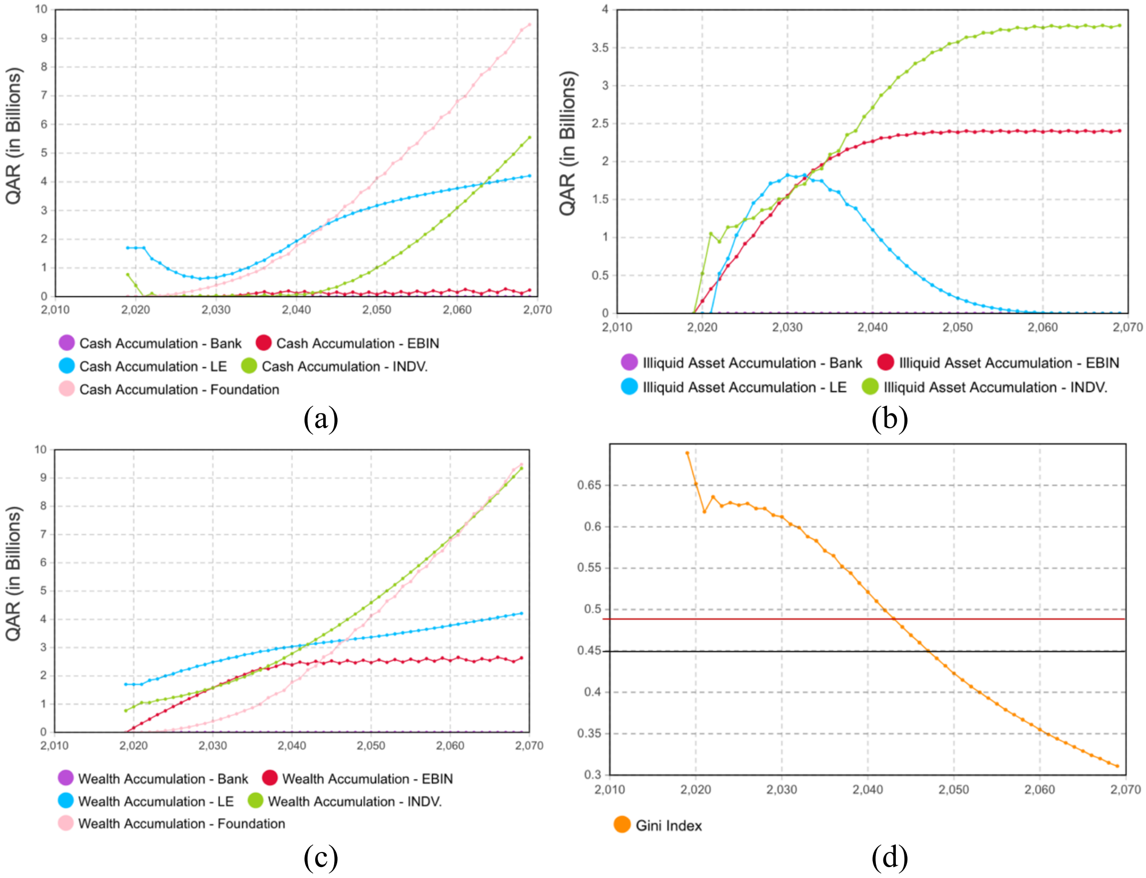


Figure 6.9. (a) The cash accumulation, (b) illiquid asset accumulation, (c) wealth accumulation and (d) Gini index of Scenario 7.

Scenario 7 is a hypothetical case that assumes the nonexistence of a banking system in the financial market. The policy variables are held exactly the same as in Scenario 6, but the only difference is that the bank agent is canceled in the model. In this scenario, the foundation pool stays at the same level as in Scenario 6 because there is no change the EBIN's illiquidity, and the liquidity accordingly, thereby the EBIN transfers the same amount of money to the foundation (Figure 6.9). Therefore, Scenario 7 performs at the same level as in Scenario 6 in terms of public benefits. However, there is a dramatic decrease in the economic inequity from 0.689 to 0.311 over the course of the simulation. The Gini index reaches the lowest point of Scenario 6 around 2043, and continues to decline rapidly, and then hit a low point at 0.311 in 2069. This value is much lower than the lowest Gini coefficient, 0.498, among 174 countries (Credit Suisse 2018). This result shows that, in this non-banking scenario, economic inequity declines more than a financial market with the banking system. In other words, this hypothetical case indicates that the banking system breaks the economic equity.

On the other hand, the large enterprises and individuals reach a peak in the liquidity at QAR 4.2 billion and QAR 5.5 billion, respectively, in the end of the simulation. These values are less than Scenario 6, when we compare them with QAR 5.7 billion and QAR 6.2 billion, respectively. This is because the large enterprises and individuals cannot deposit their initial capital and profit gains into the bank, and thereby cannot earn any interest on their savings. Furthermore, there is no cash accumulation in the bank as compared QAR 3.7 billion in Scenario 6. These decreases in the liquidity can be called a capital loss in the simulation environment. In line with this, the wealth accumulation reduces by QAR 5.9 billion with respect to Scenario 6. This finding indicates that the non-banking system becomes deficient in terms of total wealth accumulation, although the Gini index is a substantial low.

6.4.1. Key Findings

In macroeconomic perspective, this study provides quantitative evidence to support the claim that governments should innovate equity-based alternative financing models, rather than pure debt-based financing, to balance their debt-to-GDP ratio in a sustainable debt zone (Ari and Koc 2018). However, the findings indicate that this alone only benefits for reducing debt-burden, and not adequate for preventing social stress or redistributing the wealth more fairly throughout society. In this regard, this research gives promising results to solve these problems by restructuring shareholders and redistribution mechanism.

The findings of the study show that the illiquid assets rise to a point with the increase in equity, and then remains stable. In the long run, the liquid assets also grow with respect to the power purchasing agreement between the project developer and government. These results imply that a new financial intermediary needs to be established to enhance illiquid and liquid assets, hence total wealth, when illiquid asset accumulation reaches the equilibrium state namely stays constant at a level. In this respect, the study provides quantitative evidence to support the claim that there is a need for monetary reform by establishing many small, local, not-for-profit community banks (Werner 2014).

In business-as-usual cases in which large enterprises are prioritized over individuals, there is an upward trend in economic inequality over the simulation time regardless of financial instruments. In equity-based financing, the increase in wealth inequality becomes sharper than debt-based financing even though it reduces the debt-burdens on shareholders. These results show that sole equity-based financing without any policy regulations does not benefit for wealth inequality, even it gives more damages than debt-based financing in the business-as-usual cases. In these circumstances, the Gini index indicates that capital concentrates in a few hands, large enterprises, incurring an unsustainable financing model and an undesired case for social welfare. However, implementing the proposed policy results in a dramatic decrease in wealth inequality (Gini index) from 0.689 to 0.483 throughout simulation time. The resulting value is less than the lowest Gini coefficient, 0.498, among 174 countries reported in Global Wealth Databook 2018 (Credit Suisse 2018). As a proof of concept, the proposed policy framework reduces social stress by reducing the debt-burden on society and involving public participation through private investment. In addition to this, spending for the benefit of the public through the foundation pool in the proposed model decreases social and economic inequality by more equitable wealth distribution.

This study also presents a hypothetical case that assumes the nonexistence of a banking system in the financial market with the same policy framework In the hypothetical case, implementing the proposed policy framework causes a dramatic decrease in economic inequality from 0.689 to 0.311 over the course of the simulation. In this case, the wealth inequality reaches rapidly to 0.483 around 2043 namely 25 years ago from the model enabling the banking system. This result shows that, in the non-banking scenario, economic inequality declines more than a financial market with the banking system. However, there is a substantial capital loss in total wealth of the hypothetical scenario although the Gini index is considerably low. These findings show that sole equity-based financing system can outperform the conventional banking system if a proposed financing model utilizes all the cash through productive use to generate more wealth. In this case, the findings support a "green" banking reform (Dittmer 2015) that is a fundamental change in the monetary system moving away from debt-based financing to "full reserve banking" (Benes and Kumhof 2012; Lee and Werner 2018). In the opposite case, the financial market without banking become less efficient than a market with banking because the nominal value of some liquidity remains constant with no financial (interest) or non-financial (profit) income, and then this causes the wealth loss.

6.4.2. Future Work

Thus far, we have discussed the results of computer-based simulations on alternative financing models that reduce social stress and economic (wealth) inequality. In what follows, we propose several directions for future research. This study focuses on wealth distribution under different policy settings without any income and wealth taxations. The future research will include income and wealth taxation with fixed and progressive scales, and also replace the price incentives, which is in favor of equity-based financing, with the tax adjustments. In this study, we evaluated the deterministic simulation models as a proof of concept. To make more realistic simulations, we plan to incorporate the Belief-Desire-Intention model, which includes stochastic processes, into the IN, LE, and EBIN agent's structure for creating intelligent agents (Georgeff et al. 1999). This study does not include any risk from the equity-based financing, whereas in real life, this case is limited to a few public infrastructure projects, which are under governmental guarantee. Therefore, we plan to take the potential risks of equity-based financing into account by removing the PPA from the projects. This methodology brings a couple of problems that need to be tackled. In line with this, we plan to entail agency problems such as trust function in large enterprises and individuals, corruption function in the EBIN, and information asymmetry between the investors and the EBIN. In addition to this, further research is needed to investigate the change in wealth inequality when the populations of individuals and large enterprises are of the heterogeneous agents according to a realistic statistical distribution, rather than a uniform distribution. Therefore, these heterogeneous populations enable to make class transitions from individuals to large enterprises, and vice versa. This study assumes that there is only one agent for the EBIN and one for the BANK. To make more efficient financing model, we plan to expand our model into multiple EBIN and BANK agents.

6.5. Conclusion

The motivation behind the study is to develop a set of policy guidelines for sustainable financing models as a solution for these intertwined problems which are (i) financial gap in energy investments, which leads to, (ii) excessive global debt concentration, which leads to, and (iii) dramatic increase in wealth inequality. In this regard, the objective of the study is to develop the policy framework for a substantial decrease in wealth inequality without decreasing total wealth by reducing debt-burden on society and including public participation through private investments. To this end, sustainable financing models are designed using the agent-based computational economics with simple, yet powerful, policy rules and regulations, and compared with the conventional banking system. The proposed policy framework, which is open to further improvement, governs the proposed model by (i) prioritizing individuals over large enterprises as shareholders, (ii) setting limits for the participation of different shareholders, (iii) providing a self-sufficient financial intermediary and individuals for funding solar farms, (iv) accumulating money in the foundation (i.e., not-for-profit institution) pool for social welfare. First and second regulations reduce wealth inequality without decreasing the total wealth. The third rule enables the individuals and financial intermediaries to be self-sufficient for building a power plant; thereby this provides economic sustainability of the shareholders. Last rule increases the social welfare and equity by spending the money in the foundation pool on the benefits of the public.

There are many studies in the literature investigating the evolution of wealth inequality throughout the history. However, there is a gap in the literature which is investigating the effects of various policy rules on the evolution of wealth inequality in a future time frame to discuss the possible policy implications beforehand. In this respect, this paper contributes to the literature by developing simulation models for conventional and alternative financing systems that enables to investigate the change in wealth inequality and social welfare as a result of various policy implications throughout the simulation time. This study makes further contribution to the literature as follows:

i. The literature focuses on alternative financing models to maintain debt sustainability, but there is a gap for studying wealth inequality and accumulation while reducing the debt. This study investigates sustainable financing models by not only reducing debt-burden on society, but also preventing social stress and redistributing the wealth more equitable.

ii. The literature advocates monetary reforms by establishing many small, local, not-for-profit financial intermediaries. However, there is a gap in the literature on time-wise planning about when such financial intermediaries should be established. In this regard, this study investigates the potential time-schedules to create a bank or another type of financial intermediaries.

The findings of this study are expected to support decision- and policy-makers in financing sector and government with evidence-based analysis and demonstration on the alternative financing models. This study presents a sustainable financing model of reducing wealth inequality dramatically without decreasing total wealth by simply prioritizing individuals over large enterprises and establishing a foundation pool inside the EBIN. In line with this, the proposed model enables them to evaluate policy implications and shape their implementations in a wide variety of long-term public investments, which will strongly influence the requirements of a true sustainable development. Thus, they can investigate the time-wise behavior of wealth inequality and accumulation, liquid and illiquid asset accumulation by analyzing the dynamics of shareholder list and limits among individuals, large enterprises, the EBIN, and BANK. Furthermore, the proposed model enables to examine social welfare by formulating and implementing a foundation-based (non-profit institution for the public/common good) structure as a redistribution mechanism. Such an institution (i.e. like a foundation) transfers a certain share of wealth to the benefit of the public such as public infrastructure, education facilities, and health centers in the long run.

CHAPTER 7: CONCLUSION

This study is formulated on a hypothesis that unsustainable financing of sustainable large public infrastructures (such as energy, education, clean water, housing, and so on) would lead to unsustainable economic development, hence overall unsustainable development, in the long-run due to overaccumulation and unfair distribution of wealth. In line with this hypothesis, the results show that there is an indispensable need for alternative sustainable financing models to promote sustainable development by reducing debt-based financing and increasing public participation through private investment in public infrastructures, such as power plants harnessing renewable energy. To this end, this study is designed as a consecutive and linked research in three phases. First, phase 1 investigates the causal relationship between public investment and sovereign debt to evaluate the need for sustainable financing models that propose alternative financings against debt-concentrated contracts in the globe. Phase 2 examines the balance between public and private investment in the GCC countries to provide a piece of evidence to that public participation through private investment plays a crucial role in economic diversification by funding public infrastructures for sustainable development. In phase 3, by considering the results of phase 1 and 2, sustainable alternative financing models for solar farms have been studied on realizing economic and social sustainability, hence a truly sustainable development, by reducing debt-based financing and increasing the public participation. Evidently, each phase contributes to the following part of the research, thereby this study divides the conclusions into three stages as follows.

Phase 1 investigates the causal relationship between public investment and sovereign debt for the U.S., China, Japan, and Germany (those are the top four in the world with respect to their GDP) to evaluate the need for an alternative financing model by reducing the debt concentration. They have followed a similar pattern on public investment in terms of sovereign debt although the economic and fiscal policies along with geography, population, and aging have a broad range of discrepancies in the countries under consideration. In other words, either external or domestic public debt becomes considerably influential on public investment when the public debt-to-GDP ratio rises through the unsustainable debt zone. In this regard, the results provide quantitative evidence based on empirical findings to support the claim that sovereign debt is harmful to the financing of public infrastructure if it breaches certain thresholds, as proposed in this study, and according to the literature. Put differently; public borrowing might be beneficial in the beginning to promote economic growth by building public infrastructures until public debt leads to a debt trap and corruption. Therefore, this section states that the countries with high public debt should take an immediate action decisively to address their fiscal problems, and the countries with moderate (or low) public debt should take necessary precautions to sustain their debt level before becoming one of the highly indebted countries. In short, the findings enable us to make recommendations about the need for mobilizing domestic resources and innovating new financial models to promote sustainable development within the limits of sustainable public debt.

Phase 2 examines the interrelations between public and private investments from 1960 to 2015 in the GCC countries which are known as hydrocarbon-based rentier states striving significant policy changes to diversify their economies. In this regard, this section shows that there exists a non-linear dependency on public and private investments, and thereby non-linear causality is conducted to extract accurate information behind the scene, beyond the linear causality. As a result, the GCC countries indicate a limited success on that public and private investment should move up together by triggering and reinforcing each other towards sustainable, balanced and growing economics as well as social and environmental development. In other words, the results provide quantitative evidence to support the claim that, first, the hydrocarbon-based rentier economies strongly rely upon public investment, and second, economic diversification is limited in these countries. In the bigger picture, the findings enable us to make several recommendations on that the GCC states should promote public participation through the private sector in transitioning to the non-oil-based business. In line with this, investors should feel secure on the bases of calculative risks and possible investment failures by establishing institutional and relational trust among the state, ruling elites, the people, and the private sector, along with the micro and small enterprises. In short, the results show an essential need for alternative financing policies that satisfy the conditions mentioned in the previous sentence to promote public participation through private investment in building sustainable public infrastructures.

Phase 3 indicates that sustainable economic development should reduce wealth inequality at an acceptable level and increase the total wealth accumulation at the same time. Therefore, only shareholder wealth maximization does not lead to the creation of sustainable wealth. In a social aspect, this study proposes an equity-foundation-based financing model against the interest-based system to mitigate wealth inequality and promote social equity. This study also supports a "green" banking reform that is a fundamental change in the monetary system moving away from debt-based financing to "full reserve banking". The findings show that equity-based financing can outperform the conventional banking system if this alternative financing model utilizes all the cash through productive use to generate more wealth. In the opposite case, pure equity-based financings become less efficient than a financial system with banking because some liquidity remains constant with no financial (interest) or non-financial (profit) income, and this causes the wealth deficiency as evidenced from Section 4.

Thus far, preceding phases of the study show that there is an indispensable need for alternative sustainable financing models to promote sustainable development by reducing debt-based financing and increasing private participation in public infrastructures, such as power plants harnessing renewable energy. In this regard, this research attempts to answer the following question by providing a quantitative evidence. First, if renewable projects are financed excessively by debt-based financing, either from domestic or external creditors, how it may affect the long-term sustainable economic and social development? Second, the critical question to be answered eventually is: what kind of policy applications for sustainable financing should be developed for renewables, and other public infrastructures, without damaging the long-term sustainable economic and social development? To be able to answer these questions, the third phase provides an agent-based model, as a proof of concept, on alternative financing models for public infrastructures under a case study of solar farm investments with a power purchasing agreement to investigate the accumulation and change in wealth inequality and social welfare over a long period. To this end, as an alternative financing entity, an equity-foundation-based financial intermediary is designed using the agent-based computational economics with simple, yet powerful, policy rules and regulations, and compared with the conventional banking system and financing.

In response to the first question, in macroeconomic perspective, this study provides quantitative evidence to support the claim that governments should develop equity-based alternative financing models on renewable projects, rather than excessively debt-based financing, to balance their debt-to-GDP ratio in a sustainable debt zone, for preventing social stress and redistributing the wealth more equitably throughout the society. In other words, this study is in line with the claim that a debt-based system might be responsible for unsustainable development. Furthermore, the proposed policy on investment (shareholder priority and limits) and redistribution mechanism (non-profit EBIN and foundation share) show a substantial impact on the wealth distribution without reducing the total wealth by decreasing the debt-burden on society.

In response to the second question, this study discusses the policy implications after developing alternative policy settings on sustainable financing for renewables without damaging the long-term sustainable economic and social development. The proposed policy framework, which is open to further improvement, regulates the alternative financing system by (i) prioritizing individuals over large enterprises as shareholders, (ii) setting limits for the participation of different shareholders, (iii) providing a self-sufficient financial intermediary and individuals after a particular time, (iv) accumulating money in the foundation (i.e., not-for-profit institution) pool for social welfare. First and second regulations reduce wealth inequality without decreasing the total wealth. The third rule enables the individuals and financial intermediaries to be self-sufficient for building a powerplant; thereby this provides economic sustainability of the shareholders. Last rule increases the social welfare and equity by spending the money in the foundation pool on the benefits of the public. These policy implications satisfy sustainable development in each and every aspect including economic, social, and environmental pillars (see Figure 7.1). As a result, this investigation concludes that unsustainable financing models even for sustainable purposes, such as clean energy and utilities, health and education facilities, and so on, will lead to unsustainable economic and social outcomes, which are supposed to be the pillars of truly sustainable development.

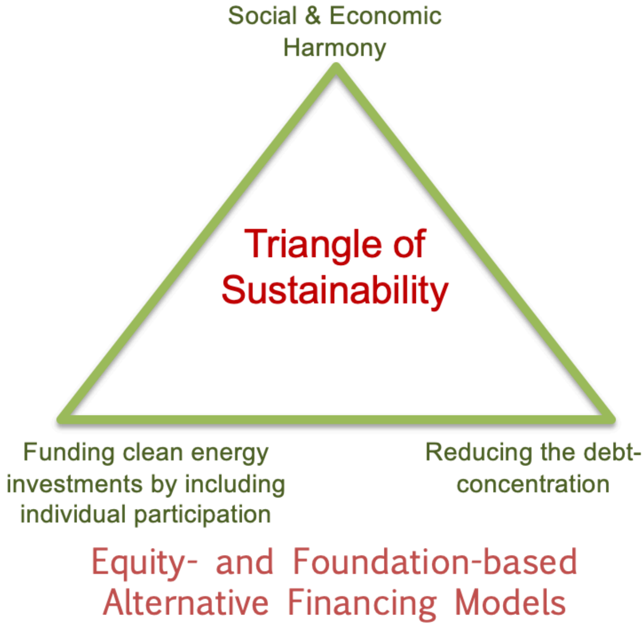


Figure 7.1. The proposed solution to the triangle of unsustainability presented in the introduction.

7.1. Future Works

This research opens new horizons to further improvements on macroeconomic subjects based on public and private investments along with sovereign debt, and microeconomic issues related to funding a project through alternative financing structures and policy rules. Phase 1 focuses on sovereign debt sustainability regarding public investment in four countries with the highest GDP (i.e., the U.S., China, Japan, and Germany) to investigate how they perform in financing for sustainable development. These countries are the pioneers in sustainable energy by installing more than half of the global capacity of renewable power and constituting around 50% of global GDP. However, we plan to expand this part of the study into the emerging countries, which sovereign debt severely limits sustainable development, to make a more comprehensive comparison and reach a broader perspective. In this part, we only investigate public debt sustainability by exploring the interrelations between public investment and sovereign debt. Therefore, further research is needed to evaluate the relationship between private investment and private debt, along with the interactions of public investment, in terms of debt sustainability.

In phase 2, this study provides a piece of evidence that public participation through private investment plays a crucial role in economic diversification by funding public infrastructures for sustainable development. In what follows, we propose several directions for future works on the second phase of the study. We plan to expand this research into the investment law and foreign direct investment (FDI) to evaluate the reasons and potential solutions for public investment dependency. Furthermore, there are also several directions towards follow-up studies based on the effects of education and culture. In the education part, future research will investigate the impact of providing access to quality education and relevant skills-based training for the entire society, local people in particular. This might increase labor productivity and flexibility and develop a social and cultural awareness for establishing and running technology-oriented high-quality entrepreneurial activities. In a cultural aspect, future study will explore the economic and financial opportunities for the GCC countries to diversify their economies by utilizing their specific conditions in terms of their geography, climate, population, language, and even religion.

The main part, phase 3, of the study brings a new perspective to evaluate the social impacts of the economic outcomes by investigating the proposed policies with the change in wealth inequality (i.e., Gini index). To this end, we have proposed several policy-rules associated with the financing structures by developing the agent-based modeling of alternative financing models that reduce social stress and economic (wealth) inequality.

In what follows, we propose several directions for future research. This phase focuses on wealth distribution under different policy settings without any income and wealth taxations. The future research will include income and wealth taxation with fixed and progressive scales, and also replace the price incentives, which is in favor of equity-based financing, with the tax adjustments. In this study, we evaluated the deterministic simulation models as a proof of concept. To make more realistic simulations, we plan to incorporate the Belief-Desire-Intention model, which includes stochastic processes, into the individuals, large enterprises, and the EBIN agent's structure for creating intelligent agent (Georgeff et al. 1999). This study does not include any risk from the equity-based financing, whereas in real life, this case is limited to a few public infrastructure projects, which are under governmental guarantee. Therefore, we plan to take the potential risks of equity-based financing into account by removing the *power purchasing agreement* from the projects. This methodology brings a couple of problems that need to be tackled. In line with this, we plan to entail agency problems such as trust function in large enterprises and individuals, corruption function in the EBIN, and information asymmetry between the investors and the EBIN. In addition to this, further research is needed to investigate the change in wealth inequality when the populations of individuals and large enterprises are of the heterogeneous agents according to a realistic statistical distribution, rather than a uniform distribution. Therefore, these heterogeneous populations enable to make class transitions from individuals to large enterprises, and vice versa. This study assumes that there is only one agent for the EBIN and one for the bank. To make more efficient financing model, we plan to expand our model into multiple EBIN and bank agents.

APPENDIX

A1. Top 20 Countries by GDP

Table 1. Top 20 Countries by their GDP (Billions $) in 2017

Country	2000	2005	2010	2015	2016	2017
United States	10284.75	13093.70	14964.40	18120.70	18624.45	19362.13
China	1214.91	2308.79	6066.35	11226.19	11232.11	11937.56
Japan	4887.30	4755.98	5700.10	4379.87	4936.54	4884.49
Germany	1955.67	2866.31	3423.47	3377.31	3479.23	3651.87
U. Kingdom	1372.45	2207.45	2651.77	2434.79	2466.47	2574.81
India	1638.70	2511.17	2431.17	2863.30	2629.19	2565.05
France	476.64	834.22	1708.46	2089.87	2263.79	2439.01
Brazil	655.45	891.63	2208.70	1801.48	1798.62	2080.92
Italy	1145.11	1855.83	2129.02	1825.82	1850.74	1921.14
Canada	742.32	1169.47	1613.46	1552.81	1529.76	1640.39
Russia	561.60	898.14	1094.50	1382.76	1411.04	1529.74
Korea	279.03	820.57	1638.46	1365.87	1283.16	1469.34
Australia	399.28	734.85	1249.65	1229.94	1261.65	1390.15
Spain	597.15	1159.26	1434.26	1193.56	1232.60	1307.17
Indonesia	679.63	866.35	1051.13	1152.27	1046.93	1142.45
Mexico	179.48	310.82	755.26	861.14	932.45	1010.94
Turkey	273.09	501.16	772.29	859.45	863.39	841.21
Netherlands	414.02	679.70	837.95	758.38	777.55	824.48
Saudi Arabia	272.28	408.79	583.23	679.15	669.04	680.65
Switzerland	189.52	328.21	526.81	654.27	646.44	678.54

Note: GDP data is gathered from The World Economic Outlook (WEO) database that was published by IMF on 10th of October 2017.

A2. Populations for top 20 countries by GDP

Table 2. Populations for top 20 countries by their GDP in 2017

Country	2015	2016	2017
China	1371220000	1378665000	1383981000
India	1309053980	1324171354	1339180000
United States	320896618	323127513	325524000
Indonesia	258162113	261115456	263991000
Brazil	205962108	207652865	209288000
Russia	144096870	144342396	144231000
Mexico	125890949	127540423	129163000
Japan	127141000	126994511	126641000
Germany	81686611	82667685	82581000
Turkey	78271472	79512426	80745000
France	66624068	66896109	67143000
U. Kingdom	65128861	65637239	66013000
Italy	60730582	60600590	60570000
Korea, Rep.	51014947	51245707	51439000
Spain	46447697	46443959	46460000
Canada	35848610	36286425	36613000
Saudi Arabia	31557144	32275687	32938000
Australia	23789338	24127159	24446000
Netherlands	16939923	17018408	17073000
Switzerland	8282396	8372098	8441000

Note: The population data is gathered from population estimates and projections database that was published by World Bank on 20th of September 2017.

A3. Data Resources

Table 3. Data sources and periods with respect to datasets

Dataset	Data Source	Country	Data Period
Public Investment	IMF FAD Investment and Capital Stock Dataset	USA China Japan Germany	1960-2015 1960-2015 1960-2015 1960-2015
External Public Debt	World Bank and IMF (joint), SDDS - Gross External Debt Pos., General Government, All maturities, All instruments, USD	USA China Japan Germany	2003-2017 1981-2017 2003-2017 2001-2017
Public Debt	IMF – World Economic Outlook, USD	USA China Japan Germany	2000-2015 1995-2017 1980-2017 1999-2017
Domestic Public Debt	(Public Debt) - (External Public Debt)	USA China Japan Germany	2003-2017 1995-2017 2003-2017 2001-2017

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