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IMPLICATIONS OF FISCAL AND FINANCIAL POLICIES FOR UNLOCKING GREEN FINANCE AND GREEN INVESTMENT

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In this report, "$" refers to United States dollars.

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Abstract

Scaling up private investment in renewable energy is indispensable for achieving decarbonization of the global economy, low carbon transformation, and climate-resilient growth. As advocated by the United Nations, governments should create a level playing field for private investment in renewable energy, and they should use fiscal policies to incentivize engagement from the private sector. While studies on renewable energy are abundant and focus on topics ranging from unlocking renewable energy investment to the effects of environmental policies on innovation, energy efficiency policies, investment policies in renewable energy, and the adoption of feed-in tariffs, studies that uncover the determinants of private investment in the renewable energy sector are limited. Unlike the previous literature, which concentrates on the total green investment, this study distinguishes between private sector investment and government investment in renewable energy. Using multilevel data from 13 countries over the period 2004–2016, this chapter investigates the impact of 4 fiscal and financial policy instruments, namely (i) feed-in tariffs, (ii) taxes, (iii) loans, and (iv) grants and subsidies, on private investment in renewable energy. A multilevel random-intercept and random-coefficient model provides evidence of the effectiveness of two policy instruments, feed-in tariffs and loans. This study could benefit policy makers and researchers by enhancing their understanding of the factors enabling the scaling up of renewable energy investment.

Keywords: Private investment; Feed-in tariff; Fiscal policy; Green investment; Government investment; Renewable energy

JEL Classification: Q58, Q42, H30

Contents

1. INTRODUCTION

According to the International Energy Agency (IEA), the globe requires $44 trillion of new investment in the global energy supply, including $9 trillion of new investment in renewable energy to sustain the growth in the energy demand until 2040 (IEA 2016). Scaling up private investment in renewable energy is indispensable for achieving decarbonization of the global economy, low carbon transformation, and climate-resilient growth. As advocated by the United Nations, governments should create a level playing field for private investment in clean energy, and they should use fiscal policies to incentivize the private sector's engagement.

Private investment in fossil fuels is still greater than private investment in renewable energy (Figure 1); therefore, one of the main objectives of a government policy supporting a low-carbon energy supply is to attract private investment to renewable energy (Mazzucato and Semieniuk 2017). That requires a better understanding of the determinants of private investment in renewable energy, with a focus on government support.

While studies on renewable energy investigate a diverse set of issues and range from studies on unlocking renewable energy investment (International Renewable Energy Agency (IRENA) 2016) to studies on the effects of environmental policies on innovation (Johnstone, Hascic, and Popp 2010; Nesta, Vona, and Nicolli 2014), the role of energy efficiency policies (Ringel et al. 2016), the role of policies in investments in renewable energy (Popp, Hascic, and Medhi 2011), and the adoption of feed-in tariffs (Romano, Scandurra, and Carfora 2015), studies examining the determinants of private investment in the renewable energy sector are scarce.

Unlike the previous literature, which focuses on the total investment in renewable energy (Eyraud, Clements, and Wane 2013), we distinguish between private sector investment and government investment in renewable energy. The following issues justify our focus on private investment.

Firstly, since one of the objectives of renewable energy policies is to attract private sector investment, it is vital to separate private investment from the total investment, which includes government investment along with private investment. Uncovering the determinants of private sector investment in renewable energy will identify the factors that promote and undermine renewable energy promotion and contribute to policy discussions.

Secondly, by focusing on private investment, we determine whether government investment is complementary to or a substitute for private investment in green energy. The literature that discusses the effects of public investment on private investment finds that public-sector investment may have a crowding-out or crowding-in effect on private investment (Wai and Wong 1982; Ghura and Goodwin 2000; Akkina and Celebi 2002; Acosta and Loza 2005; Afonso and Jalles 2015). On the one hand, public investment may reduce private investment through the increased use of physical and financial resources, hence reducing the resources available for the private sector (Akkina and Celebi 2002); on the other hand, government investment may lead to an increase in private investment, as it may increase the returns to scale in the private sector and generate further benefits (Wai and Wong 1982; Akkina and Celebi 2002). The literature studying the determinants of private investment is abundant, though studies on the effects of government investment on private investment in renewable energy are scarce. Hence, distinguishing between private and government investment helps to determine whether there are such effects on private investment in green energy.

Third, we investigate whether government support and renewable energy policies are effective in promoting private investment in renewable energy. The prices of some renewable energy sources have been declining since the People's Republic of China's (PRC's) inception of massive production of tradable energy sources, such as solar modules and wind turbines.[1] This led to larger private investments in solar and wind energy than in other forms of renewable energy (Figure A1), though renewable energy sources attracted private investment unequally across countries (Figure A2), which is likely to have been due to the differences in government support. To incentivize private investment, governments use policy instruments, especially at the early stage of technology manufacturing, when the cost of renewable energy sources is high and the price of renewable energy is not competitive. For instance, the Korea Technology Finance Corporation provides credit guarantees for the high-tech SMEs in the Republic of Korea, including SMEs in the renewable energy sector. These initiatives are too risky for regular bank loans, and it is not possible to develop them without strong government support. Researchers can measure the effectiveness of policies in meeting their objectives, including increasing private investment in renewable energy. This chapter focuses on four fiscal and financial policy instruments: (i) feed-in tariffs, (ii) taxes, (iii) loans, and (iv) grants and subsidies.

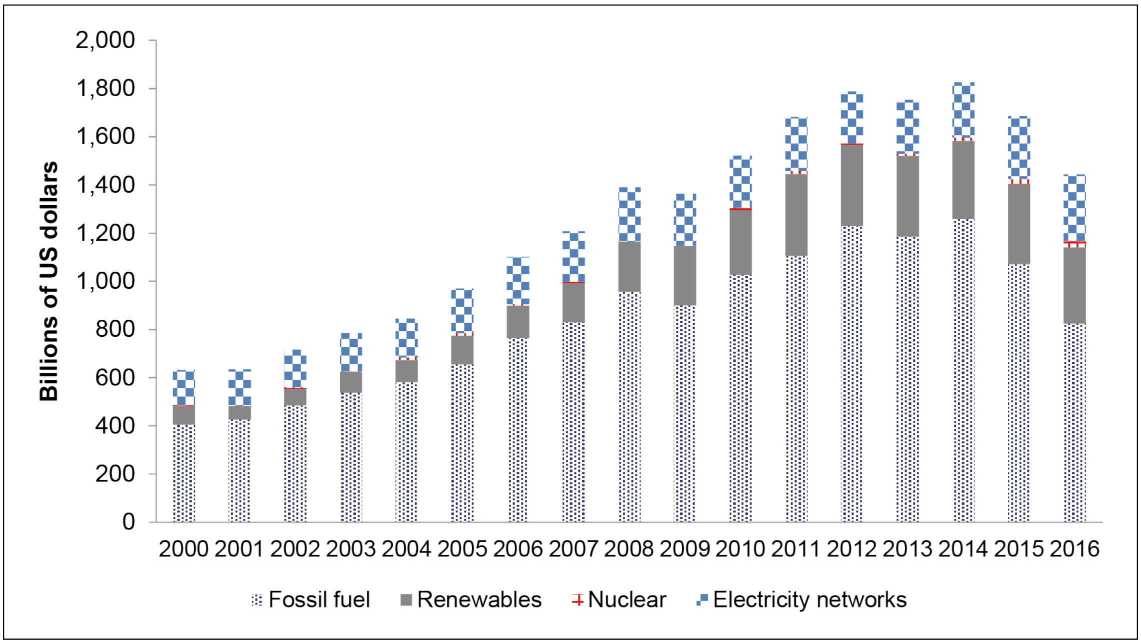
The chapter examines the private investment in renewable energy across six renewable energy sources, namely (i) solar, (ii) wind, (iii) geothermal, (iv) biofuel, (v) hydropower, and (vi) wave and tidal. The analysis uses longitudinal multilevel data from 13 countries, specifically Australia, Brazil, Canada, France, Germany, India, Italy, Japan, the Republic of Korea, the PRC, Spain, the United Kingdom, and the United States, over the period 2004–2016. We focus on these countries due to the data availability. We use cross-country annual data to investigate the determinants of private investment in renewable energy as a share of the total investment. We collect the data from Bloomberg New Energy Finance (BNEF), the IEA, the IRENA, and British Petroleum (BP).

The contributions of this chapter to the literature include: (i) the assessment of the impact of fiscal and financial policy instruments on private investment in renewable energy and (ii) the assessment of the impact of government expenditure on the research, development, and demonstration (RD&D) of renewable energy on private investment in renewable energy. This study could benefit policy makers and researchers by revealing the barriers and the factors enabling the scaling up of renewable energy investment.

The structure of the remaining sections of this chapter is as follows. Section 2.1 provides a literature review on the determinants of private investment, and section 2.2 presents a literature review on the role of fiscal and financial instruments. Section 3 provides the methodology and data. Section 4 contains the empirical results. Section 5 provides a discussion and concludes.

[1] For more information on the reasons behind the solar module price decline, see Taghizadeh-Hesary, Yoshino, and Inagaki (2018).

Figure 1: Global Investment in the Energy Supply



Source: IEA (2017a).

2. LITERATURE REVIEW

2.1 Determinants of Private Investment

Empirical studies that link private investment to macroeconomic variables are abundant. Most of the studies in the area focus on the effects of government investment on private investment (Wai and Wong 1982; Ghura and Goodwin 2000; Akkina and Celebi 2002; Acosta and Loza 2005; Afonso and Jalles 2015). On the one hand, public-sector investment may lead to the crowding-out effect on private investment through the increased use of physical and financial resources, hence reducing the resources available for the private sector (Akkina and Celebi 2002); on the other hand, government investment may lead to an increase in private investment through several channels (Wai and Wong 1982; Akkina and Celebi 2002). First, in the presence of underutilization of resources, an increase in government investment may lead to a rise in income and hence an increase in private sector investment due to the expected increase in the aggregate demand. Second, government investment in infrastructure, such as transport, communications, electricity, irrigation, and so on, may reduce the costs of production or increase the returns to scale and hence raise the profitability of private-sector investment. Third, government investment in the establishment of new factories is likely to increase the demand for “related products” and hence to result in higher private investment. Finally, government investment could lead to innovations and research and development, for example agricultural research on livestock breeding and raising, and they might lead to higher private investment. Whether government investment will crowd in or crowd out private investment (Akkina and Celebi 2002) is not a priori determined and depends on the “relative strengths” of different effects.

Wai and Wong (1982) find that government investment has a positive effect on private investment in Greece, the Republic of Korea, and Malaysia, though for Mexico and Thailand the results are ambiguous. Some results indicate a positive effect and some show a negative relationship between government investment and private investment, showing whether public investment and private investment are complements or substitutes. Blejer and Khan (1984) find that public infrastructure is complementary to private investment, while other types of private investment are substitutes for private investment and hence may crowd out private investment.

Akkina and Celebi (2002), using ordinary least-squares regression for the Turkish economy for the period 1970–76, find that the total investment of the public sector has a negative and significant effect on private investment. The study supports the hypothesis that total public-sector non-infrastructure investment and private investment are substitutes, while total public-sector infrastructure investment and private investment are complements.

Ghura and Goodwin (2000), using data for Asia, Sub-Saharan Africa, and Latin America from 1975 to 1992, find that, for a full set of countries, public investment has a positive and significant impact on private investment, confirming the complementarity hypothesis between government and private investment that assorted studies support (Wai and Wong 1982; Blejer and Khan 1984; Greene and Villanueva 1991; Serven and Solimano 1993), though credits that the government receives generate a crowding-out effect on private investment. The results are different for separate regions. For instance, in Sub-Saharan Africa, Ghura and Goodwin (2000) find a crowding-out effect of public investment on private investment, while a crowding-in effect occurs in Asia and Latin America.

Acosta and Loza (2005), using data for Argentina's economy for the period 1970–2000, find that government investment crowds out private investment in the short to medium term, while the crowding-out effect vanishes in the long run. Specifically, they find that the magnitude of the crowding-out elasticity is –0.11% in the short term; in the long term, the competition between private and public investment diminishes.

Afonso and Jalles (2015), using panel data for 95 countries for the period 1970–2008, find that in general government expenditure and government consumption spending have a negative effect on private investment. In particular, interest payments, subsidies, and social security spending have a negative effect on private investment.

The studies control for other variables, for example the dependency ratio (Afonso and Jalles 2015), which is in line with Modigliani's life cycle hypothesis; the exchange rate, trade liberalization, inflation and its lags, the aggregate demand, the expected output, and external debt (Blejer and Khan 1984; Acosta and Loza 2005; Bernoth and Colavecchio 2014). Below we discuss each control variable in turn.

The implications of the real exchange rate differ across studies. Acosta and Loza (2005) find a positive and significant effect of the real exchange rate on private investment in the short term, while Ghura and Goodwin (2000) do not find significant effects. The effects of inflation also vary. Inflation and lags have a positive effect in the short term, but with time the effect turns negative (Acosta and Loza 2005). Ghura and Goodwin (2000) conclude that inflation has a negative effect in Latin America, while they find a positive and significant effect for SSA; for Asia, the effect of inflation is insignificant. The cash-in-advance model of Stockman (1981) and the empirical findings of Ozler and Rodrik (1982) and Greene and Villanueva (1991) support the negative effect of inflation on investment. The Tobin–Mundell effect supports the positive effect of inflation on private investment in SSA. Bernoth and Colavecchio (2014) find that inflation has a negative effect on private equity investment in both

CEE and Western countries; however, it has a significant impact only in Western European countries.

Expected output and investment are positively related (Blejer and Khan 1984). The economic development of the country, as measured with the GDP per capita, has a positive and significant effect on private equity investment in Western Europe (Bernoth and Colavecchio 2014). However, the results are the opposite for Central European countries. The faster the economies grow, the less private equity capital they attract.

Financial flows have a positive and significant effect on private investment, for example a change in bank credit to the private sector and net private capital flows (Blejer and Khan 1984). However, any increase in the government spending at the expense of the private sector may lead to the crowding out of private investment. In principle, the government should invest in those projects in which the private sector has low interest. Over time, as those projects generate more returns, they should incentivize the private sector to participate in those initially risky projects. The effect of the increase in credit to the government is negative in all three regions (Ghura and Goodwin 2000). Wai and Wong (1982) also discuss the relationship between bank credit and private investment. The availability of bank credit may reduce financial constraints and increase private investment in developing countries, which rely largely on external financial resources, unlike the firms in developed countries, which tend to rely mainly on retained profits.

Finally, the effects of external debt on private investment are ambiguous. In the short run, high external debt is likely to increase private investment, as it signals a good credit rating, though in the long run its effect is negative (Acosta and Loza 2005). This is consistent with the studies on the debt overhang hypothesis, which find adverse effects of external debt on private investment (Green and Villanueva 1991; Ozler and Rodrik 1992; Cardoso 1993). Ghura and Goodwin (2000) find that the stock of external debt overall has a decreasing effect on private investment, though the effects are different across regions. They do not reject the debt overhang hypothesis for Latin America, which confirms the results of Cardoso (1993). The effects of debt servicing have a significant negative effect on private investment in Asia and a positive effect on private investment in Latin America.

Other studies also control for other variables, such as equity market capitalization, labor markets, and political stability. Bernoth and Colavecchio (2014) find that equity market capitalization has a positive effect on private investment in Western European markets only. The study identifies an unclear effect of rigid labor markets on private investment in Western Europe. Unemployment unexpectedly has a positive and significant effect on private investment in Western Europe.

Surprisingly, political stability and regulatory quality negatively affect the flow of private equity funds in Western European countries, while their effect on CEE countries is insignificant (Bernoth and Colavecchio 2014). Ghura and Goodwin (2000) find that a lower degree of political freedom is likely to decrease private investment in the countries.

2.2 Fiscal and Financial Policy Instruments

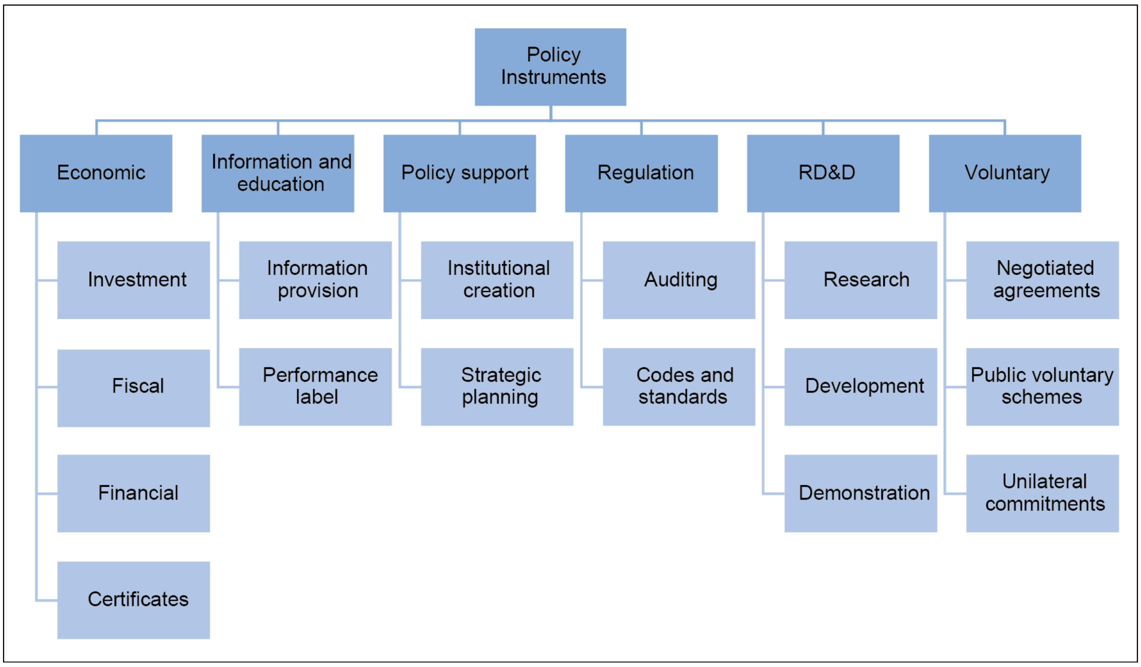
The United Nations Environment Programme (UNEP) (2015) reports that the implementation of the Intended Nationally Determined Contributions (INDC) by all countries will not be sufficient to limit the rise in temperature to 2°C by 2100. They will be sufficient to limit the temperature rise to 3°C by 2100. That requires concerted and enhanced action between different stakeholders, including businesses, investors, and governments (OECD 2016). Moreover, the actions that governments implement to reduce greenhouse gas emissions seem to be insufficient given that GHG emissions are continuing to rise, coal is still the dominant source of energy generation in OECD countries and partner economies, and energy and carbon taxes remain low to promote technological progress and make renewable electricity more attractive for investment than fossil fuel (OECD 2016).

To meet the global climate change goals, increasing the private sector investment in renewable electricity is a way forward (OECD 2016). A study (IEA 2014) finds that investment in energy efficiency and low-carbon power generation should rise eight times and three times, respectively, between 2013 and 2035 to limit the global temperature rise to 2°C by 2100. According to the IEA estimates, the total amount of investment needed is about $53 trillion by 2035 or 10% more than under the business-as-usual scenario.

The OECD (2016) urges the establishment of an enabling environment for promoting private sector investment in renewable energy by designing stronger and coherent climate mitigation policies aimed to divert the investment away from fossil fuel technologies towards renewable energy and low-carbon technologies. These policies can include carbon pricing, investment incentives, the phasing out of fossil fuel subsidies, and RD&D support.

Many countries have introduced a number of policy instruments aiming to promote renewable energy and curb greenhouse gas emissions. The policies used to decrease carbon emissions are diverse. They include financial and fiscal instruments, information and education policies, various forms of policy support, regulatory improvements, policies tailored to research and development, and voluntary approaches. Figure 2 provides a list of policy instruments that are used worldwide. Among them, the most popular and widely deployed instruments are fiscal and financial incentives, which include feed-in tariffs, grants and subsidies, loans, and taxes.

Figure 2: Policy Instruments



Source: Azhgaliyeva et al. (in press).

Feed-in tariffs are a policy mechanism introduced to encourage the deployment of renewable energy technologies, such as wind power, solar power, hydropower, geothermal power, and so on. Their design aims to accelerate investment in these technologies by providing adequate compensation above the electricity market price and hence an incentive mechanism to boost renewable energy development and reduce uncertainties for investors. Feed-in tariffs played a major role in the deployment of renewable energy in Europe, particularly in Germany, Spain, and France.

Grants and subsidies are also popular worldwide and play an immense role in the rolling-out of green power (Frankfurt School–UNEP Centre/BNEF 2017). At the same time, renewable energy is not the only sector that receives financial support; other sectors, including oil and gas exploration as well as nuclear power, are subsidized worldwide. The IEA estimates that the global fossil fuel subsidies amounted to $325 billion in 2015 compared with $150 billion allocated to subsidies for renewable energy (Frankfurt School–UNEP Centre/BNEF 2017).

Providing renewable energy producers with loans at a relatively low interest rate is another channel to boost the upscaling of renewable energy generation and distribution. In 2016, the bank lending for renewable energy sources remained high, amounting to $86.4 billion of non-recourse project finance deals for new installations and $72.7 billion of asset acquisitions and refinancing (Frankfurt School–UNEP Centre/BNEF 2017).

Countries also widely use tax relief or tax credit to promote renewable energy deployment. The US uses production tax credit extensively for the promotion of wind energy and investment tax credit for solar energy. A company could use these tax credits to reduce the deductions from income taxes or corporate taxes in exchange for investment in renewable energy. The US has extended its production tax and investment tax credit policies until 2020.

Another incentive and support for renewable energy deployment could include the utilization and refunding of the increase in the tax revenue resulting from the spillover effect of private investors' establishment of an infrastructure. Several studies discuss the spillover effects of green energy projects to other sectors and the GDP of the region, which countries could further refund partially or entirely to the private-sector investors (Yoshino and Taghizadeh-Hesary 2017, 2018).

In general, the slow penetration of green technologies into the private sector is due not only to the market failures related to the environment, including common property, externalities, hidden information, and public goods (Datt 2002),[2] but also to policy failures, such as subsidies for fuel and other goods and services that lead to serious environmental degradation. Therefore, the removal of such subsidies is arguably one of the main instruments of environmental policy.

The International Monetary Fund (IMF) estimates that fossil fuel subsidies range from $500 billion to $2 trillion annually (IMF 2013). On the one hand, subsidies crowd out priority public spending and private investment in the energy sector; on the other hand, subsidies cause underpricing of energy, which in turn encourages excessive energy consumption, further reducing private investment in alternative energy and accelerating the depletion of natural resources (IMF 2013). The IMF finds that subsidy reform will crowd in private investment in the energy sector, which Clements, Jung, and Gupta (2007) support. Furthermore, Clements, Jung, and Gupta (2007) find that subsidy reform will increase private investment proportionately across all sectors.

[2] Market failures related to the environment include common property, externalities, hidden information, and public goods (Datt 2002).

Case box: Singapore

The Government of Singapore aims to keep Singapore as an attractive location for the innovation and commercialization of technologies. As a result of this, the number of solar companies in Singapore grew from a few in 2008 to 50 in 2016, increasing private investment in renewable energy (Hwee 2017). For example, it has secured nearly $380 million of private investment in the fields of solar energy, smart grids, microgrids, energy storage, and digital technologies for the period 2017–2022 (Siau 2017). Another example of the attraction of private investment to renewable energy is a local solar panel producer, REC, which invested nearly $190 million to expand its solar energy manufacturing facility and to fund a 5-year R&D project in collaboration with the National University of Singapore's Solar Energy Research Institute of Singapore to develop the next generation of solar panels (Hwee 2017).

The Government does not provide subsidies or feed-in tariffs for renewables. Instead, it facilitates the entry of renewable energy technologies when they become commercially viable (Bhunia 2017). The government also invests in the research, development, and deployment (RD&D) of potentially promising renewable technologies. Below are a few examples of RD&D.

In 2016, Singapore launched the world's largest floating solar photovoltaic (PV) test bed worth $11 million (Boh 2016). This test bed, located on a water reservoir, studies the performance and cost-effectiveness of 10 different systems of solar PV panels. The Government invested about $13.5 million in evaluating the performance of different energy storage system technologies in Singapore's hot, humid, and highly urbanized operating environment. This investment will be spent on building the test bed with a capacity of 4.4 megawatt-hours (MWh) of grid storage solutions (Bhunia 2017). According to Singapore's Research, Innovation, and Enterprise 2020 Plan, Singapore will invest $660 million in the urban solutions and sustainability domain, which includes piloting and test bedding of clean-energy technologies, such as power systems, smart grids, energy storage, green buildings, and green data centres.

Research estimates the global market for green finance at around $80 billion, with the potential for a rapid take-off in Asia (Hadow 2017). Singapore, as an established financial hub in Asia, has great potential for developing a green bond market. The external review that is necessary for obtaining the green bond status is costly. To incentivize green bond issuance, the central bank of Singapore, the Monetary Authority of Singapore (MAS), implemented a Green Bond Grant, which covers the cost of external review for green bonds. The ASEAN Green Bond Standards defines the bonds that are eligible for the Green Bond Grant. As a result of this policy, City Developments Limited and the DBS bank issued the first green bonds in 2017 (Schuknecht 2017). To continue to review and update the regulations due to the rise of emerging financial products, the MAS introduced regulatory sandboxes for financial technologies, which can promote green investment in the future (Azhgaliyeva and Tao 2018).

Another policy that can increase green investments is Singapore's carbon tax starting from 2019. The carbon tax will require more than 30 large polluters, primarily power plants, to pay carbon taxes of between $7.5 and $15 per ton of greenhouse gas emissions (BNEF 2017; Low 2018). Although this chapter does not cover the financing of energy efficiency improvements, it is worth mentioning that Singapore has implemented a few policies supporting energy efficiency improvements, such as grants and tax incentives (Low and Bin 2017; Liu 2018). The Government also invests in education to promote talent and skills for future energy industry needs. With this aim, the Government is working with educational institutions to promote training courses, scholarships, and awards.

To increase the deployment of renewable energy significantly, private investment is the key. Only a few studies exist that test the effects of renewable energy policies on green investment, and limited studies investigate how these policies affect private green investment. Eyraud, Clements, and Wane (2013) test the implications of four policy support variables for green investment. The study finds a positive and significant effect of feed-in tariffs on green investment, which supports the view that feed-in tariffs promote the expansion of renewables.

Unlike the existing literature, our study investigates the effect of fiscal and financial policy instruments to attract private investment in renewable energy. This chapter largely focuses on the role of fiscal and financial policy instruments in the promotion of private investment worldwide. On the other hand, it is vital to net out the effects of financial and fiscal policy instruments from other instruments, such as regulatory standards, information and education support, and so on, to estimate the effectiveness of the financial and fiscal policies overall.

Box 1 provides a case study on Singapore, as it is an exemplary case of sustainable development in Asia. Singapore aims to increase its solar power capacity from a peak of 140 megawatts (MWp) in 2017 to 350 MWp by 2020 and 1 GWp beyond 2020 (Energy Market Authority 2017). This case box reviews some of the most recent of Singapore's initiatives to promote renewable energy.

3. METHODOLOGY AND DATA

3.1 Model

This section provides an empirical analysis of the extent to which the different factors discussed in previous sections contribute to explaining the variations in private investment in renewable energy. Thus, the dependent variable is private investment and the independent variables are determinants of private investment, including government RD&D and fiscal and financial policy instruments. Below we discuss each variable.

3.1.1 Dependent Variable

We measure the dependent variable, *private investment*, as the ratio of private investment in renewable energy sources to the total investment (gross capital formation), both in current US dollars, as a percentage. We calculate private investment in renewable energy as the sum of five asset classes, which are invested in renewable energy projects: asset finance, small-scale solar, public markets, venture capital/private equity, and corporate R&D. We collect the investment data from the Desktop database of the BNEF, including investments in renewable energy projects depending on the project capacity (Table 1). Investments in wave and tidal energy (also called ocean or marine energy), geothermal energy, and wind energy include only new investments in projects with a capacity greater than 1 megawatt (MW). Investments in biofuel include only new investment projects with a capacity of more than 1 million liters. We exclude investments in large hydro-electric projects of more than 50 MW, since this technology is very mature (Table 1). We apply the Frankfurt School–UNEP Centre/BNEF's (2017) investment data collection methodology. The asset class "small-scale solar," that is, small-scale solar projects, includes investment in solar projects with a capacity less than 1 MW (Table 2). Table 3 provides a description of each asset class. The data do not include energy smart technologies, such as smart meters, smart grids, virtual power plants, electric vehicles, and energy storage technologies, which are outside of the scope of this chapter.

We measure the total investment with the gross capital formation, which includes "additions to the fixed assets of the economy plus net changes in the level of inventories" (World Bank 2017).

Table 1: Renewable Energy Projects

Renewable Energy	Project Capacity
Biofuel	> 1 mln liters
Geothermal	> 1 MW
Hydropower	1–50 MW
Solar	All
Wave and tidal	> 1 MW
Wind	> 1 MW

Source: Low (2016).

Table 2: Investment Data Availability

Technology	Asset Finance	Small-Scale Solar	Public Markets	VC/PE	Corporate R&D	Government R&D
Biofuels	√		√	√	√	√
Geothermal	√		√	√	√	√
Wave and tidal	√		√	√	√	√
Small hydro	√		√	√	√	√
Solar	√	√	√	√	√	√
Wind	√		√	√	√	√

Note: √ means that annual data are available; VC/PE denote venture capital and private equity.
Source: Low (2016).

Table 3: Definitions: Asset Classes

Asset Class	Definition
Venture capital and private equity	Venture capital funding for the purposes of expansion by companies in the clean energy industry.
Public markets	New equity raised on capital or over-the-counter markets by publicly quoted companies in the clean-energy industry.
Asset finance	Financing of renewable energy projects via the balance sheets or financing mechanisms such as syndicated equity from institutional investors or project debt from banks.
Small-scale solar	Rooftop solar PV with capacity below 1 MW.
Government R&D	Government R&D expenditure data converted from current prices in national currencies into US dollars.
Corporate R&D	Corporate R&D expenditure data converted from current prices in national currencies into US dollars.

Source: Low (2016).

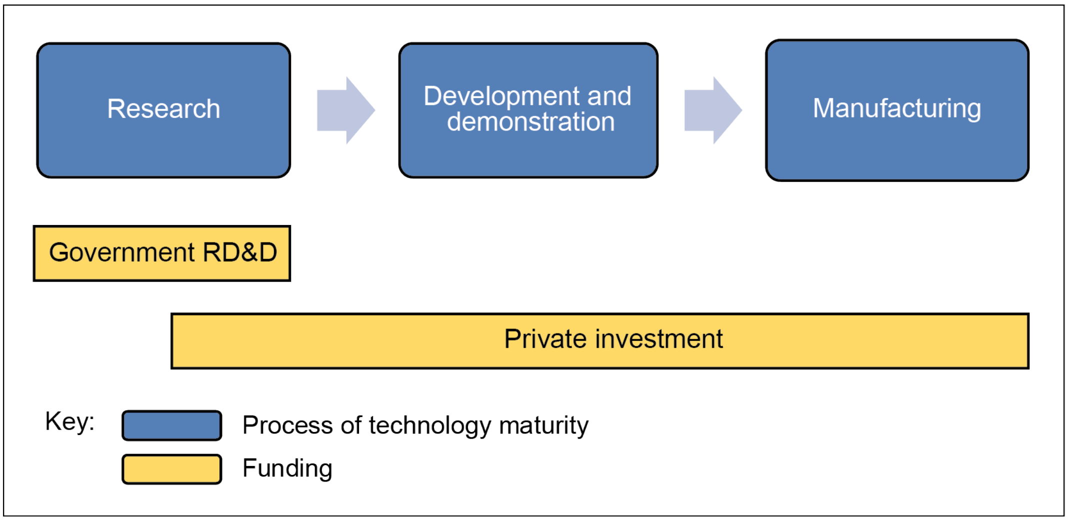
3.1.2 Independent Variables

In Section 2, we identified the determinants of private investment: the government investment, real exchange rate, GDP per capita, financial flows, external debt, equity market capitalization, labor markets, political stability, and policies. Private investment in renewable energy depends on the factors affecting investment in renewable energy in addition to the same factors affecting the total private investment. Thus, in addition to the variables that the literature widely uses in studying the determinants of private investments (see Section 2), that is, government investment, real exchange rate, GDP per capita, financial flows, external debt, equity market capitalization, labor markets, political stability, and policies, private investment in renewable energy depends on the government investment in renewable energy, renewable energy policies, fuel price, electricity price, and cost of renewable energy. Since we measure the dependent variable, private investment, as the ratio of private investment in renewable energy sources to total investment, we include only the determinants specific to private investment in renewable energy.

Government RD&D

Government expenditure on RD&D, or public investment in RD&D, is a publicly funded investment. Governments aim to incentivize private investment by investing in the RD&D of renewable energy technologies, especially at the early stage of technology research, when it is challenging to raise private investment. At the later stage of technology maturity, it is likely that technologies will attract private investment (Figure 3).

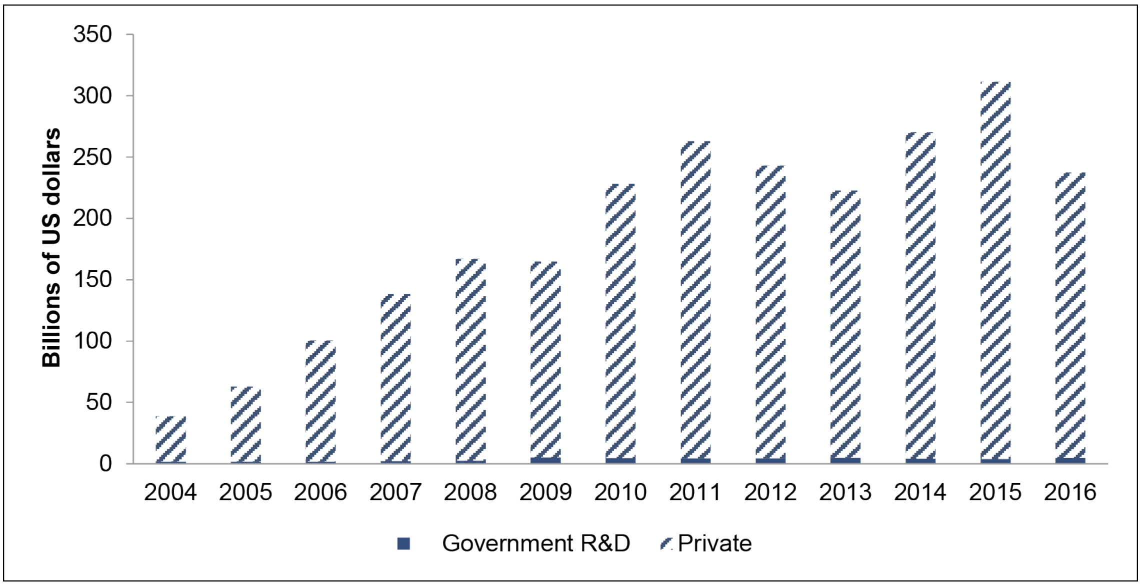
Figure 3: Technology Maturity and Sources of Funding



Source: Authors' own.

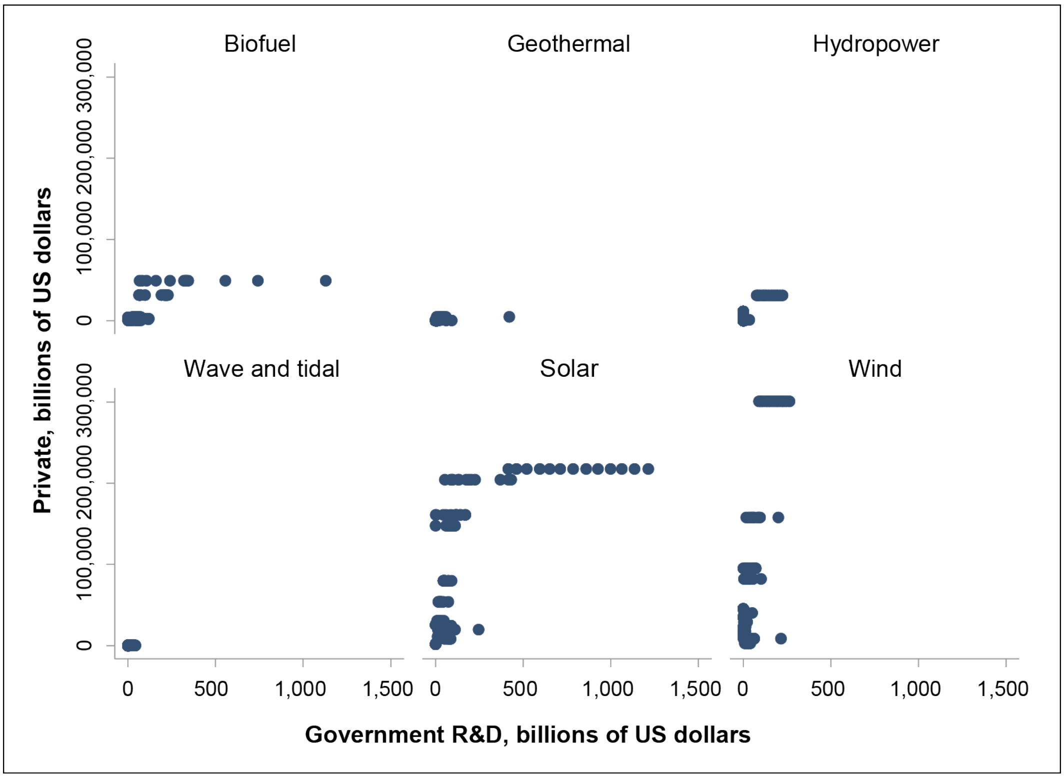
Although private investment in renewable energy is high relative to government RD&D (Figure 4), the share of private investment in total investment varies across countries, renewable energy sources, and years (Figure 5 and Figure 6). This could be due to differences in government policies and technologies.

Figure 4: Global Investment in Renewable Energy



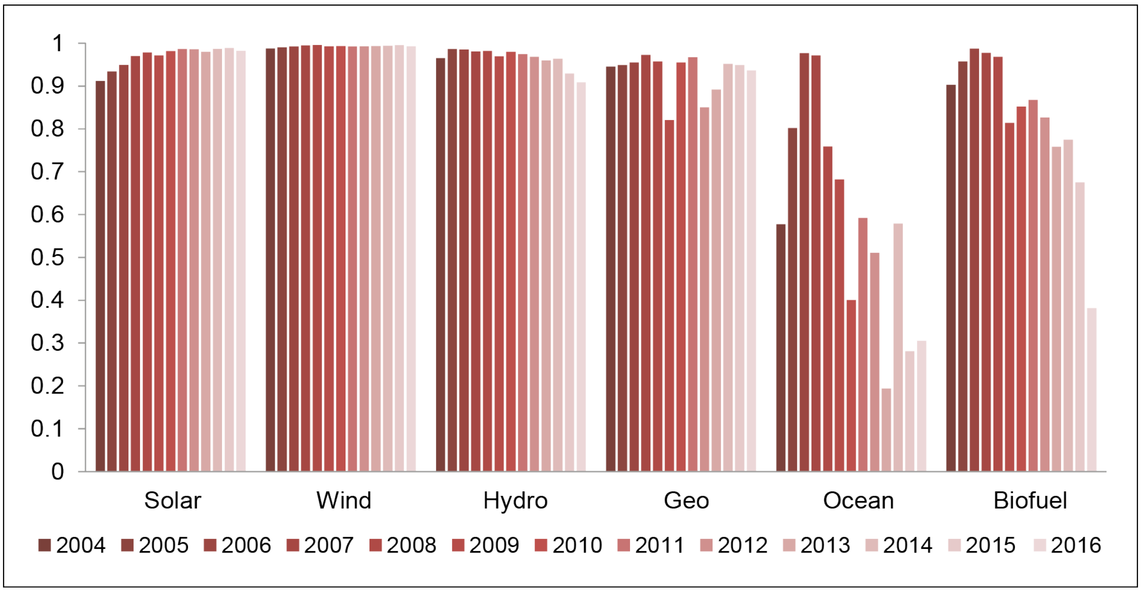
Data source: BNEF (2017).

Figure 5: Private Investment and Government Investment by Renewable Energy



Source: Adopted from the Frankfurt School–UNEP Centre/BNEF (2017) using data from the BNEF (2017).

Figure 6: Share of Private Investment in the Total Investment in Renewable Energy by Years



Data source: BNEF (2017).

Fiscal and Financial Policy Instruments

This study includes four fiscal and financial policy instruments: (i) feed-in tariffs, (ii) grants and subsidies, (iii) loans, and (iv) taxes. All the policy instruments are binary variables, which equal one when a policy exists and zero before it existed or after cancellation. We collect the data on policy instruments from the IEA and IRENA Joint Policies and Measures database (IEA/IRENA 2017); however, data on policy cancellation are not always available. The authors collect missing data using legal policy documents from each country. The included policy instruments are those that are in force, ended, or suspended. Policy instruments undergoing planning or review are not included. The variable *feed-in tariffs* also include premiums, because both feed-in tariffs and premiums allow electricity generators to sell renewable energy to the electrical grid at a tariff above the electricity price for a fixed period (Klein et al. 2010).

Fuel Price

We include the fuel price as a measure of the price of a substitute for renewable energy. The substitutes for renewable energy sources are fossil fuels. The higher the fossil fuel prices, the lower the relative cost of the electricity produced from renewables relative to that generated from fossil fuel combustion (Eyraud, Clements, and Wane 2013; Taghizadeh-Hesary, Yoshino, and Inagaki 2018). Coal is the major fuel for producing electricity after natural gas and crude oil (Eyraud, Clements, and Wane 2013; Azhgaliyeva et al. in press). However, Eyraud, Clements, and Wane (2013) argue that the crude oil price better reflects the cost of fossil fuel energy. It is clear that we cannot include both prices due to the high correlation between them (0.81). This is possibly because fossil fuel markets often use the price of crude oil as a reference price. The choice of substitute for renewable energy among fossil fuels depends on the renewable energy source. For example, gasoline is a major substitute for biofuels (Eyraud, Clements, and Wane 2013); however, coal is a major substitute for solar PVs and wind energy. Since solar and wind energy attract the most private investment, we include the price of coal as a measure of the fuel price.

Electricity Price

The electricity price can affect investors' decision regarding whether to invest in renewable energy sources producing electricity, such as solar PVs, wind turbines, hydropower, and wave and tidal energy. The electricity price is the price at which companies can sell the electricity produced from renewable energy sources to the electrical grid or the opportunity cost at which electricity can be purchased from the electrical grid. The household electricity price is included as a measure of the electricity price.

Cost of Renewable Energy

Since the measurement of *private investment* is in monetary value and not in physical value, changes in the price of renewable energy sources can affect the value of investment. For example, in 2016, the installations of renewable power capacity increased, but investment in renewable energy declined, due to lower costs of renewable energy sources, that is, solar modules and wind turbines (Frankfurt School–UNEP Centre/BNEF 2017). The main measurement of the cost of renewable energy uses the global average levelized cost of energy calculated by renewable energy technology: geothermal, small hydropower, solar crystalline silicon PVs, tidal waves, and wind energy (Figure A3). We measure the cost of biofuel with the wholesale spot price of ethanol, which is one of the two most common types of biofuel, along with biodiesel. Crystalline silicon solar modules are also one of the most popular solar modules compared with other modules, such as polysilicon, wafers, cells, and thin film (Taghizadeh-Hesary, Yoshino, and Inagaki 2018).

We use the levelized cost to have a comparable measure of costs across different technologies. The levelized cost of energy is the present value of the average total cost of electricity generation over the operational lifetime, including capital, fuel, maintenance costs, and so on, per MWh of energy generated over the operational lifetime and measured in monetary units (US$) per MWh. We determine the levelized cost of energy below (Brinsmead et al. 2015; IRENA 2015; Fraunhofer Institute for Solar Energy Systems (ISES) 2017; Obi et al. 2017):

$$LCOE = \sum_{t=0}^{T} \frac{ATC_t}{(1+i)^t},$$

where *LCOE* is the levelized cost of energy, *ATC* is the average energy cost of energy, *i* is the interest rate, *t* is a period, and *T* is the lifetime of the energy-generating technology measured in a number of periods. It is also possible to use the levelized cost of energy as a measure of renewable technology and market risk (Mazzucato and Semieniuk 2017).

3.2 Data

We collected data from six data sources, namely the BNEF, BP (2017), IEA (2017b; 2017c), IEA and IRENA (2017), and World Bank (2017). Tables 4–6 present the summary statistics, data sources, and correlation matrix. All the variables are balanced, annual, and time varying over the period 2004–16. Not all the variables vary across countries or renewable energy sources (Table 7). Private investment, government RD&D, and policy variables vary across three levels: country, renewable energy source, and year. Fuel prices vary by years. The prices of renewable energy vary across two levels: renewable energy sources and years. The data sample includes thirteen countries: Australia, Brazil, Canada, France, Germany, India, Italy, Japan, the Republic of Korea, the PRC, Spain, the United Kingdom, and the United States. It contains six types of renewable energy: solar, wind, wave and tidal, biofuel, geothermal, and hydropower. Fiscal and financial policy instruments are binary variables, that is, *feed-in tariffs*, *taxes*, *loans*, and *grants and subsidies*, which equal one when a policy exists and zero before it existed or after cancellation. We measure the costs of renewable energy sources with the levelized cost of wind, solar crystalline silicon module PVs, and hydropower and wave and tidal energy, as well as the ethanol wholesale US spot price.

Table 4: Summary Statistics and Data Sources

Variable	Source	Obs.	Mean	S.D.	Min.	Max.
Private green investment/gross capital formation, %	BNEF (2017) and World Bank (2017)	1,014	0.56	2.36	0	73.17
Government RD&D investment, million US$	BNEF (2017)	1,014	39.92	114.51	0	1,213.79
Fuel price, US$/tonne	BP (2017)	1,014	90.08	26.86	59.5	139.89
Household electricity price, US$/MWh	IEA (2017b)[3]	738	193.76	79.35	67.55	395.05
Feed-in tariffs/premiums, 0 or 1	IEA/IRENA (2017)	1,014	0.48	0.50	0	1
Taxes, 0 or 1	IEA/IRENA (2017)	1,014	0.37	0.48	0	1
Loans, 0 or 1	IEA/IRENA (2017)	1,014	0.21	0.40	0	1
Grants and subsidies, 0 or 1	IEA/IRENA (2017)	1,014	0.57	0.49	0	1
Cost of renewable energy, US$/MWh	BNEF (2017)	676	161.88	126.03	67.11	497.14

Note: T=13 and N=13.

Data source: Authors' own.

Table 5: Summary Statistics of Renewable Energy Costs by Energy Source

Renewable Energy	Measure	Period	Obs.	Mean	S.D.	Min.	Max.
Biofuel (ethanol)	Wholesale spot price	2004–16	169	95.31	18.76	71.61	127.59
Geothermal (flash and binary plants)	LCOE	2009–16	104	86.78	8.34	72.05	101.2
Hydropower (small)	LCOE	2012–16	65	75.56	4.34	67.11	79.2
Solar (crystalline silicon PVs)	LCOE	2009–16	117	166.87	63.55	100.71	292.36
Wave and tidal	LCOE	2009–16	104	434.79	61.16	320.9	497.14
Wind (onshore and offshore)	LCOE	2009–16	117	125.19	25.49	67.44	150.87

Note: LCOE denotes the global average levelized cost of energy.

Data source: Authors' own.

[3] Electricity prices from Australia, Brazil, India, and the People's Republic of China are not available from the IEA (2017b). The data come from various sources: the Australian Energy Market operator (https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Data-dashboard#average-price-table); the Brazilian Electricity Regulatory Agency (ANEEL). (http://www2.aneel.gov.br/aplicacoes/tarifamedia/Default.cfm); the Lawrence Berkeley National Laboratory (2016); and the Open Government Data Platform India (https://data.gov.in).

Table 6: Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Private investment	1							
(2) Government RD&D	0.13***	1						
(3) Electricity price	0.13***	–0.15***	1					
(4) Fuel price	0.07*	0.03	0.14***	1				
(5) Cost of renewables	–0.06	–0.08*	0.01	0.11***	1			
(6) Feed-in tariff	0.15***	0.00	0.17***	0.17***	–0.03	1		
(7) Taxes	0.01	0.15***	–0.14***	0.05	–0.10***	0.11***	1	
(8) Loans	0.15***	–0.05	0.07*	0.04	–0.04	0.17***	0.29***	1
(9) Grants and subsidies	0.11***	0.12***	0.05	0.10*	0.03	0.25***	0.14***	0.20***

Note: *** p<0.01, ** p<0.05, * p<0.1.
Data source: Authors' own.

Table 7: Multilevel Variables

Variable	Country Level (j)	Renewable Energy Level (i)	Time Related (t)	Notation
Private investment	˅	˅	˅	y_{ijt}
Government RD&D	˅	˅	˅	x_{ijt}
Feed-in tariff	˅	˅	˅	x_{ijt}
Taxes	˅	˅	˅	x_{ijt}
Loans	˅	˅	˅	x_{ijt}
Grants and subsidies	˅	˅	˅	x_{ijt}
Electricity price	˅		˅	v_{jt}
Cost of renewables		˅	˅	z_{it}
Fuel price			˅	w_t

Source: Authors' own.

3.3 Estimation Strategy

The data sample consists of longitudinal multilevel data, which is a special case of multilevel data (Laird and Fitzmaurice 2013). It is clustered in two levels, with *j* countries at level *1* and *i* renewable energy sources at level 2, as well as with *t* years. This model allows the separation of cross-sectional and longitudinal effects and the investigation of heterogeneity across renewable energy sources both in the overall level and in the development over time (Skrondal and Rabe-Hesketh 2008). The data are highly balanced; thus, we can treat them not only as univariate multilevel data but also as single-level multivariate data (Skrondal and Rabe-Hesketh 2008). We consider four multilevel models: random intercept, fixed intercept, random coefficients, and fixed coefficients.

Firstly, using the Hausman test (Hausman 1978), we test for the presence of a random intercept (Eq. 1) or fixed intercept (Eq. 2). We cannot reject the null hypothesis ($\chi^2(7) = 10.09$ with $Prob > \chi^2 = 0.18$), that is, the difference in coefficients is not systematic (random intercept); thus, the random-intercept model is preferable:

$$y_{ijt} = \mu_j + \sum \alpha_k x_{ijt} + \beta v_{it} + \gamma z_{it} + \delta w_t + \varepsilon_{ijt} \quad (1)$$

where $j = 1, \dots, 13$ indexes the cross-sectional unit (country), $i = 1, \dots, 6$ indexes renewable energy sources, and $t = 2004, \dots, 2016$ indexes the year. y_{ijt} is a country-level, energy-level, and time-related dependent variable (*private investment*), x_{ijt} are country-level, energy-level, and time-related independent variables (*government RD&D*, *feed-in tariffs*, *taxes*, *loans*, and *grants and subsidies*), v_{jt} is a country-level and time-related independent variable (*electricity price*), z_{it} is an energy-level and time-related independent variable (*cost of renewables*), and w_t is a time-related independent variable (*fuel price*). In the random-intercept model, μ_j and ε_{ijt} are independently distributed with $\mu_j \sim N(0, w^2)$ and $\varepsilon_{ijt} \sim N(0, \sigma^2)$.

The fixed-intercept (fixed-effect) model is as follows:

$$y_{ijt} = \mu_j + \sum \alpha_k x_{ijt} + \beta v_{it} + \gamma z_{it} + \delta w_t + \varepsilon_{ijt} \quad (2)$$

where μ_j are unit-specific intercepts of fixed effects and ε_{ijt} are i.i.d. and normally distributed around the mean: $E(\varepsilon_{ijt}) = 0$. The regression coefficients represent only longitudinal effects.

Secondly, using the likelihood ratio (LR) test, we test for the presence of random coefficients (Eq. 3) in addition to the random intercept. It might be possible that, in addition to the random intercept, a random coefficient is necessary (Rabe-Hesketh and Skrondal 2012). The LR test compares the random-intercept and the random-intercept with random-coefficient models. The test statistics of the LR test, LR, is $LR = -2(L_r - L_u)$, where L_r and L_u are the maximized log likelihood from the restricted model and the unrestricted model, respectively (Greene 2012). The null hypothesis is that random slopes are equal to zero (the random-intercept model), and the alternative hypothesis is that random slopes are non-zero (the random-intercept and random-coefficient model). We reject the random-intercept model in favor of the random-intercept and random-coefficient model ($\chi^2(2) = 172.95$ with $Prob > \chi^2 = 0.00$). Rabe-Hesketh and Skrondal (2012, 197) suggest obtaining the correct p-value by using a 50:50 mixture of $\chi^2(1)$ and $\chi^2(2)$ as the null distribution (Rabe-Hesketh and Skrondal 2012, 266): $0.5\chi^2(0) + 0.5\chi^2(1)$. The correct p-value ($Prob > \chi^2 = 0.00$) does not change the conclusion that we reject the random-intercept model in favor of the random-intercept and random-coefficient model. The random-coefficient model allows us to investigate whether the independent variables have different impacts on private investment by including a random coefficient in the model.

The random-intercept and random-coefficient (slope) model is as follows:

$$y_{ijt} = \mu_j + \sum \alpha_{kj} x_{ijt} + \beta_j v_{it} + \gamma_j z_{it} + \delta_j w_t + \varepsilon_{ijt}. \quad (3)$$

Finally, we test whether we need to include unstructured covariance in the random-intercept and random-coefficient model. Unstructured covariance is necessary when there is a correlation between the slopes and the intercepts. Using the LR test, we investigate whether the added correlation estimate is necessary; that is, the random-intercept and random-coefficient model is nested in the random-intercept and random-coefficient model with unstructured covariance. The test rejects the null hypothesis of the random-intercept and random-coefficient model ($\chi^2(1) = 7.02$ with $Prob > \chi^2 = 0.01$) in favor of the random-intercept and random-coefficient model with unstructured covariance. The correct p-value from using a 50:50 mixture of $\chi^2(1)$ and $\chi^2(2)$ as the null distribution (Rabe-Hesketh and Skrondal 2012, 266) ($Prob > \chi^2 = 0.02$) does not change the conclusion that the test rejects the random-intercept and random-coefficient model in favor of the random-intercept and random-coefficient model with unstructured covariance.

The LR test, versus the linear model, the results of which appear at the bottom of Table 8, tests whether there is a significant difference between the multilevel model and the standard regression with no group-level random effects. The results show significant differences; thus, we prefer multilevel models.

4. EMPIRICAL RESULTS

Based on the results of the Hausman (1978) test and the LR tests above, we use the random-intercept and random-coefficient model with unstructured covariance (Eq. 3). We present the results of this model in column 5 of Table 8. We also provide the results of other models for comparison in Table 8.

Table 8 presents the empirical results of four models: random intercept (column 2), fixed intercept (column 3), random intercept and random coefficient (column 4), and random intercept and random coefficient with unstructured covariance (columns 5 and 6). Since the data availability regarding the *cost of renewables* variable is limited, columns 2–5 exclude this variable. The results of the estimation including the *cost of renewables* variable are in column 6.

The *fuel price*, as expected, has a positive effect on private investment in renewable energy. As the price of fuel, the substitute for renewable energy, increases, private investment in renewable energy also increases. That is due to the fuel-switching effect, which decreases the demand for traditional fuel due to its high price in favor of renewable energy, which in turn raises the private investment in renewable energy. This is also in line with Taghizadeh-Hesary, Yoshino, and Inagaki (2018). Ruzzenenti and Papandreou (2015) perform an analysis of the influence of the fossil fuel price on low-carbon energy systems. Their discussion suggests that maintaining the oil price plays a role in smoothing the transition to a sustainable energy system. Cheon and Urpelainen (2012) carry out an empirical analysis of the influence that the oil price has on the technological advances in renewable energy. The analysis shows that an increase in oil prices results in an increase in factors such as public renewable R&D expenditure and renewable patents. Wong et al. (2013) obtain similar results. They conduct an analysis of the elasticity of energy R&D in relation to changes in oil prices. Their results show that oil prices have a positive correlation with renewable R&D.

Surprisingly, the *price of electricity* and the *government RD&D* in renewable energy variables do not have a statistically significant impact on private investment in renewable energy.

The empirical results provide evidence of a positive impact of two renewable energy policy instruments, namely feed-in tariffs and loans, on private investment in renewable energy. The impact of loans is stronger than that of feed-in tariffs. The implementation of feed-in tariffs can increase the share of private investment in renewable energy in the total investment by 0.10%. At the same time, loans can increase the share of private investment in renewable energy in the total investment by 0.18%. There is no evidence of the impact of taxes, grants, and subsidies on private investment in renewable energy.

Table 8: Empirical Results

Variables (1)	RI (2)	FI (3)	RI and RC (4)	RI and RC u.c. (5)	RI and RC u.c. (6)
Government RD&D	0.00**	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Feed-in tariff	0.10***	0.11***	0.10***	0.10***	0.00
	(0.04)	(0.04)	(0.04)	(0.04)	(0.05)
Taxes	0.00	–0.04	–0.05	–0.05	–0.08
	(0.06)	(0.05)	(0.05)	(0.05)	(0.07)
Loans	0.19***	0.15***	0.18***	0.18***	0.16**
	(0.06)	(0.05)	(0.06)	(0.06)	(0.08)
Grants and subsidies	–0.02	0.05	–0.01	–0.01	0.06
	(0.04)	(0.04)	(0.04)	(0.04)	(0.06)
Electricity price	0.00	–0.00	–0.00	–0.00	–0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Fuel price	0.00	0.00*	0.00**	0.00**	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Cost of renewables					–0.00
					(0.00)
Renewables' binary variables	No	Yes	Yes	Yes	Yes
Wind		–0.02	0.13*	0.15*	0.08
		(0.05)	(0.08)	(0.08)	(0.10)
Hydropower		–0.50***	–0.32***	–0.29***	–0.42***
		(0.05)	(0.08)	(0.07)	(0.12)
Geothermal		–0.54***	–0.34***	–0.31***	–0.48***
		(0.05)	(0.08)	(0.07)	(0.11)
Wave and tidal		–0.55***	–0.34***	–0.32***	–0.41***
		(0.05)	(0.08)	(0.07)	(0.15)
Biofuel		–0.50***	–0.27***	–0.24***	–0.42***
		(0.05)	(0.08)	(0.08)	(0.11)
Country binary variables	No	Yes	Yes	Yes	Yes
Brazil		0.28**	0.25**	0.24**	0.68***
		(0.12)	(0.12)	(0.12)	(0.19)
Canada		0.03	0.09	0.08	0.22
		(0.08)	(0.10)	(0.10)	(0.14)
France		–0.03	–0.02	–0.01	0.36**
		(0.11)	(0.12)	(0.12)	(0.17)
Germany		0.34**	0.16	0.15	0.88***
		(0.17)	(0.17)	(0.16)	(0.27)
India		0.01	–0.02	–0.03	–0.09
		(0.09)	(0.11)	(0.10)	(0.14)
Italy		0.33**	0.26*	0.25*	0.91***
		(0.15)	(0.15)	(0.15)	(0.23)
Japan		0.17	0.11	0.11	0.55***
		(0.13)	(0.13)	(0.13)	(0.20)
Republic of Korea		–0.05	0.00	0.00	0.17
		(0.08)	(0.10)	(0.10)	(0.14)

continued on next page

Table 8 *continued*

Variables	RI	FI	RI and RC	RI and RC u.c.	RI and RC u.c.
(1)	(2)	(3)	(4)	(5)	(6)
RPC		0.10	0.02	0.02	–0.06
		(0.08)	(0.12)	(0.12)	(0.16)
Spain		0.25**	0.23*	0.21*	0.67***
		(0.12)	(0.13)	(0.13)	(0.21)
UK		0.27**	0.26**	0.25**	0.77***
		(0.11)	(0.12)	(0.12)	(0.19)
US		0.15	0.17	0.19	0.40**
		(0.10)	(0.12)	(0.12)	(0.17)
Constant	0.01	0.28***	0.16	0.14	0.45***
	(0.07)	(0.08)	(0.10)	(0.01)	(0.16)
RE parameters					
Country var. (constant)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Renewables var. (*government RD&D*)			0.00** (0.00)	0.00** (0.00)	0.00** (0.00)
Renewables var. (constant)			0.01** (0.02)	0.01** (0.01)	0.01** (0.01)
Renewables cov. (*government RD&D*, constant)				0.00** (0.00)	0.00** (0.00)
Var. (residual)		0.21** (0.01)	0.17** (0.01)	0.17** (0.01)	0.19** (0.01)
Observations	1,014	1,014	1,014	1,014	676
Number of groups	13	13	13	13	13
Observations per group	78	78	78	78	52
Wald, χ^2	33.97***	420.16***	145.02***	140.45***	125.49***
Log likelihood	–623.57	–652.95	–590.99	–587.48	–453.52
LR test vs. linear model, χ^2	320.42***	0.00	123.92***	130.94***	115.26***

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

RI – random intercept, FI – fixed intercept, RC – random coefficient, FC – fixed coefficient, u.c. – unstructured covariance. We drop *solar* and *Australia* to avoid the multicollinearity problem.

Source: Authors' own.

5. DISCUSSION AND CONCLUSION

Fiscal and financial renewable energy policies can promote renewable energy, but they are also costly for governments. That is why it is important to evaluate their effectiveness. Using multilevel data from 13 countries over the period 2004–16, this chapter investigated the impact of fiscal and financial policy instruments, as well as the impact of government investment in renewable energy, on private investment in renewable energy. Using the likelihood ratio and Hausman (1978) tests, we identified the most appropriate model for estimation: the random-intercept and random-coefficient model with unstructured covariance. Using the random-intercept and random-coefficient model with unstructured covariance, we found empirical evidence of the effectiveness of two fiscal and financial policy instruments, namely feed-in tariffs/premiums and loans. There is no empirical evidence of the impact of taxes and grants and subsidies on private investment in renewable energy.

Feed-in Tariffs

Similar to Eyraud, Clements, and Wane (2013), we found positive effects of feed-in tariffs on private investment; general studies that examine the efficacies of different policies on upscaling renewable energy deployment support this finding. Although feed-in tariffs are attractive for private investment in renewable energy, the cost of this policy is hard for the government to predict. Feed-in tariffs are paid by electricity generated. However, renewable energy sources produce intermittent (variable) energy, which is hard to predict, and thus it is hard to predict feed-in tariff payments. In addition, feed-in tariffs are not necessarily pay for renewable energy generation. When the share of renewable energy is large, renewable energy could be wasted if it is not consumed or stored. For example, in the UK, wind farms received GBP 1 million of feed-in tariffs a week (Mendick 2015) and in Germany wind farms received $548 million of feed-in tariffs (Follett 2016) from governments to be switched off to keep the power systems balanced when the wind was too strong and the wind turbines produced more electricity than customers could consume.

Loans

The positive effect of loans on private green investment corresponds to the fact that, to promote investment from the private sector, lending is crucial. This is in line with Taghizadeh-Hesary, Yoshida, and Inagaki (2018). Some of the renewable energy technologies are immature and capital-intensive; therefore, providing financial means to support the technology development is still crucial at this stage. Compared with feed-in tariffs, the cost of loans to the government is more certain and easier to predict. However, the access of the private sector to loans challenges the implementation of this policy support, especially in developing countries, where the domestic credit to the private sector is lower (World Bank 2017).

Grants, Subsidies, and Taxes

Surprisingly, the effects of the grants and subsidies and the taxes are not significant and even negative. This is indicative of either the lower efficacy of these policies or the presence of different regional effects, such as differences in the energy distribution infrastructure. A lack of energy distribution infrastructure, which this study does not include, can affect private investment in renewable energy negatively (Lopez 2015). Furthermore, private investment in renewable energy might be correlated with investments in electricity networks, energy storage, electric vehicles, and energy smart technologies, such as smart meters. Future research can study the interconnection of all these investments.

Government R&D

We also could not find evidence that government expenditure on R&D encourages private investment. The existing literature provides controversial results on the impact of government investment on private investment. However, there is a lack of literature focusing on the impact of green government investment on green private investment. This study does not provide evidence of either the crowding-in or the crowding-out effect of government investment on private investment in renewable energy. An explanation could be that we also consider the short-term impact. Government RD&D lagged by one and two years is not significant. It is possible that the impact of government RD&D lags by several years. Due to the short time period of data available, 13 years, it is not possible to test the long-term impact in this study.

Limitations

Loans and feed-in tariffs are effective policy instruments in promoting private investment in renewable energy. However, these policies could be necessary but not sufficient to promote renewable energy generation (Azhgaliyeva et al. in press).

The study is limited as it focuses on the determinants of green private investment, excluding investments such as smart technologies, energy storage, and electric vehicles. We do not distinguish between domestic and foreign private investment in renewable energy. Perhaps further studies on green investment could incorporate these issues.

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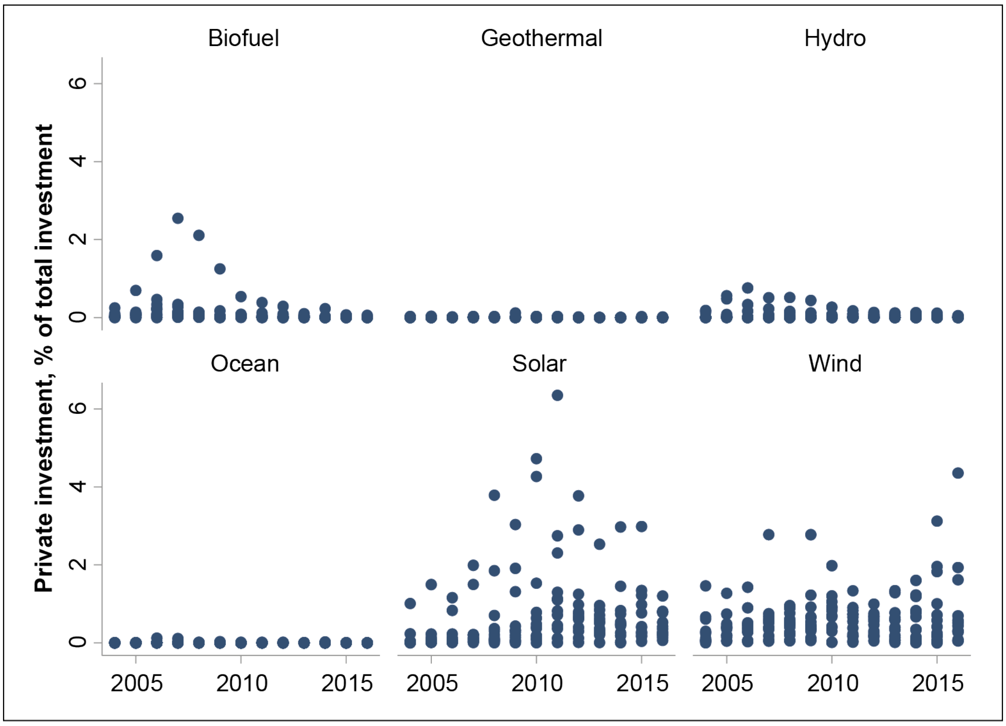
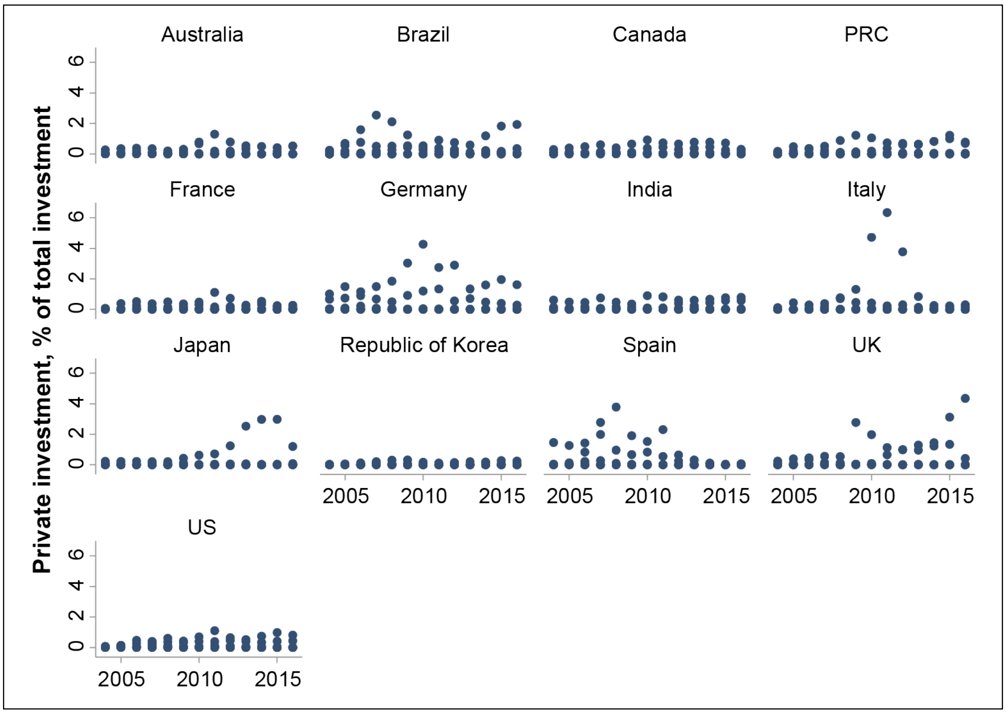
APPENDIX A

Figure A1: Private Investment by Renewable Energy



Data source: BNEF (2017).

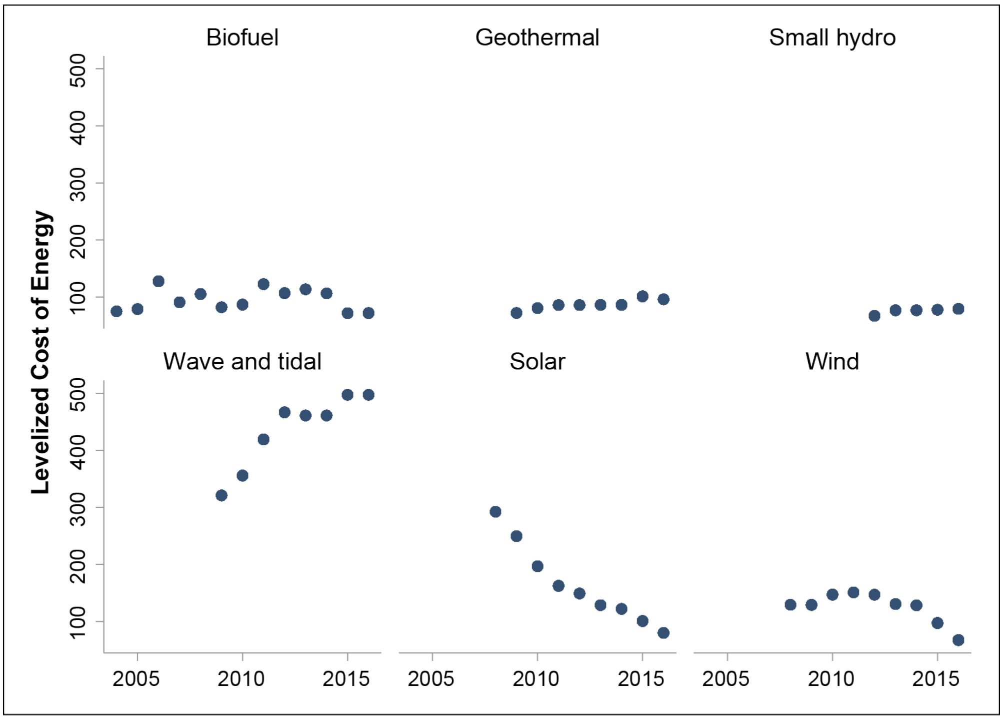
Figure A2: Private Investment by Country



PRC = People's Republic of China, UK = United Kingdom, US = United States.

Data source: BNEF (2017).

Figure A3: Levelized Cost of Energy by Renewable Energy Source



Data source: BNEF (2017).