A research framework for analysing policy implications of investment imperfections in sustainable climate finance

Menglu Zhuang

Oliver Schenker

Project: Sustainable Climate Finance and its Impact (SUFI)

WP1 Research Report

December 2019
# Content

1 Introduction.............................................................................................................1

1.1 Sustainable climate finance landscape ..................................................2

1.2 The role of policy instruments .................................................................7

1.3 Research goal .............................................................................................10

2 Identification of investment imperfections ..............................................12

2.1 Theoretical foundation: Modigliani & Miller and financial
intermediation ..................................................................................................12

2.2 Sources of investment imperfections ......................................................16

2.2.1 Political economy ...............................................................................16

2.2.2 Agency problems ...............................................................................19

2.2.3 Behavioural elements .......................................................................21

2.3 An integrated view on investment imperfections .................................27

3 Integrated modelling and a research framework .................................30

3.1 Modelling of resource allocation and finance ..................................30

3.1.1 Integrated assessment models .........................................................31

3.1.2 Assessment and critical review .........................................................33

3.2 A proposed research framework .............................................................38

4 Conclusion .....................................................................................................41

Bibliography .......................................................................................................42
Abstract

Climate change is one of the key global challenges of the human society. Sustainable climate finance is essential for the transition to a lower-carbon economy. We show in this report that although many investment imperfections in the sustainable climate finance landscape are known among practitioners, most model-based climate policy economic impact assessments do not consider these imperfections. We suggest that models capturing finance and investment imperfections could be able to generate more insights on economic impact assessment of climate policies. To facilitate the discussion and future research of assessment and design of climate policies, this report develops a research framework for analysing policy implications of investment imperfections in sustainable climate finance.

Key words: sustainable climate finance, investment imperfections, policy implications, research framework
# Introduction

Financing a sustainable future requires substantial capital flows (McCollum et al., 2018). The capital needed to finance the measures to reach the United Nation’s sustainable development goals and the commitment of aligning financial flows to cope with climate change as stated in the Paris Agreement underpin the importance of finance. Achieving sustainable development goals by 2030 will require estimated $5 – 7 trillion dollars per year globally, out of which $3.3 – $4.5 trillion dollars annually in developing countries (UNCTAD, 2014). Climate finance, the financing that supports mitigation and adaptation actions to address climate change is one of the most needed types of finance in sustainable development.

Finance serves an important function in the economy. In the transition to low carbon development, the question on how to finance the required investments and where to mobilize the funds are gaining increasing importance (Pollitt & Mercure, 2018). Though most the theorist economists take an ideal stance and assume a perfect market, there are many barriers and limitations in the sustainable climate finance landscape in the real world. Although there are many factors that should fulfil certain assumed conditions so that the market can function perfectly, in reality, market imperfections are there and many factors cannot reach the assumed perfect conditions. We use the notion of *investment imperfection* to describe these market imperfections in the investment sphere. In our definition, *investment imperfections* summarize potential market failures, barriers and limitations caused by political economy effects, principal-agent settings and human behaviours that hinder the implementation of the socially optimal investment path for the transition to a sustainable lower-carbon economy to be reached.

Investment imperfections can present themselves in many ways. Agency problems, characterized by different economic agents with different interests but imperfect ability to contract the actions and intentions of each other, may influence investment decisions, in particular in new, greener, technologies (Haas & Kempa, 2018; Hoffmann, Inderst, & Moslener, 2016). Financing going through diverse
institutions operating in different political economic systems could incur inefficiency due to a significant amount of transaction costs (Lessmann, 2019). Moreover, the factors that form individual beliefs and respond to peer pressure affect the decision of whether and to what extent an investor is willing to invest into sustainable climate technologies (Anderson & Robinson, 2019).

The ex-ante impact assessment of policies with techno-economic models (such as integrated assessment models), which serve an important role in policy decision-making are adopted widely. Technology details and various economic parameters have been developed and used in the models, but finance is largely ignored across different modelling approaches. For the sake of simplification, it is assumed that rational and fully informed agents acting on efficient financial markets, thus that financing sources are allocated optimally and the system of channelling financing from sources to recipients, sometimes via intermediaries is frictionless. However, this assumption can be rather easily challenged by the investment imperfections. The disparity between the importance of finance in reality and the assumptions on finance in the models motivates us to develop a research framework for the analysis of investment imperfections and their policy implications. A model without adequate details of finance may have missed some key insights that are essential in assessing and designing climate policies.

1.1 Sustainable climate finance landscape

In this report, we look at the issue of mobilising financial sources that are used for climate mitigation, and climate adaptation activities. The landscape of sustainable climate finance, where actors interact and are incentivised has a rather complex construction in reality. Many imperfections go into the landscape. This makes the assumption of techno-economic models on a benevolent dictator maximising social welfare in many respects unrealistic.

Under perfect information, a simplified version of a financing activity involves two parties, the financier and the recipient or borrower. The funding flows from the financier to the recipient based on a mutual agreement, based on which the
financier can expect a return from the money invested. In the real world, a complete process of a sustainable climate financing activity generally involves more than two parties. In indirect financing, frequently there are financial intermediaries in between such as banks and asset management firms, who help financiers and recipients to find one another and use specialized financial knowledge to facilitate the financial deals among them.

The landscape of sustainable climate finance is characterised by multiple financing sources, various intermediaries, numerous instruments and differentiating recipients (see Figure 1). The economic agents in the landscape are either public or private in nature. A substantial number of public entities serve as financing sources and intermediaries. Due to a lack of global implementation of mature market-based mechanism such as an emission trading system or global carbon tax, many mitigation projects rely on public subsidies to reach commercial viability. The lack of liquidity of long-term financing for new energy projects is mainly addressed by public financial intermediaries that provide long-term loans to the market.

Generally, private intermediaries and financiers expect the risks that they take on in the investments to be properly compensated, thus they are willing to be involved only if the projects offer market-rate returns. Nevertheless, there are also investors have altruism as motivation to invest in lower-return projects that focus on social impacts to internalize the externality (Nilsson, 2008).

Public financing sources for sustainable climate finance come from government budgets. The private financing sources are from households, corporate actors and project developers. Government budget comprises domestic revenues generated from general taxes, carbon taxes and/or auctioning of carbon permits, if any.
Many financial intermediaries are involved to channel finance from financiers to recipients. Development finance institutions such as bilateral, multilateral and national financial institutions are a key type of public intermediary as they intermediate a substantial share of climate finance in the landscape. These institutions receive and channel finance mainly from the government budgets, but also channel a small portion of it from external private financing sources to recipients. Other public intermediaries are the agencies for channelling bilateral and international aid as well as the funds for channelling dedicated funding for climate finance. Private intermediaries are profit-driven institutions, including commercial financial institutions, private equity and venture capital, infrastructure funds and institutional investors.

Financing instruments for sustainable climate finance can be categorised into instruments based on subsidies and commercial financial instruments. Examples of
the former are grants and low-cost project debt (concessional debt); examples of the latter are project-level market-rate debt and equity, as well debt and equity financing on the balance sheet. Public financing source entities and intermediaries mainly employ instruments based on subsidies / grants, concessional and market-rate loans, with the goal to increase the attractiveness of the sustainable climate projects. Given the profit-driven nature, private financing source entities and intermediaries use commercial financial instruments, e.g. market-rate debt and equity.

The recipients of sustainable client finance are categorized into public, private, and mixed (public & private). Public recipients are for example countries. Private recipients are mainly in the private sector. Mixed type of recipients is formed by the public and private relationship.

Finance flows through various channels. These channels are formed by the different combination of sources, intermediaries and instruments. The starting point of the financial flow is the source(s), and the ending point is the end uses. Recipients putting finance into uses is the last step in this process. If the recipients are from the private sector, the private sector can usually directly put funding into projects. However, if the recipients are local governments that have received climate funding from international public sources, they frequently have to delegate the tasks of finding on-the-ground project opportunities to others. There could be several intermediaries involved in this last step. For instance, the recipient is a national government and disburses funding to the local government. The local government finds a fund management company that looks for project developers that have good projects at hand. Contracts need to be signed among these institutions and the funding will be transferred to the project developers for implementing the projects.
Figure 2 shows the climate finance flow volumes 2012-2016. The figure illustrates the relative importance of different sources, intermediaries and instruments in terms of financing volumes. In 2016, private sources and intermediaries have taken a share of 63.19% in the total finance volume, the rest of which are from public sources & intermediaries. However, we do not know if private sources have a larger volume than public sources because intermediaries may receive funding from either public or private sources, but the clear tracking of public and private origins of funding from intermediaries is not conducted in the landscape. The financial volume that private intermediaries have channelled are less than that channelled by public intermediaries. Combining volumes of private intermediaries and private sources, the private sector plays an important role in funding and challenging funding for climate finance.
By further breaking down the financing sources and financial intermediaries, we see that the development finance institutions, project developers and commercial financial institutions are the most important players within their categories. In public intermediaries, the development finance institutions have a share at about 32.64%, whereas the government and agencies make up 3.66% and climate funds 0.52%. Project developers as a private source of financing have a share of 32.64%. Commercial financial institutions as a private intermediary have a share of 14.36%, households and corporate actors follow with 8.09% and 7.31%. These numbers are all with respectively to the total finance volume in 2016.

With regard to instruments, the commercial type of financing instruments balance sheet finance (including both debt and equity) and project debt are the dominant instrument types, taking a share of 37.63% and 34.14% respectively in the total finance volume. Project equity follows with 9.68%. Project equity ensures that the owners of the project have “skin in the game”. The debt to equity ratio in project financing is usually 70%-30% (Goldman, 2005). Instruments based on subsidy such as the low-cost project debt have a share of 12.10% and grants have a share of less than 4%. We infer that subsidy support is blended into the financing for climate finance projects to reach commercial viability so that private financiers are willing to invest. This is shown by the relative amount of financing from public and private sources and intermediaries.

1.2 The role of policy instruments

In the landscape of sustainable climate finance, we observe that the public financiers and intermediaries have a high participation in financing activities. Climate mitigation projects are mostly projects with business models, allowing them to make returns on their business activities. If there is no viable reason, the real-sector economy should not be intervened by public measures in a market economy. The involvement of the public money in the field of climate finance can be potentially justified to a certain extent if there are dedicated policies behind with the goal to correct market imperfections or failures and that the most efficient policy instrument is not implementable.
The widely-known rationale for regulation in environmental problem is based on negative externality and the tragedy of public goods. The natural environment can be seen as a public good and the market fails because there is no mechanism incentivizing self-interest driven individuals who cause the deterioration in the environment to pay a price for it (Mäler, 1974). To internalise externality, policy instruments are necessary to provide the agents in the economy with incentives to treat the environment as a scarce resource (Mäler, 1974), for example through a unit tax proportional to damage (Cropper et al., 2019). However, there is to-date, no global level implementation of policies that regulate the polluters to pay the price on carbon, which makes the polluting projects disadvantageous compared to non-polluting projects. An alternative is to enhance the attractiveness of clean technologies and projects by using public subsidies. Subsidies are currently the dominant policy approach in sustainable climate finance largely due to the preserving externality problem in environmental issues and the failure of global mutual agreement on implementing carbon pricing. Both instruments are in general equivalent in terms of costs; the differences are in the distributional effects (Coase, 1937). With maturing climate mitigation technologies, it can be expected that less public subsidies are required to leverage the same amount of private capital.

A range of policy instruments is available for addressing environmental problems and climate change. The most relevant instruments are carbon pricing (price-based), tradable certificates and permits (quantity-based), feed-in-tariffs (and support schemes done through power purchase agreement auction) and various investment support programs. Traditionally, there is also command & control instruments and standards issuing. These instruments are criticized for not being able to identify cost-minimisation solutions, but are still prevalent in the climate policy scene, e.g. emission standards for car and building codes. Figure 3 provides an overview of the policy instruments. It shows that public investment, concessional loans and grants are used by the largest number of countries around the world, followed by feed-in-tariffs.
Though policy instruments are not explicitly mapped out in the climate finance landscape, the influence of policy instruments on climate financing is substantial. Policies affect the revenues and costs of polluting and clean-technology projects, thus changing the relative attractiveness of projects for financiers. A stream of policies such as feed-in-tariff for renewable energy and investment support for climate projects aim at increasing the revenue stream of these projects while leaving the costs to the market force. Another stream of policies such as carbon taxes and emission trading schemes follows the “polluters pay” rule and their goal is to increase the costs of polluting projects.

Different types of financiers have different financing decision-making criteria. Credit holders such as lending institutions prefer projects that have a high probability to repay the fixed obligation of repaying principal and interests of the loans. These institutions look specifically at the down-side risks of the projects and may refrain from lending if perceived risks are higher than they are willing to take, instead of offering the projects higher interest rate as would happen in a perfect financial market --- leading to credit rationing (Wiser & Pickle, 1998). On the contrary, equity investors assess the risk-return profiles of projects and the
compatibility to their risk appetite in order to make investment decisions. The equity investors not only look at down-side risks, but also upward potential of the projects such as the potential of the projects to achieve more financial success than expected. To address the problem with credit rationing, development banks provide long-term financing either directly or through on-lending activities. To attract private equity holders, public money is used in structured fund as risk buffers.

Another key role that policy instruments play in the financial market is through the mandating of disclosure requirements. Financial and non-financial institutions are increasingly required by authorities to disclose environmental performance and climate-related risks in their products and services. An example is the European Union, which has issued the action plan on financing sustainable growth, setting out a roadmap for legislative and non-legislative actions to strengthen information disclosure. This type of regulation addresses the information asymmetry problem in the market. The financial market is an informative place. Climate-related risks may induce systematic risks to the financial system if climate change hits the real economy on a large scale suddenly, leaving the financial sector little or no time to adjust their lending or investment portfolios. Though the policies for financial institutions are not climate policies per se, these are policies that could have an impact on the development of actions combating climate change by affecting the financial market, thus influencing the access to finance for different types of projects, e.g. climate-friendly against non-climate-friendly projects.

1.3 Research goal

In this report, our research goal is to develop a research framework for answering questions around assessing investment imperfections, and more specifically to facilitate analysing the policy implications of investment imperfections in sustainable climate finance. There is a high level of interactions and complexity among the various financiers, institutional settings, financing instruments, channels, intermediaries and end users. On the policy level, various instruments are there either implemented or in the plan. However, it is difficult to judge how
they lead to different investment behaviours. Even if we have solved the carbon externality, there might still be the investment imperfection problem on top, which we do not understand very well currently.

The following questions come to mind:

- Are there investment imperfections?
- How important are the investment imperfections in influencing the financial flows to sustainable climate activities?
- Which investment decisions should be addressed by policies based on cost-benefit reasoning?

Financing issue in sustainable climate is important in realising the climate goals, but there is a lack of research framework on how understanding and quantifying the investment imperfections and subsequently assess policy possibilities. The proposed research framework should help to study, e.g. the understanding and quantification of the magnitude of investment imperfections, and the assessment of the economic impact of different policies or alternatives to policies for correcting the imperfections. The proposed research framework consists of a process of conducting qualitative analysis to thoroughly understand the related issues to the research objective before conducting quantitative analysis.

The structure of the report is as follows. In Chapter 1, we present a stylized climate finance landscape for understanding the complexity of the landscape. The key components of the landscape are economic agents, institutions, financial instruments and financing channels. This section is followed by a presentation on the role of policy instruments in sustainable climate finance. In chapter 2, we identify key investment imperfections in sustainable climate finance and specify their interactions. In chapter 3, we will review to what extent the modellers for economic impact assessment of climate policies have taken the interactions within the landscape and the financial effects of policies into account. A framework for research is proposed for analysing the investment imperfections and their policy implications. Chapter 4 concludes the report.
2 Identification of investment imperfections

In the current state of the global economy, resource allocation is not changing significantly to enable sharp emission reductions to mitigate the climate-related risks for a low-carbon world. By looking at the landscape of sustainable finance, we suspect that imperfections are very likely to arise because the structure is complex, involving many agents and institutions. The circumstances such as a political system, market environment and culture in which the agents and institutions operate play a role, so do contractual structure between the agents and institutions in the landscape, and inside individual agent and institution at a micro-level, e.g. behaviours. These are some of the key factors that determine the optimal investments for transitioning the world to a low-carbon economy. Sub-optimal investments lead to economic inefficiency and ineffectiveness, therefore, hampers reaching the climate goal. In this section, we will identify the sources of investment imperfections and provide an integrated view on understanding investment imperfections.

2.1 Theoretical foundation: Modigliani & Miller and financial intermediation

Given the scarcity, resources need to be allocated efficiently. Ideally the savings of households are put directly into the investment projects which give the highest risk-adjust returns while taking sustainability criteria into consideration. The investment process is ideally without externalities nor traction costs. This situation corresponds to a world of direct financing under perfect market. In the real world, direct financing is operated under imperfect market. Due to the imperfections and transaction costs of direct financing in the real world, the most significant part of financing is done through financial intermediaries. Because there are transaction costs, information asymmetry and agency problems, the financial intermediaries
come into play to address these problems and make resource allocation and transactions more efficient.

Financial markets have been long ignored by most environmental and energy economists. This is a certain extent justified by Modigliani & Miller’s (1958) capital-structure irrelevance proposition that made them win the Nobel Prize in 1985. The assumptions in Modigliani & Miller theorem include frictionless and competitive markets, same information for all agents, same borrowing rates for individuals and firms, no taxes, irrelevance of the financial policy of the firms on its cash flows (Modigliani & Miller, 1958). Under these assumptions, capital structure is irrelevant because whether to increase financing for the firm with shares or with loans does not matter with regard to the firm’s total value (Brázdík & Marsal, 2011). Based on Modigliani & Miller theorem, Stiglitz (1988) also shows that public financial policy is irrelevant, meaning that short-term or long-term debt choices for governments do not matter.

Interestingly, there is a vast of literature studying the corporate financing decisions, the role of CEOs as well public financing decisions. Financial intermediation and agency theories clearly show that financial markets are not perfect, in particular with regard to information symmetry. These observations raise the question whether the theories that show finance irrelevance are fit to explain the observed phenomena in the market.

Foremost, the assumptions taken in Modigliani & Miller theorem are challenged (Brázdík & Marsal, 2011). The financial market in the real world is featured with imperfections. For instance, the credit market has market imperfection. When the projects have high risks, financial institutions should price in the risks and provide loans with high interest rates under perfect market assumptions. However, financial institutions may restrict lending to specific sectors or specific target groups instead due to information asymmetry, in which the financial institutions are not able to perfectly observe the risks. The consequence is that some projects do not get funded, though they should have been funded under information symmetry. This is phenomenon is named credit rationing. Credit rationing as one of
the most important credit market failures is characterised by extremely low or extremely high credit creation (Ramskogler, 2011).

In addition, various incentive problems such as moral hazard, effort problem and risk-shifting problem exist (Jensen & Meckling, 1976). These fall generally under agency theory, which is the study of the dilemma between principal and their agents who make decisions on behalf of the principals. Perfect contracting is not possible in the real world between the principal and the agent, e.g. because the observed outcome is not perfectly correlated to effort, which is unobservable to the principal. Agency costs arise from these imperfections. Because these problems exist, Jensen & Meckling (1976) claims that the optimal capital structure is a structure on the proportion of equity and debt that minimises the agency costs arising from the conflicts of interests between insiders and outsiders and between equity holders and debt holders. Information asymmetry, which leads to adverse selection and moral hazard of borrowers is an important source of market failure. Well-known cases coming from information asymmetry include adverse selection where the bad borrowers are likely to be the ones who actively apply for loans and moral hazard where the borrowers may engage in activities that the lenders do not desire after obtaining the loans (Igawa & Kanatas, 1990; Berndt & Gupta, 2009).

Moreover, the Modigliani & Miller theorem claims the irrelevance of financial decisions of firms, but does not make statements about the function of financial institutions. In another word, the theorem is interested in what is the optimal financing structure for firms, but it is not interested in where and how firms can obtain funding. To study the latter, we need to refer to the theories on functions of the financial system and theories on financial intermediation. Formally speaking, a financial system facilitates the transfer of funds from savers to spenders who need the funds (Boot & Thakor, 1997). The financial sector is a sector made up of institutions which provide financial services; both financial intermediaries such as banks as well as public financial markets where securities are directly traded. The functions of the financial system include channelling funds from savers to spenders,
reconciliation of consumer preferences, payment mechanism, and risk transfer (Boot & Thakor, 1997).

The existence of financial intermediaries, via indirect financing for companies to obtain financial resources is evidence that the assumptions about symmetric information, same interest rates for all borrowers and no transaction costs do not hold in reality. Indirect finance refers to financing through financial intermediaries. Compared to direct finance it is the more important channel; especially loans and bonds, compared to stocks, are the more important source of funds for raising external funds for firms (Beck, Demirgüç-Kunt, & Maksimovic, 2008). In asset transformation theory, financial intermediaries are able to conduct transformation of maturity, size, liquidity and risk and banks take and try to minimize risks by credit scoring and diversification (Mishkin & Eakins, 2006). In addition, financial intermediaries can effectively reduce costs of search, verification, monitoring and auditing, and enforcement with economy of scale, economy of scope, and technology (Mishkin & Eakins, 2006). Banks are good at dealing with information asymmetry with enhanced information and by conducting delegated monitoring for their clients to lower agency costs (Diamond, 1996).

It might well be a misunderstanding that because the environmental economists have not paid much attention to financing, then financing is not important. In fact, while financing might be less of a relevance in certain disciplines on an aggregate level. For example, financial asset of one individual is offset by the financial liability of another person (Parker, 2010), thus on an aggregate level, financial assets cancel out. It may be that though finance is very important, the complexities of financing activities and the obscure relationship financing has with the economy are too difficult to capture technically. Therefore, techno-economic models have the tendency to simplify financing activities and the importance of investment decision-making.

A concrete example is in macroeconomics. Macroeconomic theories largely ignore the role of financial intermediation. We define investment as the action to forgo consumption today with the expectation of obtaining higher future consumption. It
has a micro-founded meaning because the action is taken based on the decisions of individuals. In macroeconomics, the aggregate matters, not the individuals, and thus investment has a different meaning. Investment is a volume and it is equal to the amount of goods that are not consumed at the present time. The treatment of investment in this way simplifies finance to a volume, missing the processes and complexities involved in the financing activities. More and more studies reveal the importance of the financial sector, particularly after the 2018 financial crisis. Macroeconomic models are criticized for not modelling the financial sector and not being able to detect financial crisis (Pollitt & Mercure, 2018).

2.2 Sources of investment imperfections

As illustrated above, some theories claim financial decisions are irrelevant, but does not further discuss the role of finance, but other theories on financial intermediation and agency theory state clearly the imperfections and problems that exist in financing and in management and delegation.

In this section, we identify several key investment imperfections based on agency theory, but also expand it to include political economy and behavioural elements. The political economy sets the rules and stages for economic agents. The principal-agent relationships specify the problems of interacting economic agents. And the behavioural elements concern individual agent interacting with the context he/she is. These are sources of investment imperfections and we discuss them based on observed phenomena in the field of sustainable climate finance.

2.2.1 Political economy

In section 1.2, we have discussed how policies can affect the investment decisions of financiers. Combating climate change requires collective efforts on the political level. Without climate policies, the global temperature is highly likely to rise beyond 2 degrees while the more ambitious 1.5-degree scenario requires substantial policies to sharply reduce emissions worldwide. Climate policies are used to correct market failures. If market failures are corrected by imposing carbon
price globally, the production activities that are conductive to the climate and the environment should be preferably financed. However, as will be explained below, even when the market failures in the real sector are corrected, there could still be imperfections that make resource allocation and financing flow impeded by frictions. For instance, we have identified imperfections in the political economy system that hinder effective climate policies, eventually this would lead to aggregate climate finance volume to be smaller than it should be. Many aspects of the political economy aspect may affect the policy direction and ambition, e.g. the role of the government in the political system and ways of resource allocation, policy implementation styles, and the power of lobbying groups.

The political commitment of the largest emitters of today and the largest emitters of the past during industrial revolution play important roles in international negotiations. Currently, China and India are the largest emitters in the world and are likely to remain so in the coming years (Rong, 2010). The U.S. and the Europe are industrialized countries that have had high emissions during industrial revolutions. These countries have different political, economic structure, and are thus faced with different types of imperfections. In the following, we discuss these differences and some of the induced imperfections in general.

Depending on the nature of the economy, the perceived functions of the government in the economy are different. In a market economy, the driving thinking for policy making in the economy is based on the invisible hand allocating resources and the government should not intervene unless there are market failures. In a non-market based economy where the central government oversees and steers the economy, the key function of financial resource allocation is, to a great extent, planned and carried out by the government (Su & Yang, 2000). This is conducted through making strong policies and setting targets and goals for sub-governments to achieve. A significant difference observed in the sustainable climate finance field is the use of financial sector policies for promoting green investments. China has issued green credit policy and green credit guidelines to encourage banks to lend to green projects while forbidding them to lend to a list of
high polluting technologies (Aizawa & Yang, 2010). This practice exists in China and many other developing countries such as Vietnam are willing to consider this approach, whereas it is uncommon and debatable for developed country governments because developed countries with a market economy leave resource allocation to the market.

In the presidential election, the power of the voters drives the political direction of the party on climate policy issues. Politicians worry about the social costs of implementing climate policy measures. Thus, it could be that presidential candidates try to cater to the taste of the voters or that the climate and environmental commitments are not carried out after the election. On the contrary, if the public shows strong willingness for more stringent climate policies, the candidates are under pressure to design and implement such policies. For instance, in countries such as Germany, the increasing dedication of the public to more ambitious climate goals and concrete mitigation measures have driven politicians to rethink and act.

A political system with a centralised governmental body may have more power to make stringent climate policies and face fewer difficulties in implementing them. Some evidence is in China, where emission trading schemes have been experimented in several Chinese cities, non-electronic buses are 100% replaced by electronic buses in Shenzhen, and wind farms are constructed rapidly in the countryside, without inducing much protest from the locals. Under the political regime of a centralised government, the citizens consider it to be on the safe side to support the development policies of the central government (Kennedy, 2007).

The power of governments affects the way how policies are implemented. In a non-market-based economy, policy making frequently adopts the top-down approach. Overarching strategies are designed at the top-level authorities and are given to the lower levels in the hierarchy. While the career path of lower-level officials depends on the achievements of targets set by the top officials, they have a strong motivation to meet the targets. The advantages of this structure are that the implementation of climate policies can be fast and large scale. The disadvantages
are that there lacks flexibility and meeting the targets is usually the only goal, sometimes with unintended side effects. For instance, resettlement is forced when building wind farms, hurting the benefits of the local residents, or that wind farms are built to meet the quantity requirements, but the connection of wind to the grids is ignored because the target does not measure electricity generation.

Besides individual voters, big corporations can affect the policy making of the governments. Lobbying is an activity exists both under both democratic and authoritarian political systems. Interest groups use lobbying to influence climate policies (Gullberg, 2008a). Organised lobbying against climate policies comes from big corporations, including companies from the fossil fuel, utilities sectors and companies in the transportation sector. Climate policies put their businesses under disadvantages and the companies have an interest to keep their status quo. While there is lobbying against climate policy, there is also lobbying for climate policies. These can be observed in Germany, where schools protest for stronger climate policies and actions. In China, regulations and policy decisions are also heavily influenced by large corporations (Deng & Kennedy, 2010).

Last but not the least, in international climate negotiation, governments frequently pay substantial attention on whether the countries stay on board, and less about efficiency. Sustainable climate finance in this sense is used as side payment to form a coalition, not prioritized on the efficiency of projects, but how to use the investments to build a coalition (Hovi, Sprinz, Sælen, & Underdal, 2016).

### 2.2.2 Agency problems

The principal-agent problem is a problem where the agents have incentives to deviate from the best solutions for the principal. In section 1.1, we have seen the landscape of sustainable climate finance. Many institutions that channel climate finance is in a principal-agent relationship and each pair of them has some frictions. We identify the principal agent problem as an investment imperfection which hinders financial flows in climate finance to flow smoothly. The consequences of the frictions are on the one hand the loss of funding, meaning that the financiers
who are willing to finance under perfect conditions withdraw from doing so. Public money sources shun away from countries that have governance issues in using international funds. Private money sources are even more sensitive to financial market conditions and the trustworthiness of the borrowers. On the other hand, the transfer of funds from one agent to another result in a substantial cost of time, delaying the implementation of projects, a substantial cost factor given the limited time of substantially reducing emissions. Without liquidity provided by the financiers, some projects have to be abandoned, both in privately financed and in publicly supported projects.

Principals delegate tasks and activities to the agents because agents have specialized knowledge. In sustainable climate finance, there are many pairs of principal-agent relationships, e.g. international finance institutions and national government, national government and local government, local government and specialised finance firms, specialized finance firms and project developers. International development banks do not have the function of allocating resources within the country. National and local governments usually do not have the capacity to find project developers and project opportunities. Specialised finance firms such as asset management companies usually do not have the function to implement projects. Thus, through contractual relationships, they find counterparts that can carry out the intended tasks for them.

In sustainable climate finance, the principal-agent problems among different pairs can result in substantial efficiency losses. International donors provide funding to national governments. National governments may have other priorities such as to solve hunger problems before combating climate change, thus they may choose to spend the funding for climate for something else. Some governments may be corrupt and will use the funding for personal benefits (Tavares, 2003). The local governments may also use the funding for purposes other than climate and be corrupt. Specialised finance firms are delegated to find good project opportunities and channel the money to them. The specialised finance firms may have local connections and provide these connections the money, though there are better
The project developers in the country. The project developers have more information about the project development capacity than their financiers, and thus may use the information advantage to develop more risky projects for expected higher returns.

There are many measures with the aim to mitigate the principal agent problems in sustainable climate finance. For example, there is result-based financing mechanism, and intensive monitoring and detailed reporting requirements for the use of funding. Nevertheless, the measures do not eliminate imperfections and they also have high costs.

In a corporate setting, principal-agent problem is about setting contracts and incentives. An incentive structure in the organisation will have a high effect on how the employees behave. If the incentive structure is short-term oriented and focus on profit maximisation for the organisation, then the employees may forego the sustainability considerations in their decision-making and look for projects that maximise profits.

Last but not the least, uncertainties and risks affect the relationship between principal and agents because perceived and uncertainties and risks frequently come from the action of one-party hiding information from the other party. In the context of climate change, perceived uncertainties can come from project developers who hide true riskiness of the projects, politicians hiding information about the retrospective change of policies, but uncertainties can also come from the fact that there is no information about the situation. In the latter case, it is called deep uncertainty, where distribution and type of risks are unknown.

### 2.2.3 Behavioural elements

While classical economics assumes that all economic agents are rational, behavioural economics and behavioural finance have challenged this assumption. In the real world, the behaviour of agents is not always rational. Behaviour affects many aspects of the economic life, also including the investment decisions. Investment decisions are made based on factual elements and also institutional
and behavioural elements. Factual elements are stated facts that are objective in nature. Behavioural elements are subjective and merge from the experiences of the agents and the context the agents operate in. Because behavioural elements affect all agents in the economy, we make a rough distinction and discuss the behavioural elements of retail investor and those of employed agents in public and private institutions separately.

**Retail investors**

When making rational investment decisions, investors evaluate the risk-return profile of their portfolios and maximize returns based on their investment preferences. In rationality assumption, feelings do not play a role. However, Lucey & Dowling (2005) shows that feelings affect investment decisions, leading to predictable equity pricing. In the context of investing in sustainable climate technologies, there may be people who demonstrate altruism for doing social good while other people demonstrate fear towards new technologies.

*Figure 4* shows a stylized investor decision-making chart. The original chart from Masini & Menichetti (2013) was calibrated for renewable energy project investments. Here we have adapted it to present decision-making process of investors for general sustainable climate investments. Various non-financial factors affect decisions, including the confidence, institutional and peer pressure, as well as attitude.

The confidence level for policy and new technology is based on track-record and past experiences, as well as the cultural the individual is in. It could be that when it comes to the confidence for policy effectiveness and technology adequacy, the agents evaluate what they have experienced in the past to estimate the likelihood of getting a good result in the end. This is not an accurate numeric calculation, but rather an intuitive estimation based on gut feelings.

The opinions of investment experts, technical experts and peer affect the investment decisions of individuals. Especially when the retail investors have not
built up own opinions on the investment issues and have a high level of trust in experts, they are likely to invest according to recommendations.

On the more emotional level, investors demonstrate altruism (Puaschunder, 2018). Altruism is a characteristic of an agent which uses the resources of his/herself to benefit others. It is associated with “warm glow” feeling. We hypothesize that the characteristic should be more obvious when the investments have a clear link to doing social good. When the link is less apparent, it could be that investors are less likely to accept a lower-than-market rate of return. Altruism is a good deed, but in a financial world, if less-than-market rate projects are chosen based on altruism instead of choosing market rate projects (which signal a better project quality), then the resources are not allocated efficiently.

Emotions such as fear or, when in a weaker form, the non-acceptance without rational reasons for the unknown also play a role in investments (Shiv, Loewenstein, Bechara, Damasio, & Damasio, 2005). Investment is a field that requires specific knowledge and experiences. On top of it, underlying companies that are in different sectors have different technologies, which require specific know-how to understand. Investors do not necessarily have this type of knowledge, thus there is the delegation of portfolio management to asset managers. However,
the investors still can influence the portfolios by stating their emotional preferences. Some of them may specifically seek climate friendly and socially beneficial projects while giving up a certain amount of returns. Others may specifically avoid new technologies due to a sense of fear for the unknown.

Political obedience is another characteristic that economic agents demonstrate under authoritarian political systems (Edmundson, 2010). When the economic agents question less about the policies of the government, there are fewer discussions about the policies. The advantage is that if the policies are good, the implementation of the policies will be smooth. The disadvantage is that bad policies are not protested against, and there are fewer discussions about the topic, meaning that the general public leaves the matter to the centralized government and thus the general public lacks awareness and lacks own initiatives.

**Employed agents in public and private institutions**

There are many employed agents that work in the public and private institutions which are shown in the sustainable climate finance landscape. The behaviour of these employed agents also plays a role. In a broad term, politicians are publicly employed. Personal motivation, family expectations and environment in which people grow up have a high influence on the personality of the individuals, and affecting their decisions in economic activities. The consideration here is that some employees will have a strong preference for leisure rather than work, while other employees may have a stronger motivation for promotion and career. While we have mentioned the incentive structure on the behaviour of employees before, it is possible that some employees demonstrate the irrationality by not responding to the incentive structure and a bonus system.
After the discussions above, we have summarized in Table 1. The investment imperfections as well as some evidence of the potential consequences of these imperfections in sustainable climate finance, sometimes borrowing evidence from studies in other field.

Some questions that we have asked when identifying the sources of investment imperfections include:

- Is there any imperfection that potentially hinder the financial volume to reach the optimal amount for combating climate change on a local level, but also on a global level?
- Do all the financiers who are willing to finance have done so?
- Is the funding allocated efficiently and effectively to end users?

Consequences induced by investment imperfections include that the volume of finance does not reach the desired amount, there are financiers who are willing to finance, but could not do so due to imperfections, and funding is not allocated efficiently and effectively to end users as well as the possibility that during the funding flow path from financiers to end users, transaction costs are not minimized.
<table>
<thead>
<tr>
<th>Sources</th>
<th>Investment imperfections</th>
<th>Examples</th>
<th>Consequences</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Political economy</td>
<td>Political system-induced</td>
<td>Voter power</td>
<td>Politicians face difficulties to push climate agenda through if the majority of the voters are not for strong climate policies.</td>
<td>(Harrison, 2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lobbying</td>
<td>Corporations lobby against stringent sustainable climate policies.</td>
<td>(Gullberg, 2008a, 2008b)</td>
</tr>
<tr>
<td>Principal-agent setting</td>
<td>Information asymmetry-induced</td>
<td>Adverse selection</td>
<td>The riskiness of the projects that the potential borrowers will undertake cannot be fully identified, resulting in the inability of banks to match risk adjusted loan interest rates to the borrowers correctly.</td>
<td>(Ramskogler, 2011) (Haas &amp; Kempa, 2018)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moral hazard</td>
<td>Borrowers use the funding for purposes which are not desired by the lenders.</td>
<td>(Igawa &amp; Kanatas, 1990) (Berndt &amp; Gupta, 2009)</td>
</tr>
<tr>
<td></td>
<td>Risk induced and unknown-induced</td>
<td>Risks, deep uncertainty</td>
<td>Project risks and policy uncertainties, if not properly mitigated, hinder investors to act. Asset pricing models and risk management formula still cannot take deep uncertainty into consideration.</td>
<td>(Blyth et al., 2007) (Hailegatte, Shah, Lempert, Brown, &amp; Gill, 2012)(Hamarat, Kwakkel, &amp; Pryut, 2013)</td>
</tr>
<tr>
<td></td>
<td>Incentive structure-induced</td>
<td>Bonus structure, contract structure</td>
<td>The decisions of whether to take high risk or low risks in lending are affected by the incentive structures for key decision makers. Firms’ internal financing decisions deviate from the best due to management’s self-interests.</td>
<td>(John &amp; Qian, 2003) (Jensen &amp; Meckling, 1976)</td>
</tr>
<tr>
<td></td>
<td>Incentive &amp; uncertainty-induced</td>
<td>Short-termism, long-termism</td>
<td>Financial institutions are short-term oriented in doing businesses and making investments. Socially responsible investors have longer-term investment time horizon, but the asset managers may be driven by short-termism.</td>
<td>(Dallas, 2011)</td>
</tr>
<tr>
<td>Behavioural elements</td>
<td>Culture-induced</td>
<td>Local culture, company culture</td>
<td>Adoption of new technologies is affected by cultural contexts. Financing decisions in organizations are affected by company culture.</td>
<td>(Ho, Huang, Lin, &amp; Yen, 2016)</td>
</tr>
</tbody>
</table>

Table 1: Investment imperfections (source: author’s presentation)
2.3 An integrated view on investment imperfections

Integration deals with combining different systems and allowing the inputs and outputs of the systems feed to each other. In studying the investment imperfections and their consequences on achieving climate goals, the investment imperfections from different sources, viewed as coming from different but interacting systems should not only be observed independently of one another, but also analysed integrally because they have interdependencies. *Figure 5* shows a graph with a standard financial market structure. The sources of investment imperfections are marked in yellow boxes. Political economic factors have an influence on the context and environment in which the financial market players do businesses. Information asymmetry’s most presenting form is the agency problem discussed in section 2.2. This problem exists among all the principal-agent relationships in the market. Moreover, behavioural elements affect all players, not only savers, borrowers, but also employees of the financial intermediaries and financial markets (here a financial market refers to the market where direct finance takes place).

*Figure 5: Sources of investment imperfections in the financial system (source: own presentation)*
There are intersections among the three factors, political economy, principal agency and behavioural elements, as shown in Table 2.

<table>
<thead>
<tr>
<th>Matrix of interactions (hypotheses)</th>
<th>Agency problems</th>
<th>Behavioral elements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Political economy</strong></td>
<td>- Government-corporate relationship (collusion, cooperation based on mutual benefits, lobbying) (1)</td>
<td>- Political system induced (dis)credibility &amp; confidence - Political culture &amp; idealism (2)</td>
</tr>
<tr>
<td><strong>Agency problems</strong></td>
<td>/</td>
<td>- Not responsive to incentive structures - Informal relationship building - Personality compatibility between agent &amp; principal (3)</td>
</tr>
</tbody>
</table>

*Table 2: Interactions among sources of investment imperfections (source: own presentation)*

Looking at (1), the principal-agent relationships can be put into the specific political economic context. Government and corporation are in a principal-agent relationship. The relationships can be described in several directions, for example, local government colludes with local companies to disobey the national regulations. Corporations may also choose to establish a good relationship with the government thus to be in an advantageous position to get climate funding. Corporations and the government may also be in an opposite position, in which the corporations lobby the climate policies of the government. The political economy and political culture largely determine the types of relationship the government and the corporation take.

Looking at (2), political credibility and political culture have an influence on the behavior of the citizens. If the political head of the country has a short office period, there is likelihood of policy changes when the new political head takes office. Turbulent political situations are likely to decrease the confidence of the citizens in its government. In addition, the political culture affects the openness of communication and how people react to policies. Under an authoritarian political culture, citizens show obedience and follow the policies issued by the government.
without many questions. In more extreme cases, citizens who are immersed in a political culture adopt a type of idealism and consider supporting the policies to be the honor and duty of each citizen. And the behavior of the citizens also has an impact on the political scene of the country, e.g. the climate change video by a German youth on the internet has affected the election results of the German political parties.

Looking at (3), the principal-agent relationship involves people, and people are characterized by their behaviors. Models have been built on agency theories to study the incentive structure on human behavior based on rationality. However, it could be that some people do not respond to the incentive structures because of own preferences, e.g. leisure time is more important than more money. On an individual level, the principal and agent have a formal business relationship, but may also have informal relationship building. For instance, business partners develop friendship after working together for a long time. Moreover, the personality compatibility between the agent and the principal affects the working relationship.

Based on the evidence gathered in Chapter 1 and Chapter 2, we propose in the next chapter a research framework to study the investment imperfections and their policy implications.
3 Integrated modelling and a research framework

The treatment of the financial sector in macroeconomic models is important because the question on how and whether more investment resources should be mobilized is crucial to understanding the path to low-economy and sustainability (Pollitt & Mercure, 2018). Currently, banks and the financial sector in general are treated in macroeconomic and energy system models by imposing assumptions (Pollitt & Mercure, 2018).

The climate and energy policies based on the models which essentially not reflecting the reality are likely to lead to the misallocation of resources in the economy. For instance, computable general equilibrium models used in assessing climate and energy policy may lead to “crowding out” of capital by simplifying the assumptions on the financial sector (Pollitt & Mercure, 2018).

In the following sections, we will look at integrated assessment models and see whether it has a structure in place to study the resource allocation and financing in transitioning the economy to a low-carbon one.

3.1 Modelling of resource allocation and finance

Finance plays a key role in resource allocation. However, it is not precise to state that finance alone carries the function of resource allocation. Resource allocation is a process that involves many steps. In general, the pricing of assets in the market is the key element that decides the allocation of resources in a free market. The pricing is based on information available in the market, thus information is the fundamental starting point. The pricing is determined by the analysis and opinions from the market players that consists of the analysts, retail investors, institutional investors and many more. Though the information is produced in the financial sector and financial institutions carry out the function of disbursing funds to
suitable projects, it will not work without firstly information availability in the market, and secondly the market players that determine the pricing of assets.

Figure 6: Climate-economic model (source: own adaption based on (Hasselmann & Kovalevsky, 2013))

To study the resource allocation in climate finance, it is necessary to put it into an integrated system as shown in Figure 6. The model includes climate system, climate policies and the economic system. It is within the economic system that information, asset pricing, financial resource allocation takes place. Currently, the methodology to study such systems are the integrated assessment models.

3.1.1 Integrated assessment models

Economic impact assessment of climate policies using a modelling approach is based on economics foundations, in particular the microeconomics foundation. The integration of climate policy analysis and economic impact assessment did not exist until the early 2000s. Bill Nordhaus (1991) brought costs and benefit policy analysis to application in the field of climate change. In 2018, Nordhaus won a Nobel Prize for his work on integrating climate change into long-term macroeconomic analysis. Research on global warming shows that a drastic reduction in greenhouse gases is necessary, however, control strategies for greenhouse gases have its costs. The rationale of Nordhaus’s work is to provide a framework in weighing the costs and benefit of climate change and the control strategies, where optimal cuts are calculated based on the maximisation of the social welfare.
Nordhaus found that in a medium damage scenario, optimal cuts in global emissions should be 11% relative to base level and one third in a high damage scenario, where low, medium and high damage corresponds to damage estimates of $1.22, $7.33 and $32.97 per ton CO₂ equivalent (Nordhaus, 1991). The Dynamic Integrated Climate-Economy (DICE) model was presented in 1992 as attempts to “use the tools of modern economics to determine an efficient strategy for coping with the threat of global warming” (Nordhaus, 1992). The model has been updated over the years and is widely used in the studies of induced innovation in the energy sector, the evaluation of optimal adaptation policy, uncertainty and learning (Dietz & Stern, 2015). Amongst others, DICE model has inspired the development Integrated Assessment Models (IAMs), which are widely applied to inform policy on climate change (Stern, 2013).

While there are various publications on assessing the economic impact of different types of policies using integrated assessment models, there is rarely any application to study resource allocation and financing issues. One attempt to use energy system model framework for the investment transition pathway is from McCollum et al. (2018), which studies low-carbon investments in energy system transition using six global energy-economy modelling frameworks to understand the scale and nature of these investments. It shows that much more financing has to be mobilized to close the investment gap between 2° C consistent and 1.5 ° C consistent future (McCollum et al., 2018). However, it does not have explicit modelling of the financial sector and investor decisions.

The integrated assessment models have long provided links between energy and macroeconomic considerations, which provides a good foundation for further research on linking energy and financial sector considerations. Given their long history and wide application, we consider it a potential tool to be used for studying the policy implications of investment imperfections discussed in Chapter 2. In the following section, we look at whether and how resource allocation and financing are considered in the models.
3.1.2 Assessment and critical review

We select several models to see how they capture resource allocation and investment decision-making. Most of them are integrated assessment models that capture the interactions between climate system and economic system. These are DICE, DDM, GTAP, TIMES, MARKAL, POLES, ENV-LINKAGES, WORLDSCAN, REMIND, MESSAGE. The selection is based on the consideration of including modelling approach varieties (see Table 3).

<table>
<thead>
<tr>
<th>Bottom-up Models</th>
<th>Optimisation model</th>
<th>MESSAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TIMES / MARKAL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>REMIND</td>
</tr>
<tr>
<td></td>
<td>Simulation model</td>
<td>POLES</td>
</tr>
<tr>
<td></td>
<td>Dynamic dispatch model</td>
<td>DDM</td>
</tr>
<tr>
<td>Top-down Models</td>
<td>Stylized optimization model</td>
<td>DICE</td>
</tr>
<tr>
<td></td>
<td>Computable general equilibrium model</td>
<td>GTAP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ENV-LINKAGES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WORLDSCAN</td>
</tr>
</tbody>
</table>

Table 3: Classification of Selected Models (Source: author’s recreation based on Helgesen, P. I. (2013))

In the optimisation models, MESSAGE generates investment requirements in the energy sector based on least-cost energy supply. When linked with MACRO, MESSAGE and MACRO have feedback loops to reach a stabilised prices and energy demand level (Messner & Schrattenholzer, 2000). MARKAL supplies energy at minimum global costs. There can be a user defined constraint limiting investments in certain technologies or dictating a portion of the renewable energy generation (Loulou, Goldstein, & Noble, 2004). The TIMES model assumes perfect foresight of investors in making investment decisions in each period and care is given to track cash flow on investments and allocating it in each year of the horizon (Loulou,
Goldstein, Kanudia, & Remme, 2016). Investments in REMIND come from economic output and REMIND solves for an inter-temporal Pareto optimum in investments in each modelled region, which translates into least-cost supply (Luderer et al., 2015).

The simulation model POLES plans power capacities, taking account the investors’ expectations on policies and fuel prices, assuming imperfect foresight. The dynamic dispatch model DDM is designed to model investment decision based on corporate finance theory. The DDM model estimates revenue and costs of an example plant and technology is dispatched when the return of the technology clears the hurdle rate (Department of Energy and Climate Change, 2012).

DICE model’s investment modelling is based on neoclassical economic growth theory where economies invest in capital and technologies by reducing consumption today, which is characterized by intertemporal optimum from Euler equations (Nordhaus & Sztorc, 2013).

In the computable general equilibrium models, GTAP assumes that the nominal investment equals saving, where saving includes domestic saving and net capital inflows from foreign countries (Ianchovichina & McDougall, 2000). The dynamic GTAP uses a disequilibrium approach and perfect capital mobility is assumed; under these assumptions, saving is given to regions with the highest rate of return investments (Ianchovichina & McDougall, 2000). Perfect markets and perfect technologies that have constant returns to scale are assumed in ENV-Linkages model; the model equates investment to savings in each period and rate of returns determine investment allocation across sectors (Burniaux & Château, 2008). In WorldScan, investments are led by savings and savings are determined by population and growth rate of per capita income. In addition, international capital mobility is imperfect, thus real interest rates will be different in different countries (Hayden, Veenendaal, & Zarnic, 2010). The regional savings and investment diverge, but they equal to each other at a global level (Hayden et al., 2010).

*Table 4* summarizes the key findings on the sample models. Due to the assumptions such as perfect market and information symmetry, we see that the
models in the sample do not have structures in place to adequately capture the changes of risks and attractiveness green projects over time; nor do they reflect the real resource allocation processes. In an energy model based on the cost optimisation approach, the investments in the energy mix portfolio predicated for the real world will be equal to the investments required based on cost optimisation. However, cost optimization fails to explicitly capture the complexities of the resource allocation process, where investment imperfections are frequently prevalent. Though cost optimisations is justified with arguments from the perspective of social planner and partial equilibrium, since various decision makers may consider other factors than costs, cost optimisation cannot capture the complexity of the energy system (TrutnevYTE, 2016). In the context of political economy, the questions of who get access to which rents and for what purposes can the rents be used are not captured in the model. This aspect is of relevance for analysing energy policies in which countries corruption is prevalent.

Moreover, a cost-optimal approach fails to take account for the market barriers to climate mitigation and ignoring the interaction among actors who base their investment decisions on micro-economic founded behaviours (Li, 2017). Achieving deep decarbonisation targets are difficult even there is a strong carbon price if the actors are myopic (Li, 2017). Thus, policy strategies on reducing Greenhouse Gases based on the assumption that actors will react fully to the price signal can be flawed. The aggregation of individual behaviour in a model is not necessarily cost optimal (Pfenninger, Hawkes, & Keirstead, 2014). This holds in markets with incomplete information. The full rationality and perfect capital market assumed in the models do not realistically reflect how investors make decisions. Investment decisions are affected by priori beliefs on the technical adequacy of the investments, institutional peer pressure and views of the external consultants (Masini & Menichetti, 2013).
<table>
<thead>
<tr>
<th>Model</th>
<th>Geography</th>
<th>Market</th>
<th>Model type and usage</th>
<th>Investment theory / assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDM</td>
<td>UK</td>
<td>Power market</td>
<td>An integrated power market dispatch model that models investor behaviour and its response to policy interventions</td>
<td>Investment decision-making process based on corporate finance theory</td>
</tr>
<tr>
<td>DICE</td>
<td>World</td>
<td>Economics, policy and scientific aspects of climate change</td>
<td>Integrated assessment model and policy optimization model, where policies are chosen to maximize a social welfare function</td>
<td>Neoclassical economic growth theory, e.g. Solow growth model</td>
</tr>
<tr>
<td>ENV-LINKAGES</td>
<td>World</td>
<td>Macro economy</td>
<td>A recursive dynamic neoclassical computable general equilibrium model that helps governments to identify least-cost policies or policy mixes in a range of environmental issues.</td>
<td>Not specified</td>
</tr>
<tr>
<td>GTAP</td>
<td>World</td>
<td>Entire macro economy</td>
<td>The standard GTAP is a static, global general equilibrium model which is suitable for informative policy analyses. The dynamic GTAP is an extension of the standard GTAP to incorporate dynamic behaviour. The model helps to determine how changes in various factors such as policy, technology, population affect the path of economies over time.</td>
<td>Standard GTAP investment expenditure function is based on a Leontief utility function. Aggregate investment comes from the assumption that nominal investment equals saving. The dynamic GTAP includes an adaptive expectations theory of investment.</td>
</tr>
<tr>
<td>MARKAL and variants</td>
<td>World</td>
<td>Stationary energy system</td>
<td>The model helps to estimate energy dynamics over a multi-period horizon.</td>
<td>The MACRO model in the MARKAL-MACRO is based on a one-sector neoclassical growth model (Allen 1968). The SAGE variant of the MARKAL family model assumes that economic agents have myopic foresight.</td>
</tr>
<tr>
<td>MESSAGE and variants</td>
<td>World</td>
<td>Energy system</td>
<td>A linear programming energy model for medium- to long-term energy system planning, energy policy analysis, and scenario development. Myopic MESSAGE assumes limited foresight and thus short-term decision-making.</td>
<td>Imperfect foresight of investors is assumed.</td>
</tr>
<tr>
<td>POLES</td>
<td>World</td>
<td>Energy system</td>
<td>A partial equilibrium model that allows for assessing the contribution to future energy needs of the various energy types (fossil fuels, nuclear, renewables) and energy vectors.</td>
<td>Imperfect foresight of investors is assumed.</td>
</tr>
<tr>
<td>REMIND</td>
<td>Global multi-regional</td>
<td>Economy, climate system and the energy sector</td>
<td>An optimization model that optimizes global welfare subject to equilibrium constraints. The model allows for technology options analysis and policy proposals for climate mitigation.</td>
<td>Perfect foresight is assumed.</td>
</tr>
<tr>
<td>TIMES</td>
<td>World</td>
<td>Entire energy system</td>
<td>An optimization model that supplies energy services at minimum global cost.</td>
<td>Perfect foresight of all agents over the entire horizon is assumed.</td>
</tr>
<tr>
<td>WORLDSCAN</td>
<td>World</td>
<td>Global economy with multi-region and multi-sector detail</td>
<td>An applied general equilibrium model of the world economy, which helps construct long-term scenarios for the global economy and to enable international policy analyses.</td>
<td>The model builds upon neoclassical theory but also includes strong micro-foundations.</td>
</tr>
</tbody>
</table>

Table 4: How financing is captured in selected models

The use of the cost optimisation method in models is based on a strong assumption, that is, perfect foresight can be applied to all economic agents. It is a serious drawback that most the models share. With perfect foresight, investors have an accurate predication of the costs, technology development of the future. However, in reality, investors have limited foresight, and have a short-term investment vision (Brochet, Loumioti, & Serafeim, 2012). Solving the MIT Emissions Prediction and Policy Analysis (EPPA) model using forward-looking and the perfect foresight method and the recursive method yields shows that the optimisation method with perfect foresight represents the real economy poorly because it ignores the fact that uncertainty is likely to lead to higher costs in reality (Babiker, Gurgel, Paltsev, & Reilly, 2009).

Inspired by behavioural economics theories, many energy system models now assume that investors have limited foresight and are short-term decision makers. Myopic investors base their investment decisions only on the needs of today and postpone investment in new technologies (Fuso Nerini, Keppo, & Strachan, 2017). In the selected sample of models, many models have a myopic version. Myopic MESSAGE and SAGE variant of the MARKAL family assumes limited foresight and short-term decision-making in investments; this assumption helps to explore path-dependency and lock-in-effects in the energy system, and the effect of short-term decisions on achieving long-term goals (Keppo & Strubegger, 2010).

Several studies show the differences in modelling results when the agents have limited foresight. A study on the standard UK Times Model comparing with its myopic foresight version shows that myopic investors may delay investment decisions and it results in higher costs for achieving climate goal and a higher carbon price compared with cost estimation under perfect foresight optimisation (Fuso Nerini et al., 2017). The decision by investors to delay and wait under uncertainty is a rationale strategy since there are option values and time itself has a value because it reveals information. The same result that myopic foresight leads to higher investment needs in the future and heavier reliance on traditional fuels in the short term are founded in Keppo & Strubegger (2010) and Babiker et al. (2009).
In sum, most of the models use assumptions that frequently do not capture the key characteristics of the real-world agents and the environment the economic agents live in. The economic agents are assumed to be representative, thus ignoring the heterogeneity among individuals (Kirman, 2011). It is further assumed that there is perfect information, no transaction costs and no contract enforcement costs (Stiglitz, 2002) and the economic agents have perfect foresight, perfect rationality (Conlisk, 1996), as well as infinite computational capacities (Radner, 1968). Money and finance are ignored and policy models are “barter” models (Dillard, 1988). Though there are models that link macroeconomics with finance such as Minsky (1982), these models are not developed well enough to be used in policy decision-making (Pollitt & Mercure, 2018).

Several modelling approaches are there that consider the characteristics of the financial sector and investor decisions. The research on the financial frictions modelling suggests that the use of Dynamic stochastic general equilibrium (DSGE) models study how to financial frictions into account in order to conduct monetary policy analysis (Brázdik & Marsal, 2011). Stock-flow consistent (SFC) modelling tries to account for the financial system and to capture financing insights which are frequently missing in other models (Pollitt & Mercure, 2018). Another approach to take investor decision into account is through agent-based modelling. This type of modelling aims to combine the empirical observation from sociology and psychology with the problem that needs to be solved using a bottom-up approach (Moss, Pahl-Wostl, & Downing, 2001). There are cases where an agent-based model is used to model energy investment decisions on decentralized technologies (Wittmann, 2008).

### 3.2 A proposed research framework

The research framework that we propose consists of three steps (see Figure 7).

The first step is to identify and understand the most relevant investment imperfections. Based on our definition, investment imperfection not only includes the frequently discussed market failures, such as negative externality and
information asymmetry, but also dimensions such as political economy and behavioural elements which are new to the climate economics field. It is crucial to identify why the investment imperfections could be important and special in the climate domain. A method to do this is to relate to other fields (e.g. energy efficiency) and see the impact of investment imperfections such as problems in agency frictions, behavioural experiment.

The second step is to introduce finance into the integrated system based on a deep understanding of the integrated systems of the climate system, climate policies and economic system. Finance includes the process of information generation in the financial market, asset pricing based on available information by the market players, uptake of the pricing and financial resource allocation, and the flow of finance among principals and agents. As far as we know, this process is not available in integrated assessment models and appears to be the most challenging part of the research. This step is in preparation for measuring imperfections.

![Figure 7: Three steps of the research framework](image)

The third step is to use the integrated model with certain finance characteristics to assess different policies. In this step, the design and assessment of policies for correcting investment imperfections in the political economy, agency problems and behavioural elements are emphasized. Since our society is currently one investment cycle away from the needed financing amount for low-carbon
transformation, it is important to understand the mechanisms of it and what impact the delay implies, and evaluate policy needs.

The research framework proposed above may also be used to double check whether the declared financing volume estimated by current research is an underestimation of the actual volume necessary, because these have not taken investment imperfections in political economy barriers, agency problems and behavioural elements into account.
4 Conclusion

Sustainable climate finance has a complex landscape where many types of investment imperfections go in. Three sources of investment imperfections, political economy, agency problems and behavioural elements are identified. We consider integrated assessment models a good starting point for studying investment imperfections, however, after a review of the current approaches of these models to consider resource allocation and financing, we find that the existing approaches are not sufficient due to their assumptions and there is a research gap on more realistically modelling finance and investment decisions to be filled.

Consequently, we propose a research framework, which has three steps. The first step is to thoroughly identify and understand the most relevant investment imperfections. The second step is to introduce finance and investment decision analysis into the economic system part of the integrated assessment model. And the third step is assessing climate policies using the model. The research framework can help to study the most relevant topics in the field, e.g. policy analysis and designing instruments to remove investment imperfections.

Given the interdisciplinary nature of the problem, it may be conductive to have a network with researchers in different disciplines to understand and study the investment imperfections and publish their findings.
Bibliography


Education India.


