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Assessing the impact of climate transition risks on innovation and growth

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Abstract

As the world prepares the transition to a low carbon economy to contrast the climate crisis, the backdrop of slowing growth and growing inequalities underscores the urgent need for a new approach to growth. In an economy that is increasingly knowledge based, innovation and intellectual property play a crucial role. This thesis analyses the role of innovation on growth and specifically its effect on climate transition risk management shedding light on the importance of innovation in mitigating the impact of climate transition risks.

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Introduction

The ongoing climate crisis is highlighting the pressing need for a shift towards clean economy and a new approach to growth that is environmentally sustainable. To address the problem, governments are taking action, making the transition to a low-carbon economy an unavoidable necessity. To do so, regulations, such as carbon pricing and energy efficiency standards are required. Thus, a variety of financial solutions and innovative technologies must be activated, bringing new sources of risks to the economy. This has sparked widespread concern among global investors, which fear the effects of climate transition on asset pricing of portfolios allocations, speculating it could jeopardize global financial stability.

The policy milestone for climate transition, is represented by the Paris Agreement which aims at keeping the global average temperature increase below 2°C with respect to pre-industrial levels and advocates for coordinating international efforts to limit temperature rise in the next decades under 1.5°C. Following this, the EU aims to achieve a 55% net reduction in greenhouse gas emissions by 2030 and to be climate-neutral by 2050 (Parmesan, Portner, & Roberts, 2022). To reach policy target goals, avoiding the halt of productivity and economic growth investment in innovation is essential. By restructuring the R&D system and intangible asset valuation, innovation can be the key to to scale up technological advancement. The next decade is crucial, and the choices made now on investments, will determine whether we lock into high emissions or steer towards a low-carbon resilient growth path. The global targets raised at COP21 in Paris and COP27 in Sharm El-Sheikh in 2021, are now the main drivers in policy planning.

Companies are starting to take serious steps to decrease their carbon footprint in order to comply with targets set by global ambitions. Firms which are not able to comply with them can face backlash resulting in higher financing costs. With a higher carbon footprint firms are more susceptible to transition risk experiencing higher credit risk. In this sense innovation can influence creditworthiness of companies, particularly when compared to companies that lack a credible plan to transition to a low-carbon economy. Innovation therefore become a strategic asset in companies balance sheets.

From the Great financial crisis on, the volume of intangible assets on companies transcripts has followed an increasing trend. In particular, firms are starting to adopt intellectual property as collateral. Intangible assets, in the form of patents, grant companies a new tool to enlarge ex ante financial capability. Patents are an especially robust form of collateral in the context of climate transition risk. They confer exclusive right to innovative technologies and they can mitigate the impacts of climate change. In fact, they are able to provide a secure return on investment for those who fund the development of environmentally-sustainable technologies while avoiding climatic physical risks. Climate transition risk can indeed have a negative impact on physical collateral, such as real estate or infrastructure, can be ruined by extreme weather conditions, causing it to depreciate.

With this research we contribute to the analysis of the role of innovation in climate transition risk management. We present a financial stress applied to the field of transition scenario analysis. Using the measure of Climate Value at Risk, we assess the exposure to climate transition risks of four simulated bond portfolios, each of which with a different degree of innovation and carbon dependency. To model innovation we rely on the technique of patent application and patent granting counting. Therefore, an extensive work of code skimming was needed to select key technological environmental patents upon which the economic modeling of the innovation variable has been made.

The rest of the thesis is organized as follow. Chapter 1 introduces the general concept of climate change and provides an insight of the main risks it entails. The second chapter inspects the major contribution in the academic literature about innovation and growth. Special attention is given to the role of innovation as resilience driver and its part in the credit market. Chapter 3 discusses the methodology used to conduct climate scenario analysis created to perform financial stress testing on innovative portfolios via Climate Value at Risk. Then, chapter 4 will report the process of patent identification and selection and the implementation of the risk assessment analysis summarising in the end the key findings. The last chapter concludes the thesis.

Chapter 1

Climate change and Financial stability

The term "Climate change" describes a group of physical phenomena and a public policy issue that refers to long term shift in temperature and weather patterns (Weber & Stern, 2011). Scientists have been studying climate change for over 150 years, through a process of collective learning that involves the accumulation of observational data, the formation, testing, and refinement of hypotheses, the construction of theories and models to synthesize knowledge (Parmesan et al., 2022). On one hand, this changes stem from the natural solar cycle and therefore they are part of a rotation of climatic eras throughout the planet's history (Weber & Stern, 2011). Nonetheless, we refer to climate change as the current steep acceleration of this irreversible transformations due to human activity (Weber & Stern, 2011).

As Forbes reports, the year 2022 was marked by an unprecedented number of extreme weather events (Lehnis, 2022). For example, this past year, Pakistan has been devastated by an unusual Monsoonal season that caused significant floods, landslides and the formation of several waterborne diseases (Lehnis, 2022). The outcome of the disaster counted for 1700 deaths, with the addition of one third of the country covered in stagnant water, more than 1.7 millions of destroyed homes and around $15 billions of USD economic damages (Lehnis, 2022). In addition to this, the west coast of the United States has been hit by severe heatwaves, with temperatures above 100F (Lehnis, 2022). In the meanwhile, hurricane Ian swept the southeastern states with more that one-hundred victims in the sole Florida region (Lehnis, 2022). The same trend has been registered in Europe with extensive wildfires and droughts in Portugal, France, Romania and Italy that caused a projected loss for farmers of around 60% of the annual returns (Lehnis, 2022). Figure 1.1 shows that between 1970 and 2020 heatwaves and meteorological events have been responsible for almost half of the economic losses caused be adverse weather and by far more than half of the fatalities related to it (Zhongming et al., 2021). As can be seen in the picture, the economic losses related to disastrous events linked to climate change have been estimated to amount roughly to EUR 509 437 million on the economic side taking a toll on human lives with 100 000 fatalities (Zhongming et al., 2021).

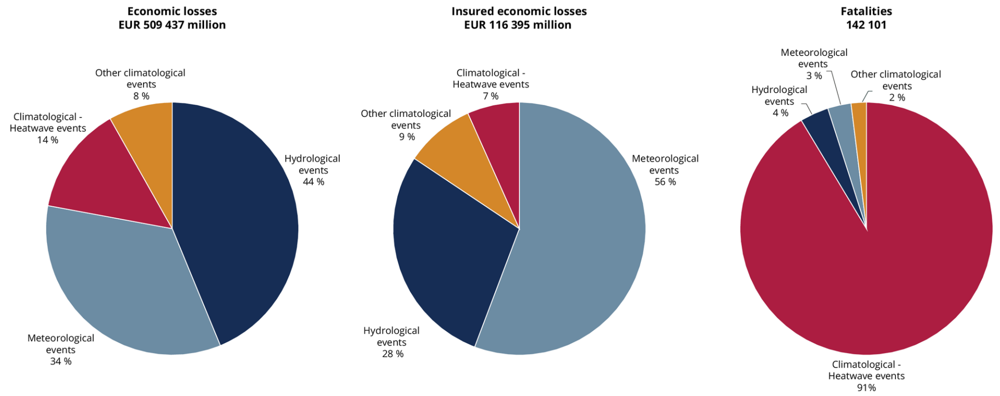


Figure 1.1: Economic losses and fatalities due to extreme climatic events

(Parmesan et al., 2022)

Furthermore, the bar chart in figure 1.2 shows that flooding risk has significantly increased in the last decade becoming the second most threatening risk associated with climate change in Europe after wildfires (Parmesan et al., 2022).

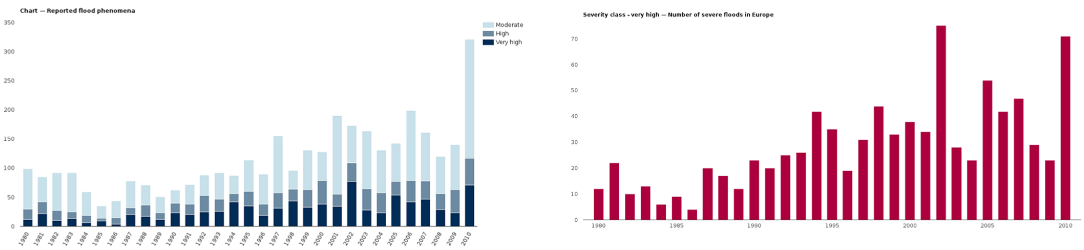


Figure 1.2: Flooding events in Europe

(Parmesan et al., 2022)

In just twenty years, the number of events in for all degrees of severity has grown drastically. The bar chart on the right-hand side highlights the number of grave floods. Also in this case we assistd at an increase in the number of severe floods in Europe starting from the late nineties with two spikes in 2002 and 2010.

A recent research by (Zhongming et al., 2021), has found that out of 77 events studied, 62 had a significant human impact. Moreover, studies on heatwaves since 2015 have consistently found that human-caused climate change has increased the likelihood of these extreme events (Zhongming et al., 2021). For instance, between 2016 and 2017, the East African drought was largely influenced by human-caused warming of the western Indian Ocean (Zhongming et al., 2021). In addition to this, climate change has also been found to increase the intensity of extreme sea level events and associated impacts, making coastal and low-lying areas more vulnerable and physical harm more likely (Zhongming et al., 2021).

As a matter of fact, starting from the second half of 1800s, in connection with the sudden development of the Second Industrial Revolution, human activities have been the main trigger factor for climate change (Weber & Stern, 2011). Indeed, with the advent of fossil fuels extraction, as for example oil and gas, and the adoption of them as main source of energy for production and everyday living, the delicate equilibrium of the earth's ecosystems have been put through derangement (United Nations, 2022). In reality, climate change involves a vast group of physical phenomena that are attributed mainly to the alteration of the ecosystem caused by the accumulation of dioxide gasses, in the atmosphere following anthropic activities (Malla et al., 2022). The increasing concentration of these gasses in the atmosphere caused temperatures to rise from the 1850s until now, as depicted in figure 1.3.

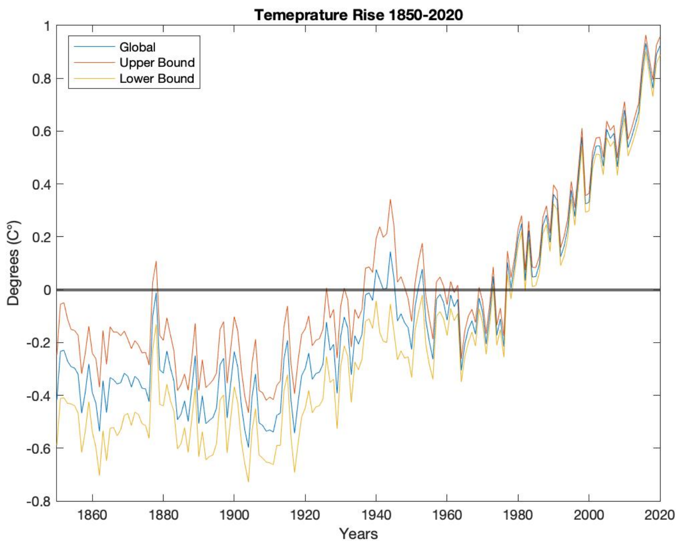


Figure 1.3: Temperature increase since 1850

The group of gasses responsible for the temperature increase takes the name Green House Gasses (GHG) and coincides with the primary cause environmental change. Therefore, since

GHG concentration is addressed to be the principal cause of higher temperature and the main driver of climate change, we can refer to the climatic crisis simply as Global Warming (Malla et al., 2022). Here below it is presented a synthetic representation of the Million-tones of GHG emission in the last couple of decades by emission countries (figure 1.4).

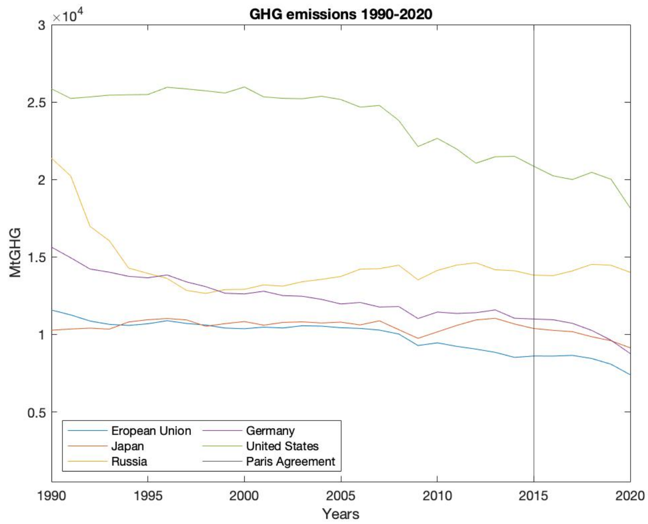


Figure 1.4: Green House Gasses emission 1990-2020

The graph has been plotted using annual data of Million-tones of GHG emission adjusted for each country GDP using the OECD database. The European Union, Japan, the Russian Federation, Germany and the United States were taken into analysis as representative of higher emitters economies. Almost all the countries have shown a mild declining trend in GHG emission over the years apart from the Russian Federation.

The climate crisis has called for international action in building a proper institutional framework and suitable forward-looking policy strategies. The first global attempt to coordinate actions in matters of climate change dates back to 2015 (black vertical line in figure 1.4). The *Sendai Framework for Disaster Risk Reduction*, the *2030 Agenda for Sustainable Development* and the *Paris Agreement* have set the first ensemble of global ambitions with the aim of supporting and facilitating changes (Raikes, Smith, Baldwin, & Henstra, 2022). In particular, the *Paris Agreement*, a legally binding treaty signed at the 21^{st} Conference of the Parties (COP21) by the United Nations' member states, has decreed as long term achievement accomplishment of climate neutrality by mid-century (Raikes et al., 2022). In a nutshell, the agreement has set as long term objective the limitation of temperature increase at 2°C above pre-industrial levels pursuing efforts to limit the further increase in temperatures to 1.5°C in the following decades (Raikes et al., 2022). Every year since then, each COP monitors the advancements in climate crisis response by each Member country and has reported the key adjustments to be followed.

Without any intervention to contrast the rise in temperature the scenario projection for the next 50 years will be dramatic (figure 1.5). The picture shows how the different possible scenarios, in terms of climate protection from GHG concentration, can change the future of global worming. The difference in scenarios lies in the pathway chosen to control temperature rise. Table 1.1 presents a possible pathway description:

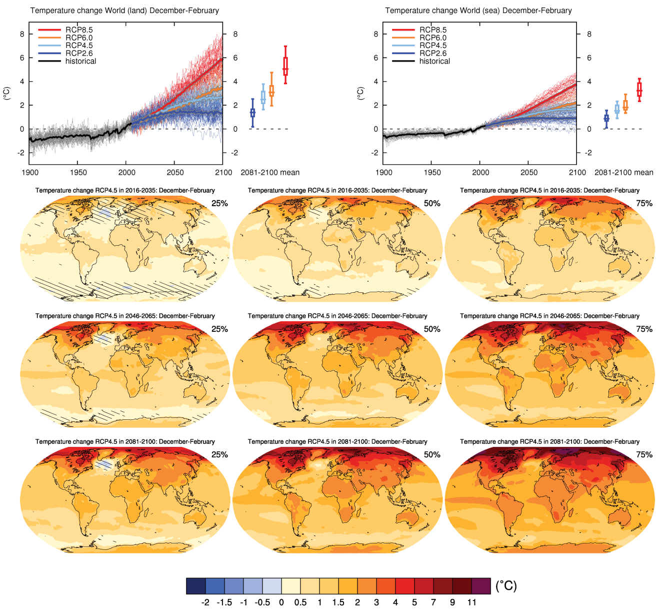


Figure 1.5: Altlas of temperature increase

Source: European Environment Agency

Scenario	RCP reference	Characteristics
No protection	RCP 8.5	No protection policy is undertaken. GHG continues to rise and in 2100 the expected radiating forcing will amount to 8.5W/m2
Slim protection	RCP 6	Climate protection is introduced but not efficiently, GHG concentration in the atmosphere continue to rise and radiating forcing by the end of the century will be 6.0 W/m2.
Limited protection	RCP 4.5	GHG emission is curbed but concentration gasses will rise for the next 50 years. The 2°C objective is not achieved. In 2100 the radiating forcing will be of 4.5 W/m2
Stringent protection	RCP 2.6	A system of protection policies is undertaken and GHG concentration increase will be stopped within 2050. The radiating forcing will amount to 2.6 W/m2 and the goals of the Paris Agreement will be reached.

Table 1.1: Representative Concentration Pathways

Introducing policies is not enough since uncoordinated transition to a low carbon regime can cause additional harm to economies around the globe (Stern & Valero, 2021). Last November, the United Nation Framework Convention on Climate Change (COP 27) held in Sharm el-Sheikh, has deliberated additional steps to coordinate the implementation of practical measures to fight the emergency and accelerate the shift to a cleaner economy (Parmesan et al., 2022). The world is now at a turning point since the time window to take action has been narrowing fast (United Nations, 2022). The report has presented a temperatures decrease of 0.3°C degrees from 2019, which is by far less of what is needed to fulfill the agenda tasks (Parmesan et al., 2022). For this reason carbon dioxide emission must be reduced by 45% within 2030 to be able to reach net-zero emissions scenario by 2050 (Parmesan et al., 2022).

To enable the implementation of international policies suggestions, a variety of financial solutions and innovative technologies must be adopted. Investments in renewable energies have been sponsored for a total amount of at least $4 trillion a year to fill the gap existing between traditional finance and its green specification (Parmesan et al., 2022). The flow of green finance, with $803 billion, represents right now still a small volume compared to the total,that is, just 30% of what is needed to reach the goal temperature within the time limit (Parmesan et al., 2022). The introduction of financial tools to shape low carbon economy is bringing growing concerns among investors. The financial world increasingly worries about the impact of the transition to a low-carbon economy financial stability as an abrupt change in the economic paradigm would entail a harsh asset revaluation and a strong adjustment of portfolio performance. For this reason, quantifying the risks exposure associated with a shift toward sustainability is essential. Climate change possesses some distinguishing traits that affect also the nature of the risks it carries. First of, it is a global phenomenon both in its causes and consequences, as it does not take into account nationalities and borders (Batten, 2018). Then, its impacts are persistent and alter reality on a long term, causing frequently irreversible changes (Batten, 2018). Finally, climate transition risk has been linked to a high degree of pervasive uncertainty (Batten, 2018). Since these risks manifests similarly to economy shocks they could affect both the supply or the demand side of the economy (Batten, 2018). All financial intervention have been focused on contrasting the increase of GHG gasses to halt temperature increase because no significant new technology is yet available (Monasterolo, 2020). Necessarily, the economies that rely the most in intensive production systems and therefore, emit higher volumes of GHG gasses have shown higher concerns for the transition. Table 1.2 lists the top 10 countries for emission of $MtCO_2$ for the most important fossil activities.

In practice, policies can act on three sides: on one hand, they can impose limits to reduce the production or consumption of products with an elevated carbon footprint, on the other hand, they can focus on improving energy efficiency and incentive the use of alternative energy sources (Batten, 2018). Most importantly, ad hoc policies can be devoted to promote research and innovation towards clean energy and low carbon production (Batten, 2018). One of the most recognised tool to respond to the climatic emergency has been the adoption of carbon prices,

GAS	MtCo2	**OIL**	MtCo2	**COAL**	MtCo2
United States	1637	United States	2234	China	7956
Russian Federation	875	China	1713	India	1802
China	774	Russian Federation	403	United States	1002
Iran	467	Japan	395	Japan	419
Saudi Arabia	270	Saudi Arabia	370	Russian Federation	380
Canada	235	Germany	248	Germany	230
Japan	222	Canada	242	Canada	44
Germany	174	Iran	223	United Kingdom	24
United Kingdom	159	Mexico	196	Iran	19
Mexico	158	Unied Kingdom	154	Saudi Arabia	3.7

Table 1.2: Top 10 countries by carbon dioxide emission for gas, oil and coal sectors

which are aimed to internalize the negative external costs of CO2 emissions (Batten, 2018). Transitioning towards a new regime is a very delicate procedure and require precise timing. A delayed policy structure could lead into catastrophe, on the contrary a sudden and aggressive policy regime may result in a bigger drag on growth in the medium term due to insufficient means of mitigation (Batten, 2018). For example, a sudden passage away from fossil fuels can translate into energy shortage caused by a reduction in energy supply and energy prices would skyrocket causing adverse macroeconomic outcomes (Batten, 2018). In addition to this, if assets of portfolios remain deeply dependent on carbon and fossil fuel activities, a sudden shift toward a low carbon economy would cause heavy price adjustments undermining portfolio performance. This would lead to a ripple effect of corporate defaults, undermining financial instability (Batten, 2018).

1.1 The effects of physical and transition risks

The financial system is subject to two different classes of risks. The most immediate form of risk that comes to mind is the one comprising physical risks. Physical risks are defined as an as any type of risk that arises from the interplay of climate related hazards and the vulnerability of the human natural system exposure to them, including their degree of adaptability (Batten, 2018). The two main roots in these types of threats are gradual global worming and extreme weather events (Batten, 2018). The drivers of physical climate change are disparate and their concentration varies between geographic region and type of sector. The main drivers in Europe are floods, water stress and finally heat stress that has manifested with increasing wildfires each year (Alogoskoufis et al., 2021).

In the time window between 1980 and 2017 climate related events have caused approximately

435 billion euros economic losses in the European Economic Area (EEA) and they are expected to rise 50 billion per year by the end of the century if no action is provided (Alogoskoufis et al., 2021). This type of risks have an effect on both the assets and liabilities of financial agents. From the asset side, increased frequency and severity of extreme weather events can affect the company direct property investments, on the other hand, physical risks can have implications on revenues and the ability to repay creditors (Alogoskoufis et al., 2021). These impacts include damage to property, business disruption, and reduced productivity.

When assessing the risks associated with physical climate change, three key factors must be considered: the extent of exposure, which calculates wither the possible proportion of the affected population or the worth and belongings in danger; the danger, which outlines the physical features of weather events like frequency and strength; and the susceptibility of the exposures to weather-related harm (Monasterolo, 2020). However, historically, an increase in frequency and intensity of weather-related catastrophes have not necessarily implied an increase in physical risk. The severity of the impact is determined by the level of exposure to the shocks, the degree of hazard and the magnitude of vulnerability (Monasterolo, 2020). The level of exposure is determined by the presence of communities, species, ecosystems or infrastructures affected by the considered disaster. The hazard, instead, describes the probability of occurrence of weather-related events such as windstorms, floods or droughts at a given location as well as their physical intensity or severity (Monasterolo, 2020). Vulnerability, instead, can be defined as the propensity of exposed population or physical assets to suffer adverse effects from the impact of natural events so, in the long-term, as extreme events become more frequent and intense due to climate change, new areas may be identified as hazard-prone revealing underlying vulnerability caused by present conditions (Monasterolo, 2020).

The concentration of risks in different geographical areas and sectors affects economics agents differently (Alogoskoufis et al., 2021). Thus, enterprises can be swept away if capital is destroyed, production lines compromised and supply chains shattered (Alogoskoufis et al., 2021). For this reason some mitigation measures have been put in place. A way to take into account of possible losses coming from physical climate risk has been through insurance. Nonetheless, at the present moment the adoption of insurance instrument has not gained enough popularity and its coverage results to be insufficient (Alogoskoufis et al., 2021). Another solution has been found in collateralization (Alogoskoufis et al., 2021). In principle, collateral has been engaged to mitigate the losses of financial intermediaries, however it has been noticed that itself could be damaged by climate related risks. In fact, when collateral is physical it can be devalued, damaged or in worst cases disrupted by physical climate accidents losing its mitigation capacity and becoming itself an amplifier of risk (Alogoskoufis et al., 2021). More than half of the collateral pledged from firms which are highly exposed to physical risks, is of physical nature (Alogoskoufis et al., 2021). This situation affects more than 60% of banks around the world (Alogoskoufis et al., 2021), stressing that physical risks is a real threat to financial stability.

The second class of risks, is identified as the risks of the transition process itself (Monasterolo, 2020). As a matter of fact, we refer to transition risks as all the risks arising from the transition to a low carbon economy. This category of risks has been more treacherous end more difficult to frame out with respect to physical risks and, up to this point, its assessment and pricing still remains a challenge (Alogoskoufis et al., 2021). Nonetheless, empirical evidence sustains transition risks to have a wide economic impact. They are transversal risks that impact the economy on all sides. On the demand side they have stemmed form the introduction of policies which promoted low carbon investments resulting in crowding out a significant level of private investment (Batten, 2018). On the supply side, instead, they have manifested as the reduction in near term growth due to mitigation costs induced by carbon emission reduction imposed to meet the need of preserving the planet environmental conditions (Batten, 2018). Lastly, transition risks can alter trades in occurrence of asymmetric climate policies which translates in a disordered transition (Batten, 2018). Companies now have to size out and devote part of their resources towards emission abatement curbing production (Dunz, Naqvi, & Monasterolo, 2021). Investors are interested in a precise quantification of transition impacts to shield from unexpected negative shocks (Dunz et al., 2021).

Chapter 2

Innovation and Growth: a Literature review

The transition to a zero-carbon economy asks for a significant shift in technology to decarbonize the productive system while sustaining growth. To scale up technological advancement innovation is essential. Innovation can be defined as any successful upgrade of goods and services which is key to the longevity of a production system (Kahn, 2018). It is characterized by three distinctive aspects. First, it stems from the synergy of three dimensions being simultaneously an outcome, hence the goal the organization need to achieve by innovating, a process, being the means though which the change occurs and a mindset (Kahn, 2018). The latter refers to the predisposition of the culture in which the innovative outcome is released to be more risk taking in favour of change and it is the distinctive trait of successful innovation (Kahn, 2018). Therefore, the role of innovation in relation to economic growth has been widely investigated.

2.1 Innovation and Growth

Starting from the 50s of last century, data from several studies have identified a positive relation between innovation and economic growth. In 1954, it has been shown empirically for the first time that roughly 90% of the increase in output per-capita in the United States between 1871 and 1951 was due to technical enhancement (Cameron, 1996). A few years later, in 1957, the same idea has been reinforced by the demonstration that the link between output level and R&D capital expenditure was positive, strong and statistically significant (Cameron, 1996). Hence, the the classical concept of growth has been revised with the integration of the effects brought innovation. Traditionally, in economic theory, growth was thought to be driven by exogenous technical progress (Cameron, 1996). In contrast to this, following (Cameron, 1996) findings, the idea that the rate of innovation was the result of profit maximization choices made by economic agents, being therefore endogenous driver of growth, must be integrated (Cameron, 1996).

Growth is defined traditionally as the increase in production from one time period to another, of services and economic goods via land, labor, capital and entrepreneurship. The current Information and Communication technology (ITC) is still based on profit maximization through mass production that have entailed throughout history the exploitation of fossil materials especially, cheap fossil fuels (Stern & Valero, 2021). Hence, a phasing out of fossil fuels to achieve zero emissions in a couple of decades requires revision of the concept of growth tilted towards a more sustainable dimension. Sustainable growth refers to that growth which, driven by zero-net carbon emission transition, can increase strength and productivity using efficiently physical, human, knowledge, natural and social capital assets and that can therefore be sustained in the long run (Stern & Valero, 2021). Actually, this shift of paradigm would enable the achievement of net zero emission goal assuring a boost in productivity and the prosperity of the financial system (Stern & Valero, 2021). The first definition of sustainability comes from the United Nations that in 1987 marked it out as *"the ability to meet the needs of the present without compromising the ability of next generations to meet their own needs"* (Goodland, 1995).

This concept can be broken down into three main areas: social, economic, and environmental field. Social sustainability is achieved through active community participation and a strong civil society (Goodland, 1995). It is maintained by shared values and equal rights and is often referred to as "moral capital" (Goodland, 1995). Environmental sustainability is necessary for human welfare and involves protecting the sources of raw materials and ensuring that the sinks for human waste are not exceeded (Goodland, 1995). Economic sustainability relates to keeping capital stable and it involves balancing human-made capital with natural, social, and human capital (Goodland, 1995). Thus, the scale of the human economic subsystem should be maintained within the biophysical limits of the overall ecosystem. This requires maintaining sustainable production and consumption, and holding waste emissions within the environment's capacity to absorb them (Goodland, 1995). Hence, to engage in sustainable growth an innovative technological shift must take place.

Technological changes can happen either by improving the existing system or via new inventions both of which depends on research activity and innovation. In 2002 (Daum, 2003), has highlighted the passage from industrial capitalism, characterized by production and financial activity anchored to tangible assets, to a new economy where value creation supposedly has been located in invisible intangible corporate assets (Daum, 2003). The economies are now increasingly knowledge based (Wurster & Hoppe, 2022) and intellectual properties and scientific discoveries play a crucial role. In the last few years, the volume of intellectual property has grown and it is now considered, by companies, a synonym of competitive advantage (Wurster & Hoppe, 2022). Innovation can be translated in intellectual property in the form of patents, trademarks or copyrights.

Policies intervention and institutional framework have therefore the role of regulating technological change giving the right direction by intervening in the intellectual property market (Freeman, 1991). Without an efficient patent and intellectual property rights system firms are not fully able to enjoy the gains from their own innovation (Cameron, 1996), as a result, the amount of innovation in the economy would be lower that what is socially optimal. Moreover, this can be emphasized when there are several knowledge leaks and flow of skilled labors from on firm elsewhere (Cameron, 1996).

2.1.1 Resilience to crisis: innovation as key

Innovation has been studied also in relation to crisis management and in association to the ability of firms and systems to be resilient. The recent example of the health crisis brought by Covid19 has stressed how fast an entire system is able to change, how far it can adapt and how fast innovation can solve new challenges if efforts and resources are put into it in case extreme measures are required (Stern & Valero, 2021). According to (Bar Am, Jorge, Furstenthal, & Roth, 2020) the Covid-19 crisis brought new opportunities of growth for the majority of the companies but just 21% of them declared to be equipped to actualize the changes to exploit them (Bar Am et al., 2020). Companies that invested more in innovation delivered a superior post-crisis growth also in the aftermath of the Great Financial Crisis, when new market places opened for underutilized asset (Bar Am et al., 2020). Similarly, the 2002 SARS crisis in China brought the country to be the leader in the field of e-commerce (Bar Am et al., 2020). This perspective has stressed how important is for a business to be able to adapt to changing scenarios in particular when preferences and needs of agents are shifting. Nonetheless, to be fully exploited, the opportunity created by each crisis must be met fast, requiring an high degree of resilience and dynamism (Bar Am et al., 2020).

The concept of resilience has been first defined by the ecologist Crawford Stanley Holling in 1973 as the phenomenon of persistence despite disturbance (Lv, Tian, Wei, & Xi, 2018). In economics it has been outlined as the capacity of a productive system to transform and adapt balancing stability and adaptability (Lv et al., 2018). In particular, resilience originates from the balance between the ability to withstand stress and the capability to adjust to environmental change taking advance of new rising opportunities (Lv et al., 2018). Resilience is identified as a process of transformation that is enabled by innovation (Zupancic, 2022). Therefore, resilience enables organizations to deal with changes in the surroundings as opportunities, being the pathways towards innovation, and hence, in the case of this research, of sustainability (Zupancic, 2022). In other words, innovation is at core of both resilience and sustainability and the former is then essential to achieve and maintain a sustainable system in a dynamic environment (Lv et al., 2018). Moreover, resilience has been translated also as the ability of agents to handle risk embedded in innovation outcome itself (Lv et al., 2018).

Innovation has not always been synonym of success since it involves a significant degree of unpredictability. So, risk management should insource the concept of innovation resilience. This is the ability to account for uncertainties carried by innovation activities (Lv et al., 2018). It is strictly related to the concept of resilience in the sense of the ability of rearrange resources in case of an adverse outcome to mitigate its negative effect and reorganize them to overcome the obstacles (Lv et al., 2018). From the literature, companies that have focused on innovation during the financial crisis were the ones which displayed higher post crisis returns and more solid growth (Bar Am et al., 2020). Meaning that, innovation enabled organizations to recover faster and sounder after disruption. Therefore, a successful innovation process is able to recognize opportunities with the right timing and it is sufficiently resilient to know how to deal with all possible uncertain outcomes.

Path dependencies in technological advancement are one if the major obstacles in exploiting innovation potential. That explains why some technologies continue to exists even in the presence of superior options (Stern & Valero, 2021). Nonetheless, for (Stern & Valero, 2021), innovation path dependencies can be used to redirect R&D sectors and realign growth with sustainable long term goals (Stern & Valero, 2021). Path dependence refers to the principle that the range of possibilities in a given scenario is formed by prior events and decisions (Stern & Valero, 2021). This principle suggests that the current trajectory of a system or process is primarily determined by historical developments, as opposed to present conditions or future objectives. Hence, as (Stern & Valero, 2021) state, increasing investment in clean technologies, or technologies that directly or indirectly enable the transition to net-zero emissions, is necessary to break possible opposing path dependencies (Stern & Valero, 2021).

There are three specific types of path dependence, as far as it concerns innovation: in the production of research and knowledge, in the deployment of innovation, and in the diffusion of new technologies (Stern & Valero, 2021). Path dependence in the production of research and knowledge occurs when scientists prefer to work in areas that are well-funded and where other good scientists are working, allowing them to generate, build upon and benefit from knowledge spillovers (Stern & Valero, 2021). Path dependence in the deployment of innovation, instead, arises when the incentives to deploy products or technologies that use existing infrastructure are higher than those where the infrastructure is not yet rolled out at scale (Stern & Valero, 2021). Finally, the emergence of path dependence in the adoption of new technologies arises as a result of network effects and substantial switching costs (Stern & Valero, 2021). The advantages of utilizing a specific technology increase as the number of users grows, and the investments made in infrastructure and assets frequently prevent a transition to alternative systems due to the prohibitive costs involved.

Being technological advancement necessary, different economic opportunities stems in the international scenario, from the possession of clean innovation techniques. In fact, if some countries have a comparative advantage in particular areas of clean innovation that can be deployed in other markets, they can exploit opportunities for growth domestically, while also reducing emissions globally (Stern & Valero, 2021). For example, certain emerging nations, such as China and Brazil, occupy a pivotal position on the world's innovation frontier. However, many other countries are more likely to adopt or imitate clean technologies that have been developed elsewhere (Stern & Valero, 2021). Thus, policies that promote clean innovation in high-income countries may not lead to socially optimal emission reduction unless there are additional interventions that support the transfer and deployment of clean technologies in the remaining geographical locations (Stern & Valero, 2021). Policies that price carbon and subsidize clean R&D in more innovation-intensive economies, North, should be accompanied by policies that facilitate technology transfer and build absorptive capacity in the South (Stern & Valero, 2021).

It has not yet been developed a unique technique to study the magnitude of the effects of innovation in economic models. One possibility is to examine data on traded goods. This means measure a country's competitiveness in a particular product by looking at their "revealed comparative advantage" in trade (Stern & Valero, 2021). For example, if a country exports a higher percentage of solar panels than the global average, it can be assumed that the country has some level of competency in this product (Stern & Valero, 2021). However, different products offer varying potential for future growth in a country. The Product Complexity Index (PCI) suggests that more complex products tend to be more technologically advanced and offer greater knowledge spillovers into other products and as a matter of fact, research has shown that "green" products tend to have higher complexity than average (Stern & Valero, 2021). Another possibility entails the use of web-intelligence data, such as company websites, communications, and news, which provide insights into emerging sectors that are not captured by existing industrial classification systems (Stern & Valero, 2021). This data can also be used to identify connections between firms and other parts of the innovation system, such as universities and investors, and analyze the factors driving success in these areas (Stern & Valero, 2021). However, creating new classifications of firms and sectors will require collaboration and agreement on definitions, measurement methods, and updating methods that are practical and widely accepted and it is therefore a difficult route to walk (Stern & Valero, 2021).

An effective way to capture innovation outcome is via patent counting (Stern & Valero, 2021). While not all innovations are patented, patent data show several advantages. They are available across countries, over time, and technologies and they can be easily classified as "clean" (Stern & Valero, 2021). The research has found that knowledge spillovers, measured by global patent citations, for clean innovations, are over 40% greater than their high-carbon counterparts in the energy production and transport sectors (Stern & Valero, 2021). Patents provide a legal framework for the protection of intellectual property, guarding inventors and companies against unauthorized use and infringement of their innovations (Stern & Valero, 2021). This helps to ensure that the creators of new products and technologies are able to enjoy the rewards of their efforts and ingenuity (Stern & Valero, 2021). Patents are a good indicator of innovation activity and of the economic value associated with it (Bloom & Van Reenen, 2002).

2.2 Innovation and credit risk

In a transition economy that is fundamentally knowledge based, in which technological change is constantly sought, patents acquire increasing value. Several studies have assessed the impact of larger patent portfolio holdings and higher market value of firms. More intense patents activity has produced a statistically and economically significant impact on both market value and productivity rate of a firm (Bloom & Van Reenen, 2002). The impact on productivity manifests slowly and depends on the decision and time of the firm of investing the rights it has granted via the patent into the market (Bloom & Van Reenen, 2002). Nonetheless, patents impact immediately the market value of a firm since they give the patentee all the rights to their own technology (Bloom & Van Reenen, 2002). Thus, in case of an economic downturn and a consequent delay in the investment of the new technology in the market, patents represent real and valuable options in the market as they can be ether held or sold (Bloom & Van Reenen, 2002). That being the case, when it comes to intellectual property, patents are perceived as real option for shareholders (Frey, Neuhäusler, & Blind, 2020).

The impact of patent holding on the credit side of companies is still a partially explored field. In order to be able to assess the transition risk in relation to innovation it is necessary to investigate the relation between innovation and credit risk. While the role of patents as catalyst of external capital when it comes to companies' equity has been empirically verified, the incidence of patenting activity on their debt capacity remain quite uncharted. More and more patents are used as means of collateralization to enlarge firms debt capacity (Frey et al., 2020). Patents falls within the class of intangible assets and therefore they are able to avoid physical transaction risks and the traditional asset depletion trajectory (Frey et al., 2020).

The popularity of patents as companies assets, comes form the necessity, during the Great Financial Crisis, of liquidating the totality of the asset balance sheet part, to repay creditors (Frey et al., 2020). When physical assets were not enough firms started to liquidate intellectual property assets as well (Frey et al., 2020). From that point on, the interest for patents as a debt financing mechanism increased. Due to their nature of strategic collateral, patents are now seen as a debt mechanism other than real option for shareholders (Frey et al., 2020). Collateral enable a company to increase its financing capability ex ante because it gives option to liquidate the named assets to repay creditor if needed enhancing the company's debt capacity (Frey et al., 2020). Evidence has shown that intangible assets are a growing share of companies asset value (Frey et al., 2020). Due to this trend, intellectual property rights has become an additional collateral channel (Frey et al., 2020). The collateral channel refers to the amplification effect of real shocks propagated through the decrease in value of underlying collateral asset during economic downturns and the resulting reduction of investment (Frey et al., 2020).

Unlike shareholder, creditors do not share the upside of firm investments. That is, they are interested in the bottom tail of return distribution. Since financing of R&D is associated with adverse selection and moral hazard, creditors will be likely to ask for higher interest rates to compensate for the additional risk (Frey et al., 2020). Therefore the Probability of Default (PDF) associated with the debt instruments issued by R&D companies is expected to be higher than the others (Frey et al., 2020). The link between patents and company creditworthiness, therefore, becomes an important policy matter. Creditworthiness of R&D intensive firms influence the creditors' willingness to channel capital to innovation projects (Frey et al., 2020). Nonetheless, companies with bigger patents portfolios receive higher credit ratings (Frey et al., 2020). On that account, opinions about issued debt creditworthiness are higher in the case of companies deeply invested in R&D which patent their innovations, meaning that, their are perceived as more likely to be able to amortize the debt and to fulfill interest payments (Frey et al., 2020). Moreover, intellectual property licensing contribute to the operating income of a company that will result in and higher EBITDA (Frey et al., 2020). In addition to this, licensed technological improvement and patented intellectual property rights result to be a meaningful competitive advantage to the holders since they represent a powerful barrier of entry (Frey et al., 2020). In light of these findings, companies tend to build their patent portfolio strategically, sometimes inflating it (Frey et al., 2020).

Even though the quantity of patents held by a company is key, creditworthiness depends also on the quality those patents (Frey et al., 2020). Assessing the quality of a patent is still a grey area but is needed to assign patents a appropriate weight. Usual patent quality indicators are the number of forward citations related to a specific patent, the geographical influence of a patent family, the grant outcome it is supposed to provide and the corresponding renewals (van Zeebroeck, 2007). As a matter of fact their distribution is highly skewed with a long right tail (Hall, Thoma, & Torrisi, 2007) meaning that only a few patents compared to the total amount provide significant value to their owners. By studying the quality of patents gathered by the European Patents Office (EPO), the market value of R&D in Europe has been proved to be high with respect to other databases (Hall et al., 2007).

Chapter 3

Methodology: Climate transition risk modeling

Climate risk modeling do not allow to calculate future impact based on past information as the scenarios involved are forward-looking in nature (Battiston & Monasterolo, 2020). Additionally, the outcome of adverse scenarios is influenced by risk perception and the reaction of various agents, making it an endogenous issue (Battiston & Monasterolo, 2020). Therefore, in this context, conventional methods of valuing assets fall short. To model economic transition risk we rely on the literature of (Monasterolo, 2020).

We present an economy in which $n \in \mathbb{N}$ companies operate, each indexed by j, and where investments can be spread over S sectors each of which is characterized by a different energy technology (Battiston & Monasterolo, 2020). To fund their operations, firms issue corporate bonds, which then are chosen by investors as part of bond portfolios (Monasterolo, 2020). Our model assess cclimate risks over different possible policy scenarios.

Climate policy scenarios refer to the the future advancement of international agreements regarding the mitigation of climate change (Battiston & Monasterolo, 2020). In the model, the variable *ClimPolScen* (equation 3.1) collects different possible climate policy interventions. All this scenarios consider the goal of GHG emission reduction that align with the 1.5°C and 2°C temperature targets set by the Paris Agreement (Battiston & Monasterolo, 2020). B represents the Baseline scenario in which no climate policy is put into place, instead P_l refers to scenarios in which different path of climate policies are introduced. The scenarios have been developed by the international scientific community and have undergone review by the Intergovernmental Panel on Climate Change (Monasterolo, 2020).

$$ClimPolScen = \{B, P_1, ..., P_l, ..., P_{nScen}\} \tag{3.1}$$

In addition to this, a set of economic output trajectories are calculated for each country C, sector S, scenario P, using a specified climate economic model M. These trajectories embody the output of various sectors with differing energy technologies, contingent upon the P scenarios, and aligned with the associated GHG emission reduction targets (Battiston & Monasterolo, 2020). This set is shown in equation 3.2 and it is referred to as *EconScen*:

$$EconScen = \{Y_{1,1,1,1}, ..., Y_{C,S,P,M}, ...\} \tag{3.2}$$

For this research, as model M, we choose the class of Integrated Assessment Models (IAM).

3.1 Integrated Assessment Model overview

Integrated Assessment Models provide a tool to capture all sectors interactions for different regions combining them with data from the physical ecosystem to estimate economic output trajectories for long future time horizons (De Bruin, Dellink, & Agrawala, 2009). Thus, thanks to IAM models it is possible to merge economic theory with real data stemming from other scientific disciplines, that are essential to describe the changes in the natural environment in the long term (Nordhaus, 2013). When dealing with climate transition risk is essential to inspect all technologies, all sectors and institutional requirements in synergy (De Bruin et al., 2009). The backbone of these models is a recursive approach that enable to compute a general economic equilibria on the economic side while also considering the impact of a land-based model on various physical indicators such as air pollution and carbon emission density (De Bruin et al., 2009). Hence, IAM models are tools able to produce a single framework trough dynamic computerized models (Nordhaus, 2013). To start with, the model converts every economic activity into monetize values by using a common account unit (Nordhaus, 2013). This allows policymakers to weight the costs of slowing down or speeding up the transition from a carbon intensive economy by regulating CO_2 releases or introducing subsidies and taxes on GHG gasses emission (Nordhaus, 2013).

The origin of IAM models stems from energy models designed between the 80s and 90s and can be grouped into tow classes (Nordhaus, 2013). The first group focuses on policy evaluation practices. These are recursive equilibrium models that describe the paths of selected variables of importance, without optimizing any economic output (Nordhaus, 2013). Instead, we focus on the second group of IAM models, which regards policy optimization measures. These models maximize an objective function, which typically is a welfare function, under constraint conditions. Doing so, alternative policies can be compared (Nordhaus, 2013). We follow the classical maximization problem where a flow of generalized consumption overtime is optimized (Nordhaus, 2013), as presented in equation 3.3:

$$W = \sum_{t=1}^{T_{max}} U[c(t), L(t)]R(t). \tag{3.3}$$

The welfare function is the discounted sum of the population utility, which depends on per capita consumption level, $c(t)$ and population volume over time, $L(t)$, weighted trough a discount factor $R_(t)$ (Nordhaus, 2013). The discount factor R(t) is actually a built in function of pure rate of social time preferences,ρ, as shown in 3.5:

$$R(t) = (1+\rho)^{-t}. \tag{3.4}$$

In addition to this, we assume the utility function to be a constant elasticity utility function,

$$U[c(t), L(t)] = L(t)\left[\frac{c(t)^{1-\alpha}}{(1-\alpha)}\right] \tag{3.5}$$

so that, the marginal utility presents constant elasticity α.

Production is generated using the Cobb-Douglas function with inputs of capital, labor, and energy (Nordhaus, 2013). The latter can be either carbon-based, like coal, or non-carbon-based, such as solar, geothermal, or nuclear (Nordhaus, 2013). Technology advancements are categorized into two types: overall technological progress and technology specialized in reducing CO2 emissions, signaled by the decrease in the proportion of CO2 emissions per output (Nordhaus, 2013). Since carbon fuel sources have a limited availability, carbon-based fuels become more costly due to scarcity or emission reduction policies, hence there is a gradual shift towards non-carbon-based energy sources (Nordhaus, 2013). Finally, output is measured in terms of purchasing power parity and regional output is projected using a partial convergence model (Nordhaus, 2013). As a last step all these figures are combined to give the total world output.

3.2 The Economic Projection and Policy Analysis EPPA5 model

Among various IAM models we use the Regional Integrated Assessment Model. It has been developed by the MIT Joint Program on the Science and Policy of Global Change at the end of the 90s and now reviewed at its fifth version it takes the name of EPPA5. The EPPA5 model is a comprehensive, dynamic, multi-region, multi-sector, computable general equilibrium (CGE) model, that simulates the global economy with a detailed representation of energy technologies, greenhouse gas emissions, air pollutants, and land use changes (Chen, Paltsev, Reilly, Morris, & Babiker, 2015). The model uses the Global Trade Analysis Project (GTAP) dataset of property of Purdue University, which is based on the year 2004, to illustrate the relationship between economic sectors (Chen et al., 2015). It includes information on exports, imports, government, investment, and household demand for final goods, as well as the distribution of labor, capital and natural resources among each sector(Chen et al., 2015). The model is solved forward in 5-year steps from 2005 to 2100. For the historical years between 2005 and 2015, the model's inputs are calibrated to match macroeconomic data from the International Monetary Fund and energy data from the International Energy Agency (Chen et al., 2015). Here below it is presented a schematic graphic static representation of the model (3.1).

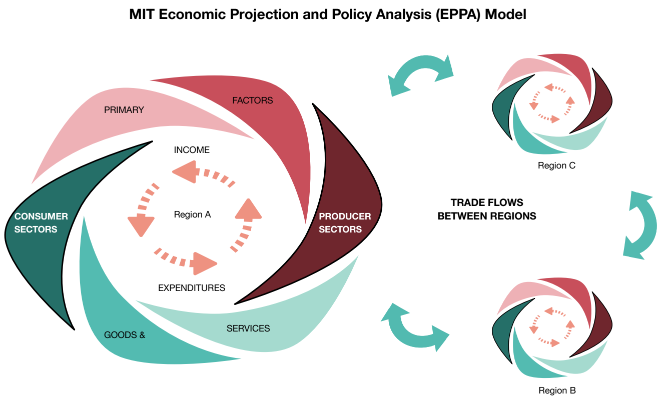


Figure 3.1: EPPA model functioning

The EPPA5 model's standard economic specification is measured in billions of dollars, it includes inputs such as capital rents, labor, and resource rents, and outputs like gross output of each sector and output supplied to each final demand sector (Chen et al., 2015). Additionally, the model includes physical terms for energy (measured in exajoules), emissions (measured in tons), land use (measured in hectares), population (measured in billions of people), natural resource endowments (measured in exajoules and hectares) and efficiencies (measured as energy produced/energy used) of advanced technology (Chen et al., 2015). These physical accounts provide insights on the depletion and use of natural resources, technical efficiencies of energy conversion processes, and the limitations of annual availability of renewable resources such as land and the number of people affected by health effects (Chen et al., 2015). Representing the human system in the MIT Integrated Global System Modeling (IGSM) framework, this model provides projections of physical changes, such as emissions of GHG and other pollutants, and land use, including atmospheric chemistry model and climate and terrestrial ecosystems to produce scenarios of climate and environmental change (Chen et al., 2015). The model can also be run in a stand-alone mode, without coupling with other IGSM components, when the focus is on the economics and policy of energy, agriculture, or emissions (Chen et al., 2015).

The model simulates the effect of various policy options in the economy, and provides insight into their potential costs and benefits (Chen et al., 2015). For example, we can simulate the impact of a carbon tax on emissions and its effect on economic welfare, or the impact of subsidies for renewable energy on energy production and consumption (Chen et al., 2015). Additionally, the model can also evaluate policies that target specific sectors, such as phasing out nuclear or coal, or implementing renewable portfolio standards. EPPA5 is formulated in the GAMS-MPSGE language, which is a mathematical programming software for general equilibrium analysis which can find solutions that simultaneously clear all markets for goods and primary factors given existing taxes and distortions (Chen et al., 2015). This feature allows the model to take into account the interdependence of different economic sectors and markets and provide a comprehensive view of the economy.

3.2.1 The Equilibrium Structure of the EPPA model

The model is formulated and solved as a mixed complementary problem (MCP), where three inequalities must be satisfied: the zero profit, market clearance, and income balance conditions (Chen et al., 2015). Using the MCP approach, a set of three non-negative variables is involved: prices, quantities, and income levels. First, the zero profit condition ensures that any activity operated at a positive intensity must earn zero profit, and that the value of inputs must be equal or greater than value of outputs. Here, π_i indicates the profit level for each firm and y_i the respective output (equation 3.6).

$$\pi_i \geq 0, \quad y_i(-\pi_i) = 0 \tag{3.6}$$

Then, the market clearance condition requires that any good with a positive price must have a balance between supply and demand, so that any good in excess supply must have a zero price. The variables considered for each agent are x_i, which is, in general terms, the demand for a specific good, y_i the correspondent supply and p_i the price level as presented in equation 3.7.

$$y_i - x_i \geq 0, \quad p \geq 0, \quad p_i(y_i - x_i) = 0 \tag{3.7}$$

Lastly, the income balance condition requires that for each agent, the value of income, m_i must equal the returns to factor endowments w_i and tax revenue t_i as depicted in equation 3.8.

$$m_i = w_i + t_i \tag{3.8}$$

For the production side, we use a Constant Elasticity of Substitution (CES) production function assuming constant returns to scale (Chen et al., 2015). For this reason, all inputs are necessary inputs and therefore all the conditions mentioned above hold with strictly inequalities and supply must be strictly equal to demand (Chen et al., 2015).
The problem firm faces is described in the equation 3.9 as,

$$\max_{y_{ri}, x_{rji}, k_{rfi}} \pi_{ri} = p_{ri} y_{ri} - C_{ri}(p_{ri}, \omega_{rf}, y_{ri}) \quad s.t. \quad y_{ri} = \phi_{ri}(x_{rfi}, k_{rfi}) \tag{3.9}$$

The representative firm in each region (indexed by r) and sector (indexed by i or j) chooses a level of output y, amount of primary factors k (indexed by f) to maximize profits while being constrained by, $\phi_{ri}(x_{rfi}, k_{rfi})$, its production technology (Chen et al., 2015). In this maximization problem C_{ri} stands for cost function which depends on the prices of goods, p_{ri}, factors, ω_{ri} and level of output choice y_{ri} (Chen et al., 2015). Since constant returns to scale imply that in equilibrium the economic profits of the firm will be equal to zero, it follows that, assuming c as the unit cost function, the equilibrium condition for the optimizing firm will be:

$$p_{ri} = c_{ri}(p_{rj, w_{rf}}) \tag{3.10}$$

By Shepard's Lemma we can derive the demand for good and factors which will be respectively:

$$x_{rji} = y_r \frac{\delta c_r}{\delta p_j} \tag{3.11}$$

$$k_{rfi} = y_r \frac{\delta c_r}{\delta w_f} \tag{3.12}$$

Similarly, the representative household maximizes, in every region, a welfare function subject to a budget constraint as the following equation presents, note that indexing does not vary:

$$\max_{d_{ri}, s_r} \; W_{ri}(d_{ri}, s_r) \quad s.t. \quad M_r = \sum_f w_{rf} K_{rf} = p_{rs} s_{rf} + \sum_i p_{ri} d_{ri} \tag{3.13}$$

In equation 3.13 M_r represent the income, K_{rf} the endowment in aggregate form and d_{ri} it is the final demand for commodities and s_{rf} savings.

For the representative household we assume a CES utility, therefore, through duality and the principle of linear homogeneity, there is a single expenditure function or welfare price index, that corresponds to each region, as depicted in 3.13 and it is provided by:

$$p_{rw} = E_r(p_{ri}, p_{rs}) \tag{3.14}$$

As before the respective demand for goods and savings is given using Shepard's Lemma and result in equations 3.15 and 3.16.

$$d_{ri} = \overline{m}_r \frac{\delta E_r}{\delta p_{ri}} \tag{3.15}$$

$$s_r = \overline{m}_r \frac{\delta E_r}{\delta p_{rs}} \tag{3.16}$$

here the initial level of expenditure for each region is represented by the variable $\overline{m}_r$.

Since system is closed and operates with a set of market clearance equations the equilibrium prices in the various goods and factor markets is established. For the purpose of simplicity, these equations exclude the final demand categories of investment, government, and foreign trade resulting at equilibrium in:

$$y_{ri} = \sum_j y_{rj} \frac{\delta C_{rj}}{\delta p_{ri}} + \overline{m}_r \frac{\delta E_r}{\delta p_{ri}} \quad , \tag{3.17}$$

$$K_{rf} = \sum_j y_{rj} \frac{\delta C_{rj}}{\delta w_{rf}} \tag{3.18}$$

We select activities depending on their energy dependence. The GTAP dataset used in the EPPA5 model only includes production activities that existed in the benchmark year (Chen et al., 2015). However, as our model considers future scenarios with severe environmental policy constraints, advanced energy technologies that are not currently used because of current scarce profitability, may become more important in the future. To account for this, the model includes "backstop technology sectors" that represent these advanced technologies modeled as perfect substitutes for existing sectors (Chen et al., 2015). The cost of data and production structure for these technologies are based on engineering estimates from the literature. The input share parameters for these technologies are set so that they sum to 1.0, as with conventional technologies(Chen et al., 2015). The relative cost of advanced and conventional technologies after the base year is determined endogenously as input costs change (Chen et al., 2015). Following EPPA5 structure, we include 14 electricity generation technologies, including 5 traditional technologies and 9 advanced technologies (Chen et al., 2015). The input shares and markups for the advanced electricity technologies are determined using a legalized cost of electricity calculation (Chen et al., 2015).

3.3 Climate Transition Value at Risk

To assess risk exposure to climate transition impacts, we first introduce the concept of transition scenario and climate policy shocks. In fact, in the model, we establish a set of Transition Scenarios, referred to as *TranScen*, to describe a disordered transition from the Baseline scenario to one of the other climate policy scenario P_l (equation 3.19).

$$TranScen = \{BP_1, ..., BP_l, ..., BP_{nScen}\} \tag{3.19}$$

Starting from this definition we compute climate policy shocks as,

$$PolShock = \{..., \frac{Y_{C,S,P,M} - Y_{C,S,B,M}}{Y_{C,S,B,M}}, ...\} \tag{3.20}$$

Climate policy shocks have been estimated for each country C, sector S, and each transition scenario, using the EPPA5 model. These shocks are obtained by computing the differences in the output, indicated as $Y_{C,S,P,M}$, of individual sectors between the trajectory in B and the corresponding trajectory in the Climate Policy Scenario P (Battiston & Monasterolo, 2020). Recall that, climate policy shock affects the bond issuer j's revenues as follow,

$$u_j(BP) = \frac{rev_j(P) - rev_j(B)}{rev_j(B)} = \sum_S \left(\frac{rev_{j,S}(P) - rev_{j,S}(B)}{rev_{j,S}(B)} \frac{rev_{j,S}(B)}{rev_j(B)} \right), u_j(BP) = \sum_S (u_{j,S}(BP) w_{j,S}(B)) \tag{3.21}$$

The effect of the transition scenario BP on company j's revenues causes a disturbance, represented by shock $\eta_j(BP)$, in the value of j's assets that is written as,

$$\eta_j(BP) = \chi_j^0 u_j(BP), \tag{3.22}$$

$\chi_j^0 u_j$ being the asset elasticity with reference to revenues. The model assumes that any shock endures up until the maturity of the bond (Monasterolo, 2020).

We are interested in the effect of climate transition hazard on investor risk. We therefore rely on an additional valuation framework to to assess exposure of financial intermediaries projects to climate transition risk (Monasterolo, Zheng, & Battiston, 2018). We develop a climate stress-test methodology aimed evaluating the expected value of a bond portfolio affected by a balance sheet shock linked to the beneficiary's business operations due to a climate policy shock (Monasterolo et al., 2018). This methodology is modular and based on a simplified model, but it is able to capture the order of magnitude of shocks on the project's value (Battiston, Mandel, Monasterolo, Schütze, & Visentin, 2017).

To conduce the scenario analysis we operate with Climate Policy Relevant Sectors (CPRS), theorized by (Battiston et al., 2017). These sectors are designed to fill a gap in the use of the "Network for Greening the Financial System" (NGFS) scenarios for climate risk assessment by providing a clear correspondence between international standard classifications of economic activities, Nomenclature of Economic Activities (NACERev2), and IAM variables (Battiston et al., 2017). All the economic activities classified with NACERev2 method are now divided between suppliers of fossil fuels and users of fossil fuels and electricity (Battiston et al., 2017). This last group can itself be subdivided between transport, housing and manufacturing (Battiston et al., 2017). This result in a classification of economic activities that is unique for climate transition risk classes. The CPRS provide a high-level classification of economic activities based on their Greenhouse Gas emissions profile, energy and technology profile, business model, and policy relevance, and they are available at increasing levels of granularity (Battiston et al., 2017). This classification includes sectors such as utilities, transportation, agriculture, manufacturing, and households as well as the mining branch, which even though it has small direct emissions it a crucial plays a role in the extraction of fossil fuels (Battiston et al., 2017). We take also into account the carbon leakage risk classification, which identifies activities that may be heavily affected by the introduction of a carbon price (Battiston et al., 2017).

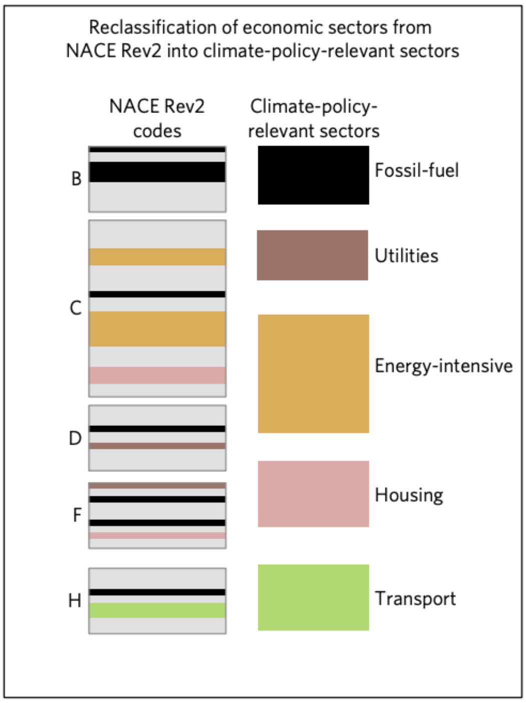


Figure 3.2: Regrouping of NaceRev2 sectors into CPRS by Battiston et al.

Once the trajectories are assessed for the interested sectors and regions, we structure the valuation methodology for bonds portfolios in the following way. A financial actor, which is indexed by the letter i, is given a portfolio of investments through bond contracts and each bond in signed by a different borrower j (Monasterolo et al., 2018). The model evolves in three temporal steps, the first, t_0, in which the valuation is executed, the second one, t^*, in which the climate policy shock occurs and the last one that represent the maturity of the single bond, T_j so that $t_0 < t^* < T_j$ (Monasterolo et al., 2018). The financial valuation of an agent's investment in a specific project at a specific time t_0, is denoted as "$A_{ij}(t_0, T_j)$", where i represents the agent, and j represents the project (Monasterolo et al., 2018). The portfolio of a bank's investments in various projects can be represented as the sum of the individual valuations of each project (equation 3.23)

$$A_i(t_0) = \sum_j A_{i,j}(t_0, T_j) \tag{3.23}$$

Our model uses expectation to conduct the valuation of the bond project j as shown in eq 3.24,

$$A_{i,j}(t_0, T_j) = p_j(t_0, T_j) r_j F_{ij} + (1 - p_j(t_0, T_j)) F_{ij} = F_{ij}(1 - (1 - r_j) p_j(t_0, T_j)), \tag{3.24}$$

where $p_j(t_0, T_j)$ is the probability of default of borrower j with the information known at time t_0, F_{ij} refers to the face value of the bond and r_j corresponds to its recovery rate. In this case, the recovery rate intended as the proportion of funds returned to the lender in the event of the borrower defaulting, is taken as exogenous (Monasterolo et al., 2018). So, in this situation, a common method for modeling the default of a borrower j at maturity T_j is to traet it as a consequence of an unexpected and random event $\eta_j(T_j)$ that affects the borrower's assets and is noticed at time T_j (Monasterolo et al., 2018).

At a specific point in time t^*, the implementation of a climate policy (e.g. a carbon tax or coordinated GHG targets) by a government leads to a change in the market shares of certain sectors in the economy. Therefore there is a shift from the baseline scenario B to a new scenario P (Monasterolo et al., 2018). We assume that this transition modifies the likelihood of default of the borrower j due to changes in the market share of the sector in which borrower j operates (Monasterolo et al., 2018). It follows that there will be a proportional change in the expected value of the bonds as presented in equation3.25, where $\Delta p_j(P)$ refers the difference in default probability going from one scenario to another (Monasterolo et al., 2018)

$$\Delta A_{i,j}(t_0, T_j, P) = -F_{ij}(1 - r_j) \Delta p_j(P), \tag{3.25}$$

To quantify the impact of a passage to a climate scenario P, the total assets of the borrower j at time T_j is modeled as a random variable described by the following equation:

$$\tilde{A}_j(T_j) = A_j(t_0) + \xi_j(t^*, P) + \eta_j(T_j), \tag{3.26}$$

where $\eta_j(T_j)$ refers to the idiosyncratic shock at time T_j, $\xi_j(t^*, P)$ symbolizes the shock due to the climate policy introduction occurring at time t^* and $A_j(t_0)$ is the asset value at time t_0 (Monasterolo et al., 2018). The default condition for the borrower is therefore the following,

$$E_j(T_j) = A_j(t_0) + \eta_j(T_j) + \xi_j(t^*, P) - L_j = E_j(t_0) + \eta_j(T_j) + \xi_j(t^*, P) < 0, \tag{3.27}$$

The borrowers defaults at time T_j if their net worth at maturity, described as assets minus liabilities, becomes negative (Monasterolo et al., 2018). So, for a specific policy shock $\xi_j(t^*, P)$, the conditional probability of the borrower defaulting is determined by the likelihood that the idiosyncratic shock $\eta_j(T_j)$ at time T_j is less than a threshold value $\theta_j(P)$, which is based on the borrower's liabilities, its initial level of net worth , and the impact of the climate policy shock ξ_j on the borrower's assets at time t^*. Hence we formulate the default condition as follows:

$$\eta_j(T_j) < \theta_j(P) = -(E_j(t_0) + \xi_j(t^*, P)). \tag{3.28}$$

When no policy occur or else, when the policy is introduced but the shock associated with is zero, then, the condition in equation 3.28 is,

$$\eta_j(T_j) < \theta_j(P) = -(E_j(t_0)). \tag{3.29}$$

So, the probability of default can be written as,

$$\mathbb{P}\{\eta_j < \theta_j(P)\} = \int_{\eta_{inf}}^{\theta_j(P)} p(\eta_j) d\eta_j, \tag{3.30}$$

being η_{inf} the lower bound of the probability distribution support. Then, the difference in probability caused by the shock produced by the policy introduction is presented in equation 3.31

$$\Delta\mathbb{P} = \int_{\theta_j(B)}^{\theta_j(P)} p(\eta_j) d\eta_j. \tag{3.31}$$

Since the policy shock affects the borrower's financial statements and subsequently the expected value of the bonds, through the mechanism of a shift in the market share of the sector in which the project is located, we can define the market share shock as $u_{S,R}(P,M,the^*)$ (Monasterolo et al., 2018),

$$u_{S,R}(P,M,t^*) = \frac{m_{R,S}(P,M,t^*) - m_{R,S}(B,M,t^*)}{m_{R,S}(B,M,t^*)}. \tag{3.32}$$

The value of a loan to a borrower j can be impacted by changes in the economic performance of the sector S depending on the geographic region R in which the borrower operates. Under the assumptions of constant demand, prices, and returns to scale, a decrease in a firm's market share results in a corresponding decrease in its sales and profits. So, we assume that a relative change in the market share of the borrower's sector S within a geographic region R, represented by $u_{S,R}(P,M,t^*)$, leads to a proportional relative change in the borrower's profitability (Monasterolo et al., 2018). Since net worth is the accumulation of profits over a period of time, the relative change in net worth and profit are the same and, as a result, it is equivalent to assume that a relative change in net worth is proportional to the relative shock in market share (Monasterolo et al., 2018), which become formally,

$$\frac{\Delta E_j}{E_j} = \chi u_{S,R}(P,M,t^*). \tag{3.33}$$

In equation 3.33, χ is the elasticity of profitability with respect to changes in market and we assume it to be of constant and equal to one (Monasterolo et al., 2018). To compute analytically the this model trajectories for future values of market shares are needed and can be found in the LIMITS database (Monasterolo et al., 2018).

By assuming that the probability distribution of the shocks to the borrower's assets $\mathbb{P}(\eta_j)$ follows a uniform distribution with a range of σ and an average of μ, for a given model, region, and sector, the change in default probability can be written as,

$$\Delta\mathbb{P} = \frac{\theta_j(P) - \theta_j(B)}{\sigma}, \tag{3.34}$$

hence, by considering that the variation in the default threshold is the alteration in loan value brought about by the climate policy shock $\xi_j(t^*)$. The shock caused by the climate policy and the idiosyncratic shock are assumed to be independent (Monasterolo et al., 2018):

$$\Delta\theta_j = \theta_j(P) - \theta_j(B) = -\Delta E_j = -\xi_j = -E_j \chi u_{S,R}(P,M,t^*) \tag{3.35}$$

so, using this information, the change in default probability can be written as,

$$\Delta\mathbb{P} = -\frac{E_j}{\sigma}\chi u_{S,R}(P,M,t^*). \tag{3.36}$$

From this it is possible to evaluate the change in value of each loan (equation 3.37) and following this reasoning it is possible to evaluate the change in value of the entire portfolio by summing over the j projects (equation 3.38).

$$\Delta A_{ij} = F_{ij}(1-r_j)\frac{E_j}{\sigma}\chi u_{S,R}(P,M,t^*), \tag{3.37}$$

and

$$\sum_j A_{ij}(t_0, T_j, P) = \sum_j F_{ij}(1-r_j)\frac{E_j}{\sigma}\chi u_{S,R}(P,M,t^*). \tag{3.38}$$

Formally, the Climate Value-at-Risk (Climate VaR) of investor i portfolio is defined as the amount at risk, calculated in relation to the transition scenario BP, with π as the portfolio loss $\phi_P(\pi)$ as the distribution of losses given the Climate Policy Shock, and α representing the level of confidence (Battiston & Monasterolo, 2020).

$$\int_{ClimateVaR_\alpha(BP)}^{1} \phi_{BP}(\pi)d\pi = \alpha \tag{3.39}$$

Nonetheless, to estimate the traditional Value at Risk in a climate stress test, the projected distribution of the idiosyncratic shock and the probability of occurrence of climate policy shocks must be available. Therefore, for this research it is more suitable to adapt the definition of project-level Climate Value at Risk (Monasterolo et al., 2018). The PC Var is defined as *"the value such that, conditional to the same climate policy shocks for all n projects, the fraction of projects leading to losses larger than the VaR is equal to the confidence level c* (Monasterolo et al., 2018), formally,

$$|\{j|\Delta A_{ij}(t_0, T_j, P, B) \geq Var\}|/n = c \tag{3.40}$$

While this notion has some limitations, it provides an initial understanding of the portfolio's greatest exposure under specific conditions(Monasterolo et al., 2018).

Chapter 4

Empirical Analysis

We now apply the model empirically to four simulated bond portfolios and by doing so we introduce the modeling of innovation as a variable. We adopt the scenario narrative and origination data provided by the Bank of Canada in 2019 (Hosseini et al., 2022).

4.1 Key assumptions and Narrative

Four agents are considered, each endowed with a distinct bond portfolio i. These portfolios can be marked as either heavily reliant on carbon or more environmentally friendly, and can also be distinguished as either innovative or not. The scenario analysis is carried out using scenario projection data selected from the LIMITS dataset and provided by the Bank of Canada as a result of the application of the EPPA5 model. We consider four distinct scenarios over a 30-year period, from 2020 to 2050 (Hosseini et al., 2022). These scenarios take into account two key drivers that influence climate transition risks: the ambition and timing of climate policy, and the pace of technological change based on the availability of carbon dioxide removal (CDR) technologies (Hosseini et al., 2022). These scenarios are not exhaustive or predictive in nature and they rather delve into a range of plausible, yet intentionally challenging, global transition pathways that align with specific international climate objectives (Hosseini et al., 2022). The baseline scenario serves as a benchmark and is assumed to reflect market participants' expectations of climate policy in 2019. This scenario assumes that countries continue to pursue their 2019 policy frameworks and take no further policy action to limit global warming (Hosseini et al., 2022). As a result, emissions are expected to rise in an unconstrained manner, leading to a further rise in the global average temperature. The *below 2°C immediate* and *below 2°C delayed* scenarios, instead, consider a plausible policy path consistent with limiting the increase in global average temperatures to below 2°C by 2100 but that is accelerated, in the first case, or delayed in the second case with respect to the actual policy plan (Hosseini et al., 2022). For the immediate scenario we assume action to begin in 2020 and for the delayed scenario we assume action does not begin until 2030. In this case, due to delayed action, emissions must fall rapidly to compensate for the additional emissions associated with the delay, implying a sharp transition through mid-century. The emissions paths for these scenarios are based on countries' nationally determined contributions submissions, scaled to be consistent with the ambition and timing of the respective scenario (Hosseini et al., 2022). The *net-zero 2050 (1.5°C)* scenario considers a plausible path aligned whit the current policy program for greenhouse gas emissions reduction (Hosseini et al., 2022). This scenario reaches net-zero global carbon dioxide emissions by mid-century assuming that all targets set by the international agreements are met in time by all countries (Hosseini et al., 2022). All the key narrative adopted are summarized in table(4.1). The process of modeling policy assumptions was conducted in two phases. To start with, various

Scenario	Technical Change	Climate Policy Ambition
Baseline (2019 policies)	The rate of technological advancement is low and the options for carbon dioxide removal are limited	The world continues on a trajectory that aligns with current climate policies, resulting in a increase in greenhouse gas emissions and a predicted increase in average global temperature of between 2.9 and 3.1 degrees by 2100.
Below 2°C immediate	The rate of technological advancements is moderate and the access to CDR technologies is restricted	Efforts made to decrease emissions begin in 2020, with the goal of preventing an increase of more than 2 degrees in global temperature by 2100
Below 2°C delayed	The rate of technological advancements is moderate and the access to CDR technologies is restricted	After a 10-year period following the policy frameworks fixed in 2019, collective global efforts for a target of below 2 degrees begin in 2030. A more rapid transition is required to compensate for the additional decade of emissions rise.
Net-zero 2050 (1.5°C)	The rate of advancement in technology is rapid and there is an adequate supply of carbon dioxide removal techniques.	From 2020 onward, the world takes action to decrease emissions with the aim of reaching a 1.5 degree target. This scenario includes the adding of net-zero commitments.

Table 4.1: Key assumptions for the climate scenario analysis

non-carbon price policies for each distinct geographic region have been grouped (Hosseini et al., 2022). These policies included sector-specific mandates, restrictions on certain fossil fuel-based electricity generation technologies, goals for minimum levels of renewable energy, and any other policy measures that could potentially impact emissions levels (Hosseini et al., 2022). Then, each country and region included in the analysis has been subject to an emissions pathway constraint that was consistent with the scenario considered (Hosseini et al., 2022). This constraint served as an input for the model, and was used to ensure that the modeled policy assumptions were aligned with the overall scenario pathway (Hosseini et al., 2022). As far as it concerns the regions considered in this analysis we relied on the selection made for the Bank of Canada in its project which chose eight of the 18 regions presented by the EPPA5 model. We have selected the regions of Africa, Canada, China, Europe, India, Japan, United States and grouping the the remaining geographical areas as "Rest of the World". Table 6, in the Appendix, presents a short summary all the variable included in the original dataset available on the official web-page of the Bank of Canada. Of them, we focus on the primary source of energy exploited, hence, we extract the primary energy source categories, "Total", "Coal", "Gas", "Hydro", "Bioenergy", "Renewable (wind&solar)", "Oil", "Nuclear" to build our scenario dataset. In the Appendix the comprehensive table with all the projection data can be found.

Then, we proceed with the quantification of the market shocks up until 2050 for each region and sector using the projected data presented in tables 7, 9, 8 and 10 of the appendix. We present below a graphic representation of the shocks produced by sector for each policy regime.

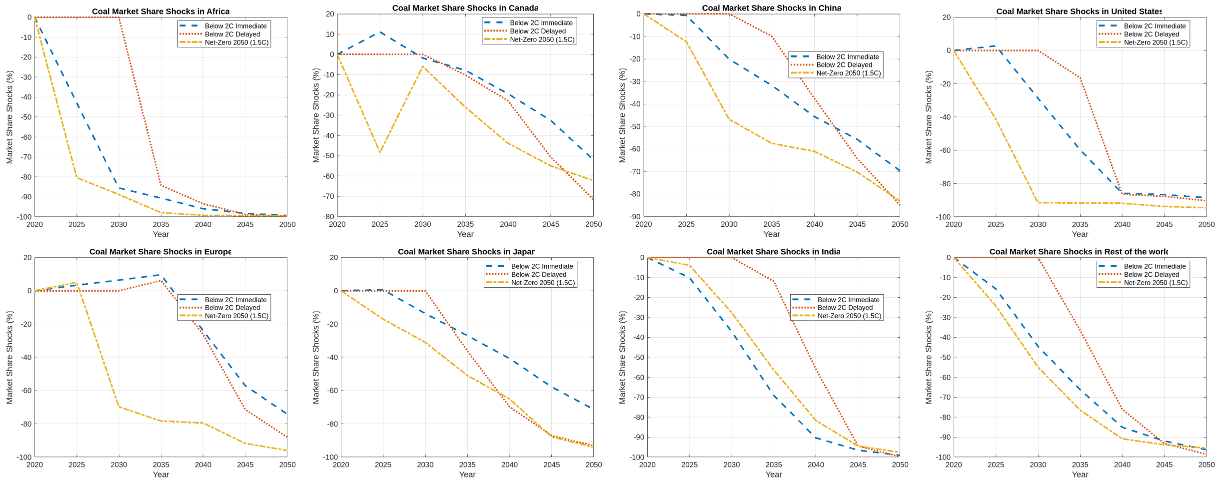


Figure 4.1: Market share shocks for Coal sector

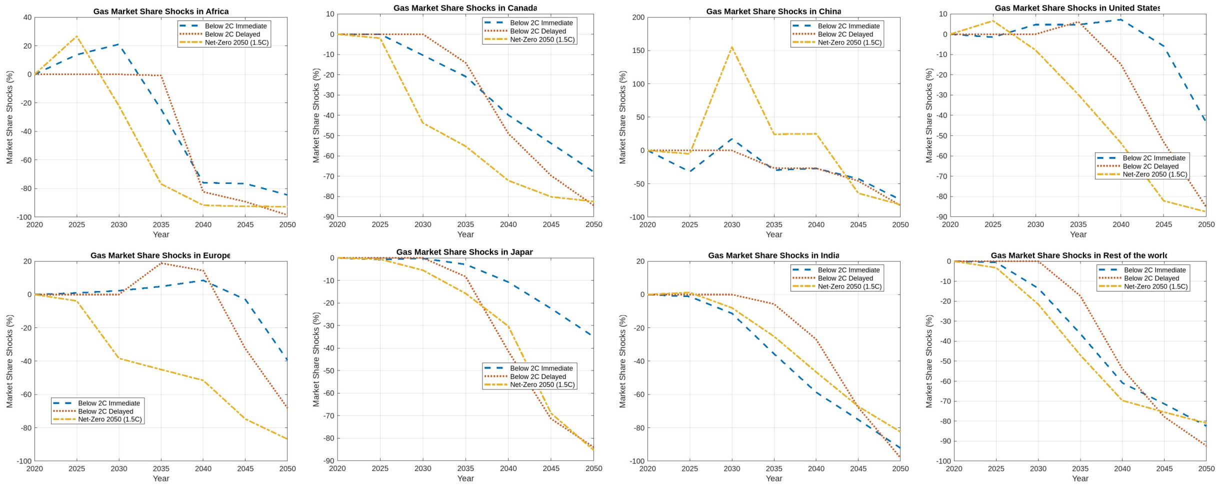


Figure 4.2: Market share shocks for Gas sector

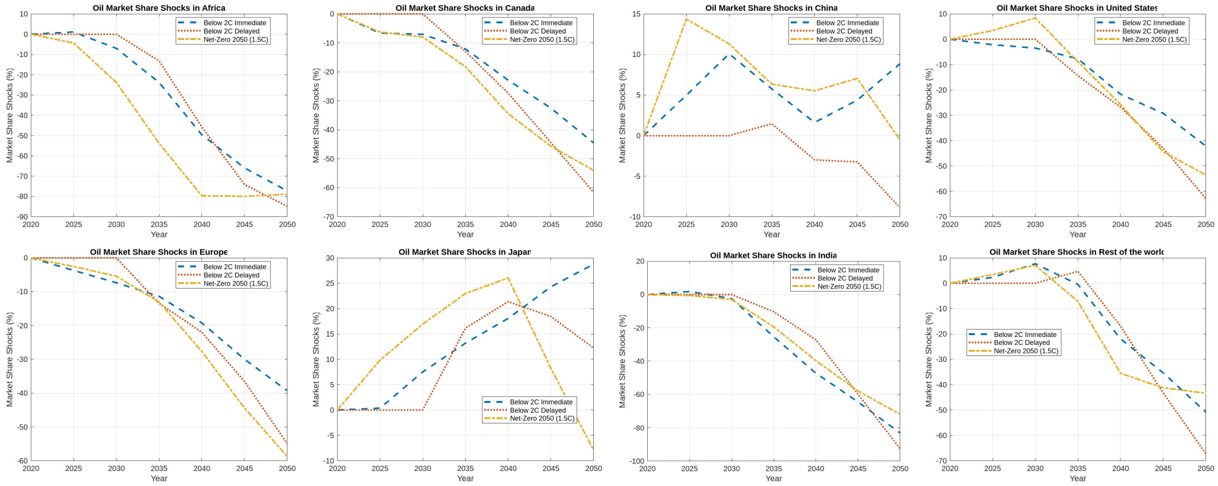


Figure 4.3: Market share shocks for Oil sector

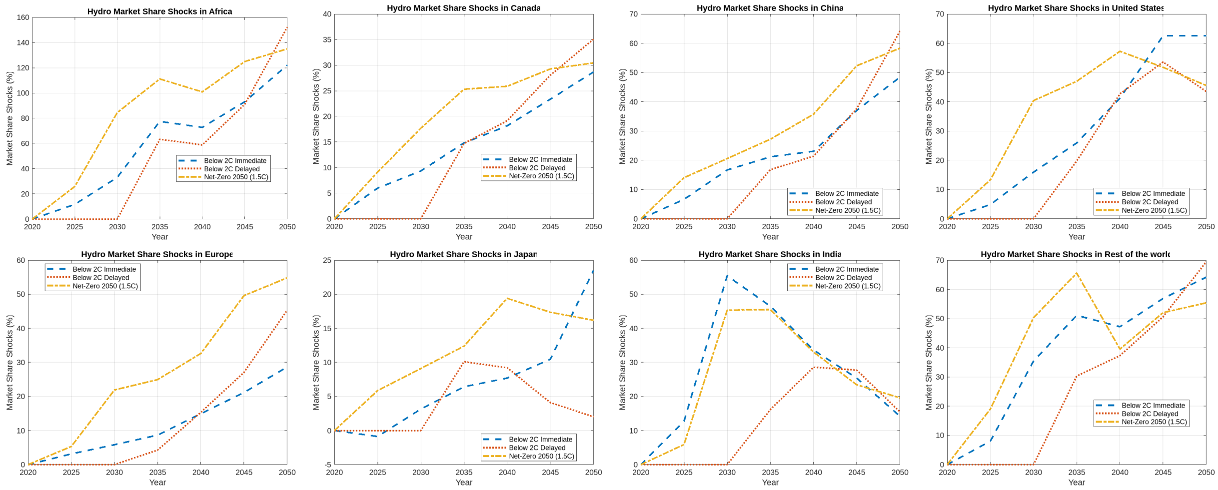


Figure 4.4: Market share shocks for Hydro sector

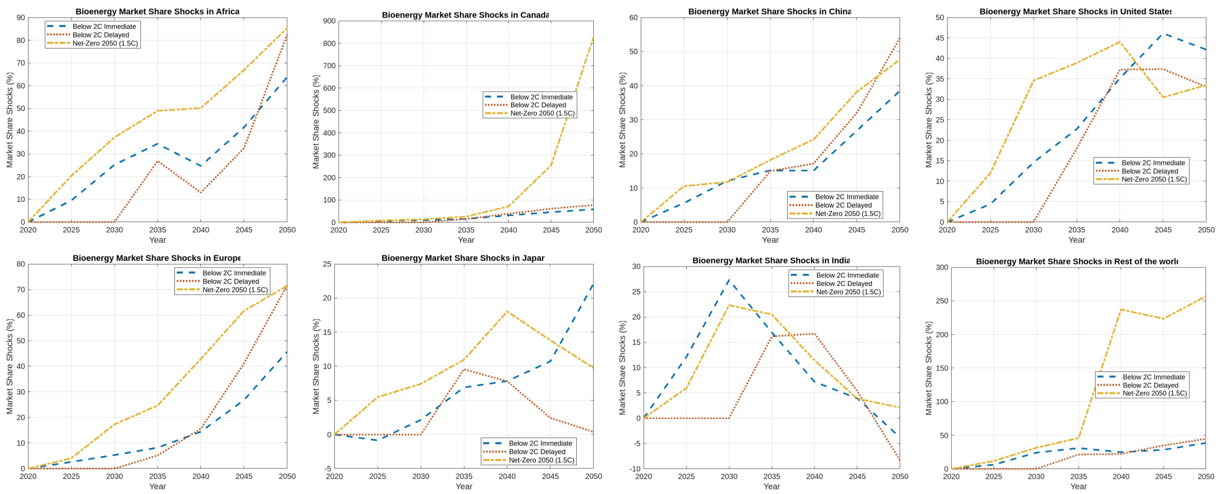


Figure 4.5: Market share shocks for Bioenergy sector

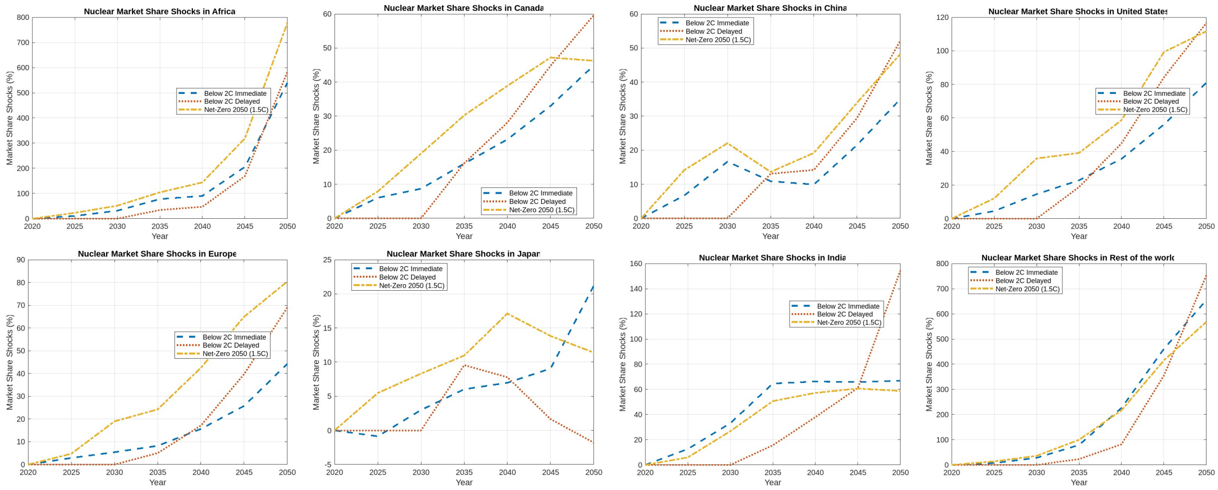


Figure 4.6: Market share shocks for Nuclear sector

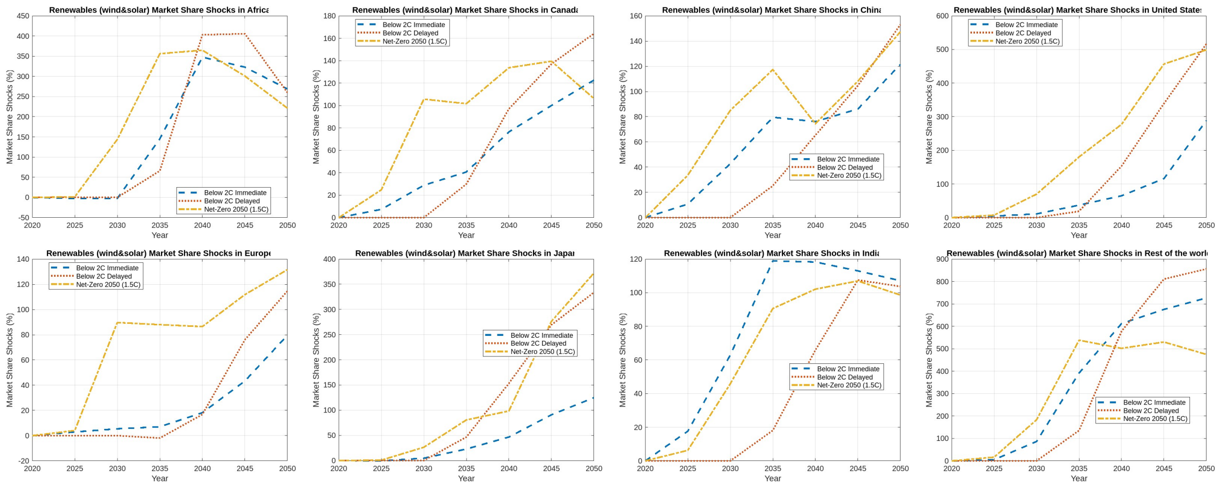


Figure 4.7: Market share shocks for Renewables sector

On one hand, we notice that the fossil dependent sectors, Coal, Oil and Gas, register in average a negative shock coming from the introduction of climate policies independently of the path chosen. In particular Africa and India market share are the most affected by the introduction of policies in any of the possible scenarios. In addition to this we notice that in some cases the sharpest negative inflection occurs in relation to the most drastic transition. In the case of India, as far as it concerns the coal sector, the adoption of the 2°C regime immediately would cause more harm than the Net-Zero program. Moreover, a similar trend is delineated for the Gas sector. As before, India is one of the country which is worsen off by any policy program introduction and its market share for the Gas sector record among the sharpest negative decline along the timeline in all scenarios. Similarly, China sees its market shares harmed mainly by the transition in the Gas sector. The market share shocks for the United States, instead, show an higher degree of robustness until 2030 when then they start a slow decline. Lastly, if we look at the oil sector, we see that until 2040 policy introduction for low carbon transition would impact positively the market shares of Japan, in contrast with the overall general decreasing trend.
On the other hand, figures prove all the shock trends are positive for the energy sectors non related with carbon dependent energy. For the Bioenergy sector, all trends are positive and the United States registers the highest positive boost coming from either of the scenario realizations. As far as it concerns the Renewable sector and the Nuclear sector, again, the graphs show an increase in market share coming from the policies shocks. For renewable energy, Canada and the United States are favoured, whereas, in the nuclear sectors, India reacts better than the other regions. Moreover, the highest positive shock in these carbon fossil free sectors, is provided in all cases by the Net-Zero 2050 scenario, meaning that, a delay in policy implementation, or a faster transition, would harm the potential growth in market shares in all regions.

4.2 Climate transition risk and innovation

4.2.1 Innovation modeling

We now introduce the additional variable of innovation. We decide to adopt the approach of patents counting. Knowing that the quality of EPO patents is high, we select for each sector the most active corporations in terms of number of patents application and number of granting using the Global Patent Index (GPI) provided by EPO. The Global Patent Index is a tool that allows to access, thorough searches, to an extensive global data collection, which encompasses bibliographic data, legal events, and full-text documents. The GPI is updated on a weekly basis, every Friday at 12:00 CET, adding approximately 500,000 new patent documents to the collection each month. The GPI uses the International Patent Classification (IPC), established by the Strasbourg Agreement in 1971, and provides a hierarchical system of symbols that are independent of language for categorizing patents and utility models based on the different technological fields they belong to. Thus, we conduct our selection trough ICP codes, year of publication and key words.

This patent selection process implied a fine skimming of patents families and a code mapping. Since, there is no direct correspondence between CPRS division and IPC families classification, we started by making a first coarse skimming using CPRS-NACERev2 correspondence. Here below, 4.2 shows which NACErev2 codes are assigned to each sector.

CPRS sector	**NACE codes**
1 Fossil fuel	05, 06, 08.92, 09.10, 19, 35.2, 46.71, 47.3, 49.5
2 Utility & electricity	35.11, 35.12, 35.13
3 Energy intensive	07.1, 07.29, 08.9, 08.93, 08.99, 10.2, 10.41, 10.62, 10.81, 10.86. 11.01. 11.02, 11.04. 11.06. 13, 14. 15, 16.29. 17.11 17.12, 17.24, 20.12, 20.13, 20.14, 20.15, 20.16, 20.17, 20.2, 20.42, 20.53, 20.59, 20.6, 21, 22.1, 23.1, 23.2, 23.3, 23.4, 23.5, 23.7, 23.91, 24.1, 24.2, 24.31, 24.4, 24.51, 24.53, 25.4, 25.7, 25.94, 25.99, 26, 27, 28, 32
4 Buildings	23.6, 41.1, 41.2, 43.3, 43.9, 55, 68, 71.1
5 Transportation	29, 30, 33.15, 33.16, 33.17, 42.1, 45, 49.1, 49.2, 49.3, 49.4, 50, 51, 52, 53, 77.1, 77.35
6 Agriculture	01, 02, 03

Table 4.2: Battiston CPRS-NACE coding correspondence

Then, using the World International Intellectual Property Organization portal we have provided a correspondence between NACErev2 classification and IPC categorization. The complete correspondence for each CPRS sector is represented in tables 11,12,13,14,15,16,17,18,20, and 21 all of which are placed in the Appendix.

Nonetheless, not all patents falling into the CPRS have significant influence in the matters of low carbon transition. There are some key technological patents that have higher economic impact than others (Wurster & Hoppe, 2022). Empirical evidence provided by (Wurster

& Hoppe, 2022), shows that key technological patents can be grouped into nine categories: mobility, energy, health, industry, digitalization, materials, infrastructure, security and finally environment (Wurster & Hoppe, 2022). As a matter of fact, a 1% increase in crucial patents in technology corresponds to a 0.108% growth in GDP per capita (Wurster & Hoppe, 2022). The extent to which a patent has a technological impact is determined by the number of citations it receives at patent offices and the breadth of its market coverage (Wurster & Hoppe, 2022). Therefore, we filtrate our patent sample to focus on key technological pieces. To do so the comprehensive dataset of patents have been trimmed following the OECD description of crucial environmental patents (Haščič & Migotto, 2015). Hence, we cross the comprehensive dataset stemming from our selection with key technological patents criteria, creating the final set of IPC codes to be used (table 4.3).

We then have selected, though the GPI index database, the most innovative companies for each energetic sector taken into analysis. The sorting of the most active companies have been the starting point for innovative bond selection. Here below, the bar chart 4.8 represents the top 100 companies that filed and received granting fro key environmental technological patents in the years between 2020 and 2022.

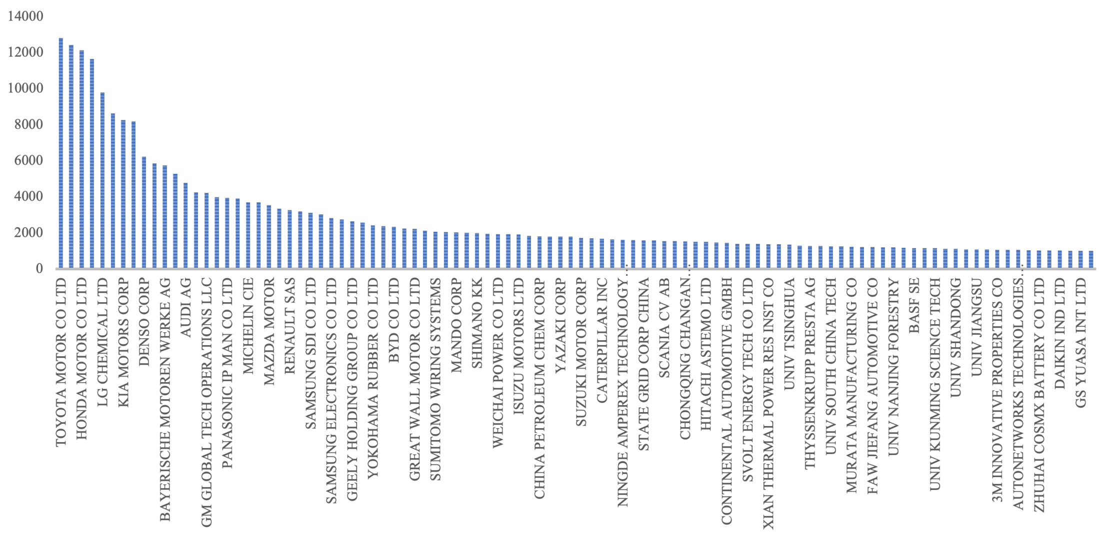


Figure 4.8: EPO top 100 applicants for key technological environmental patents between 2020 and 2022

Bond portfolios scenario analysis

We now apply the theoretical model to four simulated bond portfolios incorporating the innovation variable. The first portfolio was formed bonds issued by innovative companies but with a high carbon exposure. The second portfolio comprised bonds issued by innovative companies

KEY PATENTS FAMILIES IPC

B01D46	D21C5	B62	B60K
B01D47	D21H17	B62D67	B60W
B01D49	B09B	D21B1	B60L7
B01D50	F23G5	D21C5	B60L11
B01D51	C09K3	B29B17	C22B25
B01D53	E02B15	C08J11	E01H6
B03C3	E03B3	B60W10	E01H15
C10L	E03C1	B60K6	B01D53
C21B7	E03F	B60W20	F02B47
C21C5	C05F7	B60R16	D01B5
F01N3	A23K1	B60S5	D01G11
F01N5	A43B1	B60W10	D01G19
F01N5	A43B2	F02B43	F23G5
F01N7	A61L11	F02D19	F23G7
F01N9	B03B9	F02M21	D21B1
F01N10	B09B	H01M10	D21C5
F23B80	B09C	H01M8	D21H17
F23C9	B22F8	A23K1	F02M3
F23J15	B27B33	F02D45	F02M23
F27B1	B29B17	F02M27	F02M25
G08B21	B29B7	F02M31	F02M67
F23G7	B30B9	F01N11	F01N9
B63J4	B62D67	F01N3	F02D41
C02F	B65F	G01M15	F02D43
C05F7	B65H73	F01M13	
B03B9	C04B7	F01N5	
B29B17	C04B11	F02B47	
B30B9	C04B18	F02D21	
B65D65	C04B33	F02M25	
C03B1	C05F9	B01D53	
C03C6	C08J11	B01D23	
C05F17	B60L15	B62D	
C05F9	B60K1	B60C	
C09K11	B60L8	B60T	
D21B1	B60K16	B60G	

Table 4.3: Strategic technological patents sample

with a lower carbon footprint. The third portfolio consisted of bonds issued by non-innovative companies with a high carbon exposure, while the fourth portfolio comprised bonds issued by non-innovative companies with a lower carbon exposure. The distribution for each portfolio is presented in table 4.4. We selected bonds with a similar risk profile, all of them with a fixed term maturity.

Sector	Portfolio 1	Portfolio 2	Portfolio 3	Portfolio 4
Bioenergy	2%	5%	2%	5%
Coal	15%	15%	15%	15%
Gas	2%	10%	2%	10%
Hydro	15%	40%	15%	40%
Nuclear	2%	3%	2%	3%
Oil	60%	20%	60%	20%
Renewable	4%	7%	4%	7%
Total	100%	100%	100%	100%
	INNOVATIVE		**NON INNOVATIVE**	

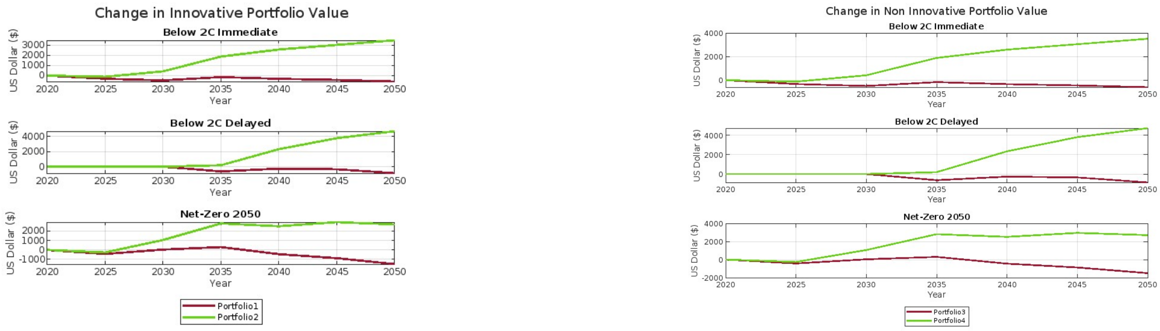
Table 4.4: Portfolios sector exposure

In order to ensure a meaningful comparison, we have maintained a similar regional exposure for the two groups of portfolios, innovative and non innovative, resulting in comparable exposure to various sectors. In addition to the innovation specification, we have included the following variables: the bond ID, borrower credit rating, bond type, portfolio affiliation, interest rate, interest type, borrower identification ticker, borrower region, borrower sector, bond origination date, maturity date, face value, and fair value. Once we have formed the two groups of portfolio we have proceeded with the simulation of the climate transition stress test evaluating for each portfolio the respective project-climate VaR. The results of the simulation are presented in the following section.

4.2.2 Findings

By applying our bond valuation framework we have found the change in value of each portfolio in each scenario due to climate policy shocks. The total changes have been calculated by summing the change in value of each bond. The results are represented by picture 4.9.

We observe that, since the portfolios have a similar risk structure and differ only in terms of their innovation component, the changes in value for the innovative group mirrors those of the non-innovative one. However, a significant difference in trend is noticeable between the portfolios highly dependent on carbon and the greener ones. Given the focus of portfolios 1 and 3 on fossil fuels, and that of portfolios 2 and 4 on green energy, the values of the fossil fuel portfolios are



(a) Change in innovative portfolios

(b) Change in non innovative portfolios

Figure 4.9: Policy introduction affect portfolio evaluation

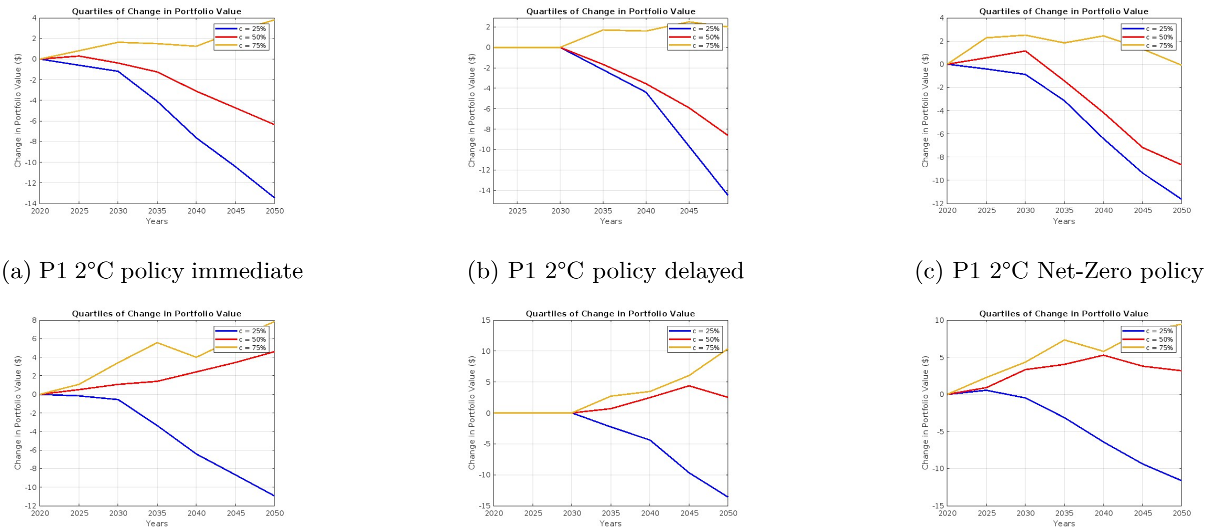
doomed to decrease over time in each scenario, while the values of the greener portfolios are expected to increase. The gap between the values of carbon-intensive portfolios and sustainable portfolios grow over time and is narrower in the Net-Zero 2050 scenario compared to the other scenarios.

We need now to examine the comprehensive distribution of changes in value for each specific climate scenarios for each portfolio so to calculate the respective distribution quartiles.

Quartile graphs divide the distribution of the data into four quarters. The first quartile, also known as the lower quartile, represents the 25th percentile and contains the lowest 25% of the data. The second quartile, also known as the median, represents the 50th percentile and separates the lower half of the data from the upper half. The third quartile, also known as the upper quartile, represents the 75th percentile and contains the highest 25% of the data. By interpreting quartile graphs, we are able to get a quick overview of the distribution of our dataset and identify patterns and outliers in the sample. Here, the most striking difference is found again between green portfolios and fossil fuel depended portfolios.

Fossil fuels portfolios are found to carry higher risk compared to portfolios with a focus on green investments based on a more accentuated steepness of the graph. This suggests that investing in fossil fuels is more susceptible to financial losses than investing in green assets. Furthermore, the sudden implementation of an abrupt climate policy is accompanied by a more pronounced incline in the quartiles graphs, which is steeper for fossil fuel-based assets. This result advocates in favour of the idea that a sudden introduction of climate policy can negatively affect the financial system rather than strengthening it. Thus, these findings suggest that a transition towards more sustainable investments should indeed be approached carefully and with a precise timing.

The portfolios with a focus on sustainable investments tend to have an upward sloping third



(a) P1 2°C policy immediate (b) P1 2°C policy delayed (c) P1 2°C Net-Zero policy

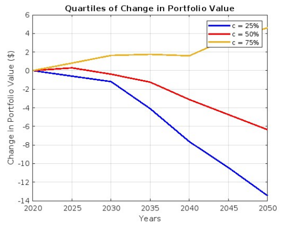
(d) P2 2°C policy immediate (e) P2 2°C policy delayed (f) P2 2°C Net-Zero policy

Figure 4.10: Quartiles of the value fluctuations of non innovative portfolios

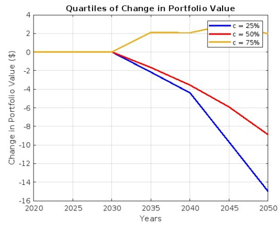
quartile and median, in contrast with carbon-based portfolios. This suggests that portfolios invested in sustainable assets have a higher level of returns compared to portfolios invested in carbon-based assets. The upward slope of the third quartile and median in sustainable portfolios indicates that the upper 25% of the returns in the sample are increasing with the size of the investment.

We then compute the project climate Value at Risk to assess the effect innovation in relation to transition risk. In general terms, Value at Risk (VaR) is a widely used measure of the risk for portfolios or investments. It is interpreted as the maximum loss that can be expected with a certain degree of confidence over a specific time horizon. The percentile used for VaR estimation are usually set to be 90% or 99%, meaning that there is a 90% or 99% confidence that the actual loss will not exceed the VaR value. VaR is widely used in finance as a tool for risk management, as it provides a concise way to summarize the tail risk of a portfolio or investment.

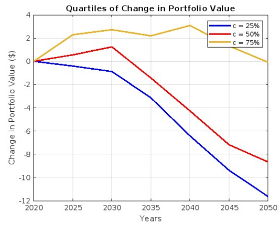
The Climate Value at Risk (CVaR) is a financial risk management tool that evaluates the potential financial losses of an investment portfolio due to the physical and transitional impacts of climate change (Monasterolo, 2020). CVaR takes into consideration the probability distribution of the expected losses, considering both the likelihood and the magnitude of potential adverse climate events. To calculate standard risk metrics like the Value-at-Risk (VaR) of a portfolio, it is necessary to have information about the joint probability distribution of idiosyncratic shocks and the likelihood of climate policy shocks. We work with a forward looking empirical model for which none of the two distribution estimates were available. We therefore rely on a project-level



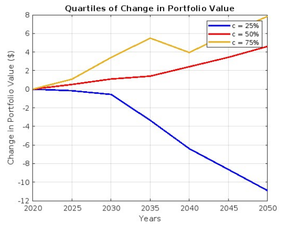
(a) P3 2°C policy immediate



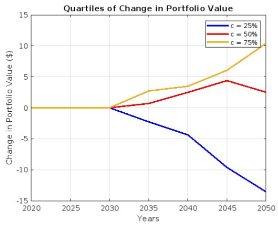
(b) P3 2°C policy delayed



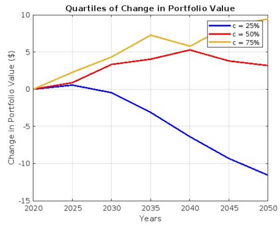
(c) P3 2°C Net-Zero policy



(d) P4 2°C policy immediate



(e) P4 2°C policy delayed



(f) P4 2°C Net-Zero policy

Figure 4.11: Quartiles of the value fluctuations of non innovative portfolios

climate VaR. We interpret it as the value that, under the condition of the same climate policy shock for all n bonds, resulted in a loss greater than the VaR for a specified confidence level c. Formally, as presented in chapter 3:

$$|\{j|\Delta A_{ij}(t_0,T_j,P,B) \geq Var\}|/n = c \tag{4.1}$$

The table below (4.5) summarizes the project climate Var for each scenario and each portfolio at a 1% and 10% level of significance.

In figure 4.2.2 the influence brought by innovation is perceivable. In fact, in all scenarios the project climate Value at Risk (VaR) for the 90% confidence interval result in a lower maximum expected loss for innovative portfolios compared to non-innovative ones. This reduction in project climate VaR across all innovative portfolios is translated to a lower level of transition risk associated with them. A lower VaR indicates a lower level of uncertainty or volatility in the potential outcomes of the project, in this case the return related to the investment in such bond portfolio. On the contrary, non innovative portfolios suffer from policies introduction and deliver, all in all, an higher level of climate VaR. The power of innovation can be seen in a clearer way, comparing the project CVaR of green portfolios for the two groups. In all scenarios non innovative sustainable portfolios perform poorly compared to the innovative ones. Note that the differences here are minimal due to the construction of the portfolios. Since portfolios possess similar sector exposure and an analogous risk structure we, as a matter of fact, did not expect great deviations one from another.

PROJECT CLIMATE VAR ($)

Innovative Portfolios				Non Innovative Portfolios		
Below 2°C immediate						
		Portfolio1	Portfolio 2		Portfolio 3	Portfolio4
	1%	16.0890	16.0896	1%	16.0893	16.0896
	10%	**16.0861**	**16.0385**	10%	**16.0896**	**16.0735**
Below 2°C delayed						
		Portfolio 1	Portfolio 2		Portfolio 3	Portfolio4
	1%	16.1511	16.1514	1%	16.1512	16.1514
	10%	**16.1001**	**16.07**	10%	**16.1513**	**16.1352**
Net-Zero 2050						
		Portfolio 1	Portfolio 2		Portfolio 3	Portfolio4
	1%	16.1222	16.1229	1%	16.1290	16.1291
	10%	**16.0717**	**16.0417**	10%	**16.1229**	**16.1068**

Table 4.5: Project Climate Var

Moreover, the highest loss degree is registered if the introduction of the policy is delayed. It appears that, even for carbon intensive portfolios a delay in the adoption of the policies result in an higher maximum potential loss, especially for non innovative carbon intensive portfolios. That is, if the introduction of the policy is delayed, the gap between innovative and non innovative portfolios enlarges in favour of the innovative selection. Furthermore, in general, portfolios with high exposure to carbon-intensive assets suffer from the introduction of climate policies and result in a higher level of climate VaR. As a matter of fact, in the table, it is clear how greener portfolios perform better compared to the fossil dependent ones. In all the scenarios, the project climate VaR of sustainable portfolios were lower than the respective counterpart.

It is important to notice that this research suffered from some natural limitations. The sample size has been limited to a small group of companies and portfolios impacting the generalization of the results. Future research could benefit from a larger and more diverse sample, as well as the use of objective measures to corroborate the findings. Nonetheless, being the simulated portfolio representative, we see that innovative bonds preform better than non innovative ones and greener innovative bonds have been the less affected by climate transaction risks.

Conclusion

To sum up, this thesis adds to the ongoing discussion about the importance of innovation for economic growth and crisis management, by assessing its role in the context of climate transition risk assessment. The transition towards a net zero emission economy implies a radical technological change which could impair portfolios performance and financial stability. In this research we notice how innovation has the ability to reduce the impact of climate transition risks. To do so, we ran a climate stress test over four different simulated bond portfolios each of which presented a different exposure to the fossil fuel sector and a different degree of innovation. We then evaluate risk exposure by adopting as risk measure the Climate Value at Risk (CVar). To apply our model we relied on the economic output trajectories computed by an Integrated Assessment Model (IAM), specifically, by the MIT Economic Projection and Policy Analysis project, the EPPA5 model. The scenario analysis data were projected out over a thirty year time window, 2020-2050, using 5 year steps.

We modeled innovation by patent application and granting counting. We took into consideration the Climate Policy relevant Sectors (CPRS) sectors and we draw the respective concordance with the NACERev2 framework. This enabled the selection of the ICP families of patents related to climate transition. We proceeded with a further skimming of patents families though the concept of "key technological patents", obtaining a final sample of significant ICP codes for patent identification. We then used the Global Patent Index database to draw up the most innovative companies for each energetic sector considered.

We then created four bond portfolios with a similar risk structure, two with a similar high carbon exposure and the remaining two more invested in alliterative cleaner energy source. One for each kind was labeled as innovative, and was therefore composed just of innovative bonds. Then the quartile disposition and the distribution of value change of each portfolio was computed. So, we applied the concept of project-climate transition VaR, interpreted as the maximum expected loss over a given time horizon and confidence level, due to the impacts of climate change on a particular investment or project.

We have observed that for all possible climate scenarios considered in the model, the expected maximum loss has been lower for innovative portfolios with respect to the control group. The influence of innovation was more perceivable on the project Climate Value at Risk (VaR) for the 90% confidence interval. The findings show that innovative portfolios resulted in a lower maximum expected loss compared to non-innovative portfolios, reducing the level of transition risk associated with them. The reduction in project climate VaR became evident when comparing the project CVaR of green portfolios. Non-innovative sustainable portfolios performed poorly compared to innovative ones. Innovation was able to mitigate the effects of a delayed policy introduction in which the potential loss for both green and carbon intensive bonds increased. In all scenarios, the project climate VaR of sustainable innovative portfolios is lower than the respective counterpart. All in all, given all the limitations of this research, these findings have significant implications for financial institutions and policymakers and provide a foundation for future research in this field.

Appendix

<table>
<tr><th>Sectors</th><th>Variables</th><th></th><th></th></tr>
<tr><td>Electricity</td><td>Capital expenditure</td><td>Inflation Y/Y</td><td>Primary Energy | Renewables (wind&solar)</td></tr>
<tr><td>Energy-intensive industries</td><td>Carbon price</td><td>Input price | Coal</td><td>Primary Energy | Total</td></tr>
<tr><td>National</td><td>Direct emissions costs</td><td>Input price | Crops</td><td>Production</td></tr>
<tr><td>Global</td><td>Emission intensity</td><td>Input price | Electricity</td><td>Real exchange rate (+ = depreciation)</td></tr>
<tr><td>Commercial transportation</td><td>Emissions (scope 1)| CH4</td><td>Input price | Energy-intensive industries</td><td>Real GDP</td></tr>
<tr><td>Livestock</td><td>Emissions (scope 1)| CO2</td><td>Input price | Forestry</td><td>Real investment</td></tr>
<tr><td>Refined oil products</td><td>Emissions (scope 1)| HFC</td><td>Input price | Gas</td><td>Revenue</td></tr>
<tr><td>Other</td><td>Emissions (scope 1)| N2O</td><td>Input price | Livestock</td><td>Secondary Energy | Electricity| Bioelectricity (CCS)</td></tr>
<tr><td>Oil & Gas</td><td>Emissions (scope 1)| PFC</td><td>Input price | Oil</td><td>Secondary Energy | Electricity| Bioelectricity and other</td></tr>
<tr><td>Crops</td><td>Emissions (scope 1)| SF6</td><td>Input price | Refined oil products</td><td>Secondary Energy | Electricity| Coal (CCS)</td></tr>
<tr><td>Emissions/removals from forestry</td><td>Emissions (scope 2)| total GHG</td><td>Input price | Transportation</td><td>Secondary Energy | Electricity| Coal (without CCS)</td></tr>
<tr><td>Oil</td><td>Emissions | total GHG (scope 1)</td><td>Nominal exchange rate (+ = depreciation)</td><td>Secondary Energy | Electricity| Gas (CCS)</td></tr>
<tr><td>Gas</td><td>Emissions/removals from forestry</td><td>Nominal investment</td><td>Secondary Energy | Electricity| Gas (without CCS)</td></tr>
<tr><td>Coal</td><td>Employment</td><td>Non-energy commodity prices</td><td>Secondary Energy | Electricity| Hydro</td></tr>
<tr><td>Forestry</td><td>Energy intensity</td><td>Output price</td><td>Secondary Energy | Electricity| Nuclear</td></tr>
<tr><td>Totale complessivo</td><td>Equity valuation</td><td>Policy rate a.r.</td><td>Secondary Energy | Electricity| Oil</td></tr>
<tr><td></td><td>Final energy demand | COAL</td><td>Primary Energy | Bioenergy</td><td>Secondary Energy | Electricity| Wind&Solar</td></tr>
<tr><td></td><td>Final energy demand | ELEC</td><td>Primary Energy | Coal</td><td>Unemployment rate</td></tr>
<tr><td></td><td>Final energy demand | GAS</td><td>Primary Energy | Gas</td><td>US GDP</td></tr>
<tr><td></td><td>Final energy demand | OIL</td><td>Primary Energy | Hydro</td><td>US inflation Y/Y</td></tr>
<tr><td></td><td>Final energy demand | ROIL</td><td>Primary Energy | Nuclear</td><td>US policy rate a.r.</td></tr>
<tr><td></td><td>Global GDP</td><td>Primary Energy | Oil</td><td>Indirect costs</td></tr>
</table>

Table 6: Sectors and variables of the dataset

Baseline 2019 policies

Geography	Year	Bioenergy	Coal	Gas	Hydro	Nuclear	Oil	Renewables	Total	Total Baseline
Africa	**2020**	**155,018**	**45,909**	**46,492**	**11,347**	**0,1314**	**71,662**	**0,2753**	**334,495**	**665,3297**
	2025	153,023	56,219	53,757	11,56	0,1388	85,627	0,7134	368,709	729,7472
	2030	152,206	57,016	59,099	11,943	0,285	94,709	12,465	390,287	778,01
	2035	150,715	58,537	71,467	12,29	0,255	104,95	22,046	422,554	842,814
	2040	150,163	56,75	84,018	12,709	0,2779	114,268	36,249	456,936	911,3709
	2045	142,494	68,305	95,209	13,157	0,3074	126,876	45,141	494,255	985,7444
	2050	135,908	85,146	103,782	13,546	0,3459	141,612	59,431	542,886	1082,6569
Africa Total		**1039,527**	**427,882**	**513,824**	**86,552**	**1,7414**	**739,704**	**176,3207**	**3010,122**	**5995,6731**
Canada	**2020**	**0,0953**	**0,5418**	**34,346**	**34,635**	**0,8946**	**52,542**	**0,528**	**142,12**	**265,7027**
	2025	0,1079	0,3732	36,112	34,79	0,8337	55,519	0,836	147,929	276,5008
	2030	0,1221	0,1398	38,074	35,042	0,8043	51,972	12,288	148,038	286,4802
	2035	0,1333	0,1409	37,044	35,203	0,7545	52,479	18,548	153,56	297,8627
	2040	0,1535	0,1455	36,375	35,244	0,7137	52,832	23,989	158,567	308,0197
	2045	0,1696	0,149	36,219	35,31	0,6771	53,138	25,992	160,615	312,2697
	2050	0,186	0,1524	35,737	35,297	0,6425	53,33	28,315	162,486	316,1459
Canada Total		**0,9677**	**1,6426**	**253,907**	**245,521**	**5,3204**	**371,812**	**110,496**	**1073,315**	**2062,9817**
China	**2020**	**40,404**	**800,229**	**82,466**	**118,336**	**22,665**	**293,992**	**50,088**	**1408,18**	**2816,36**
	2025	46,202	838,1	110,355	123,24	33,252	315,732	110,045	1576,926	3153,852
	2030	48,954	854,492	95,74	136,6	47,321	331,877	199,211	1714,194	3428,389
	2035	50,345	804,488	150,701	151,713	54,368	323,278	295,987	1830,88	3661,76
	2040	52,956	736,064	149,417	162,806	61,642	310,07	419,367	1892,321	3784,643
	2045	51,81	736,463	182,123	168,989	61,776	307,527	447,018	1955,707	3911,413
	2050	51,777	736,708	243,006	173,753	62,196	304,388	444,766	2016,594	4033,188
China Total		**342,448**	**5506,544**	**1013,808**	**1035,437**	**343,22**	**2186,864**	**1966,482**	**12394,802**	**24789,605**
Europe	**2020**	**18,082**	**77,267**	**144,264**	**51,634**	**73,903**	**264,973**	**55,968**	**686,092**	**1372,183**
	2025	22,934	55,307	161,047	52,723	67,042	265,676	79,427	704,157	1408,313
	2030	25,124	40,946	173,978	53,729	61,793	264,301	91,156	711,027	1422,054
	2035	25,749	33,695	149,82	54,997	55,123	258,776	107,014	685,174	1370,348
	2040	26,447	24,397	136,213	56,756	53,003	254,651	124,442	675,909	1351,818
	2045	27,827	21,777	133,19	58,194	52,221	252,055	135,454	680,719	1361,437
	2050	29,069	20,827	130,915	59,827	50,939	251,707	141,997	685,282	1370,563
Europe Total		**175,232**	**274,216**	**1029,427**	**387,86**	**414,024**	**1812,139**	**735,458**	**4828,36**	**9656,716**
Global	**2020**	**474,32**	**1511,34**	**1228,12**	**381,449**	**238,211**	**1847,804**	**189,966**	**5871,21**	**11742,42**
	2025	486,807	1569,423	1397,992	392,023	246,809	1988,376	352,27	6433,699	12867,399
	2030	495,769	1576,594	1484,953	412,656	268,634	2071,861	544,292	6854,759	13709,518
	2035	499,647	1520,646	1612,112	434,336	261,68	2131,251	772,085	7231,757	14463,514
	2040	506,031	1437,005	1669,101	453,716	265,694	2176,457	1078,094	7586,099	15172,197
	2045	494,651	1445,776	1792,09	467,994	262,391	2239,654	1197,635	7900,191	15800,382
	2050	488,043	1450,623	1939,747	480,84	265,824	2285,649	1310,322	8221,049	16442,097
Global Total		**3445,268**	**10511,407**	**11124,115**	**3023,014**	**1809,243**	**14741,052**	**5444,664**	**50098,764**	**100197,527**
India	**2020**	**75,873**	**177,189**	**24,37**	**12,114**	**0,4395**	**98,475**	**10,446**	**402,863**	**801,7695**
	2025	76,758	197,191	31,336	12,668	0,5799	114,185	38,425	476,361	947,5039
	2030	77,439	214,414	38,186	13,565	0,9452	132,037	87,496	572,59	1136,6722
	2035	76,948	221,532	42,866	14,467	14,998	146,38	148,021	665,213	1330,425
	2040	77,082	228,664	47,633	15,124	27,551	161,737	238,49	796,281	1592,562
	2045	74,485	225,927	51,237	15,838	35,161	172,373	298,775	873,796	1747,592
	2050	72,998	216,27	55,692	16,279	43,407	186,092	365,71	956,448	1912,896
India Total		**531,583**	**1481,187**	**291,32**	**100,055**	**123,0816**	**1011,279**	**1187,363**	**4743,552**	**9469,4206**
Japan	**2020**	**0,0115**	**41,795**	**37,858**	**0,753**	**0,5601**	**68,612**	**0,5683**	**167,194**	**317,3519**
	2025	0,0122	41,951	37,793	0,7626	10,241	64,191	0,8464	170,389	326,1862
	2030	0,0122	39,327	35,747	0,7732	16,43	57,408	0,8873	165,639	316,2237
	2035	0,0122	37,691	34,499	0,7843	16,057	51,855	12,391	160,458	313,7475
	2040	0,0127	35,532	33,192	0,7959	14,603	45,088	17,647	154,147	301,0176
	2045	0,0131	35,244	33,135	0,8069	12,571	42,515	17,057	148,722	290,064
	2050	0,0135	34,993	32,98	0,8173	10,58	40,368	16,593	143,821	280,1658
Japan Total		**0,0874**	**266,533**	**245,204**	**5,4932**	**81,0421**	**370,037**	**65,99**	**1110,37**	**2144,7567**
Others	**2020**	**166,298**	**230,276**	**582,087**	**121,193**	**51,27**	**688,308**	**20,707**	**1860,138**	**3720,277**
	2025	166,725	259,149	662,952	124,274	55,702	781,777	39,587	2090,165	4180,331
	2030	168,817	266,693	725,021	128,139	60,974	838,651	56,481	2244,776	4489,552
	2035	170,775	279,553	792,74	131,539	55,702	892,525	79,74	2402,575	4805,149
	2040	172,095	284,631	840,557	136,405	50,395	936,02	120,502	2540,606	5081,211
	2045	168,474	297,942	906,826	141,319	45,387	981,708	137,79	2679,447	5358,893
	2050	166,274	304,963	966,403	146,426	41,416	1002,631	161,177	2789,29	5578,58
Others Total		**1179,458**	**1923,207**	**5476,586**	**929,295**	**360,846**	**6121,62**	**615,984**	**16606,997**	**33213,993**
United States	**2020**	**17,576**	**133,257**	**276,237**	**24,66**	**70,117**	**309,24**	**39,041**	**870,129**	**1740,257**
	2025	19,963	117,774	304,64	25,143	65,047	305,668	60,829	899,063	1798,127
	2030	21,885	102,309	319,109	25,907	61,771	300,906	76,322	908,209	1816,418
	2035	23,66	83,742	332,974	26,284	55,338	301,008	88,338	911,344	1822,688
	2040	25,626	69,512	341,697	26,715	48,586	301,791	97,407	911,333	1822,667
	2045	27,734	58,628	354,151	27,118	45,43	303,462	90,408	906,931	1813,862
	2050	30,022	50,192	371,233	27,54	47,402	305,521	92,333	924,242	1848,485
United States Total		**166,466**	**615,414**	**2300,041**	**183,367**	**393,691**	**2127,596**	**544,678**	**6331,251**	**12662,504**
Total		**6881,0371**	**21008,0326**	**22248,232**	**5996,5942**	**3532,2095**	**29482,103**	**10847,4357**	**100197,533**	**200193,1771**

Table 7: Dataset for Baseline 2019 scenario

Below 2°C delayed

Geography	Year	Bioenergy	Coal	Gas	Hydro	Nuclear	Oil	Renewables	Total	Total delayed
Africa	**2020**	**155,018**	**45,909**	**46,492**	**11,347**	**0,1314**	**71,662**	**0,2753**	**334,495**	**665,3297**
	2025	153,023	56,219	53,757	11,56	0,1388	85,627	0,7134	368,709	729,7472
	2030	152,206	57,016	59,099	11,943	0,285	94,709	12,465	390,287	778,01
	2035	150,841	0,7288	55,925	15,832	0,2705	71,887	28,848	333,327	657,6593
	2040	152,305	0,3378	13,346	18,123	0,3674	55,694	163,712	410,233	814,1182
	2045	146,516	0,0623	0,7964	19,513	0,642	25,484	177,213	383,732	753,9587
	2050	146,446	0,0151	0,088	20,185	13,959	12,702	126,299	320,623	640,3171
Africa Total		**1056,355**	**160,288**	**229,5034**	**108,503**	**15,7941**	**417,765**	**509,5257**	**2541,406**	**5039,1402**
Canada	**2020**	**0,0953**	**0,5418**	**34,346**	**34,635**	**0,8946**	**52,542**	**0,528**	**142,12**	**265,7027**
	2025	0,1079	0,3732	36,112	34,79	0,8337	55,519	0,836	147,929	276,5008
	2030	0,1221	0,1398	38,074	35,042	0,8043	51,972	12,288	148,038	286,4802
	2035	0,1351	0,1107	27,839	35,314	0,7665	39,946	21,062	134,283	259,4563
	2040	0,1807	0,0953	15,775	35,694	0,7771	32,618	40,169	134,786	260,0951
	2045	0,218	0,0585	0,8743	36,012	0,7808	23,527	49,061	127,916	238,4476
	2050	0,2516	0,0329	0,423	36,362	0,7824	15,625	57,049	123,935	234,4609
Canada Total		**1,1107**	**1,3522**	**153,4433**	**247,849**	**5,6394**	**271,749**	**180,993**	**959,007**	**1821,1436**
China	**2020**	**40,404**	**800,229**	**82,466**	**118,336**	**22,665**	**293,992**	**50,088**	**1408,18**	**2816,36**
	2025	46,202	838,1	110,355	123,24	33,252	315,732	110,045	1576,926	3153,852
	2030	48,954	854,492	95,74	136,6	47,321	331,877	199,211	1714,194	3428,389
	2035	49,666	621,952	95,167	152,064	52,779	281,522	318,268	1571,419	3142,837
	2040	51,683	382,333	91,17	164,669	58,649	250,58	577,359	1576,443	3152,886
	2045	50,529	194,625	73,019	171,843	59,096	219,861	675,979	1444,953	2889,905
	2050	50,333	70,388	26,735	179,99	59,738	175,067	710,651	1272,902	2545,804
China Total		**337,771**	**3762,119**	**574,652**	**1046,742**	**333,5**	**1868,631**	**2641,601**	**10565,017**	**21130,033**
Europe	**2020**	**18,082**	**77,267**	**144,264**	**51,634**	**73,903**	**264,973**	**55,968**	**686,092**	**1372,183**
	2025	22,934	55,307	161,047	52,723	67,042	265,676	79,427	704,157	1408,313
	2030	25,124	40,946	173,978	53,729	61,793	264,301	91,156	711,027	1422,054
	2035	25,663	33,896	168,758	54,352	54,889	212,423	99,494	649,474	1298,949
	2040	26,329	15,516	134,216	56,395	53,488	171,153	125,198	582,295	1164,59
	2045	30,94	0,4904	70,792	58,252	57,473	126,058	187,885	536,304	1068,1944
	2050	34,363	0,1714	28,697	59,861	59,276	78,092	209,882	471,885	942,2274
Europe Total		**183,435**	**223,5938**	**881,752**	**386,946**	**427,864**	**1382,676**	**849,01**	**4341,234**	**8676,5108**
Global	**2020**	**474,32**	**1511,34**	**1228,12**	**381,449**	**238,211**	**1847,804**	**189,966**	**5871,21**	**11742,42**
	2025	486,807	1569,423	1397,992	392,023	246,809	1988,376	352,27	6433,699	12867,399
	2030	495,769	1576,594	1484,953	412,656	268,634	2071,861	544,292	6854,759	13709,518
	2035	498,177	1058,67	1246,277	447,066	260,601	1757,301	877,202	6145,295	12290,589
	2040	510,86	563,169	835,207	483,128	298,328	1469,453	2149,141	6309,285	12618,571
	2045	521,45	239,502	464,408	517,178	427,239	1089,041	3075,991	6334,809	12669,618
	2050	530,45	82,472	164,668	548,153	635,648	682,389	3701,298	6345,079	12690,157
Global Total		**3517,833**	**6601,17**	**6821,625**	**3181,653**	**2375,47**	**10906,225**	**10890,16**	**44294,136**	**88588,272**
India	**2020**	**75,873**	**177,189**	**24,37**	**12,114**	**0,4395**	**98,475**	**10,446**	**402,863**	**801,7695**
	2025	76,758	197,191	31,336	12,668	0,5799	114,185	38,425	476,361	947,5039
	2030	77,439	214,414	38,186	13,565	0,9452	132,037	87,496	572,59	1136,6722
	2035	76,923	167,888	34,79	14,461	14,921	112,969	150,469	572,421	1144,842
	2040	78,18	87,531	30,23	16,899	33,047	102,396	343,72	692,002	1384,005
	2045	78,835	12,696	16,513	20,327	56,927	69,582	622,918	877,798	1755,596
	2050	81,775	0,0473	0,1346	22,981	135,07	16,806	910,69	1169,142	2336,6459
India Total		**545,783**	**856,9563**	**175,5596**	**113,015**	**241,9296**	**646,45**	**2164,164**	**4763,177**	**9507,0345**
Japan	**2020**	**0,0115**	**41,795**	**37,858**	**0,753**	**0,5601**	**68,612**	**0,5683**	**167,194**	**317,3519**
	2025	0,0122	41,951	37,793	0,7626	10,241	64,191	0,8464	170,389	326,1862
	2030	0,0122	39,327	35,747	0,7732	16,43	57,408	0,8873	165,639	316,2237
	2035	0,0122	21,945	28,869	0,7882	16,057	54,975	16,598	146,448	285,6924
	2040	0,0127	0,9975	18,02	0,8064	14,603	50,766	41,447	143,002	269,6546
	2045	0,0132	0,4499	0,9317	0,8263	12,571	49,536	61,98	146,298	272,6061
	2050	0,0138	0,2453	0,5369	0,8491	10,581	46,132	73,291	146,454	278,1031
Japan Total		**0,0878**	**146,7107**	**159,7556**	**5,5588**	**81,0431**	**391,62**	**195,618**	**1085,424**	**2065,818**
Others	**2020**	**166,298**	**230,276**	**582,087**	**121,193**	**51,27**	**688,308**	**20,707**	**1860,138**	**3720,277**
	2025	166,725	259,149	662,952	124,274	55,702	781,777	39,587	2090,165	4180,331
	2030	168,817	266,693	725,021	128,139	60,974	838,651	56,481	2244,776	4489,552
	2035	170,135	145,695	537,826	140,69	56,28	766,85	154,178	1971,654	3943,308
	2040	175,059	56,697	322,72	155,788	76,312	646,978	679,598	2113,152	4226,304
	2045	186,121	16,602	164,044	174,333	169,397	456,012	1027,793	2194,302	4388,604
	2050	184,59	0,3275	56,254	190,317	271,318	251,757	1181,874	2139,385	4275,8225
Others		**1217,745**	**975,4395**	**3050,904**	**1034,734**	**741,253**	**4430,333**	**3160,218**	**14613,572**	**29224,1985**
United States	**2020**	**17,576**	**133,257**	**276,237**	**24,66**	**70,117**	**309,24**	**39,041**	**870,129**	**1740,257**
	2025	19,963	117,774	304,64	25,143	65,047	305,668	60,829	899,063	1798,127
	2030	21,885	102,309	319,109	25,907	61,771	300,906	76,322	908,209	1816,418
	2035	23,476	58,899	297,104	26,47	55,305	216,73	88,286	766,269	1532,539
	2040	25,369	0,6785	209,731	27,496	50,784	159,268	177,938	657,371	1308,6355
	2045	26,197	0,4968	114,016	28,635	57,546	118,981	273,163	623,506	1242,5408
	2050	30,288	0,3688	41,158	29,966	77,883	86,208	431,563	700,753	1398,1878
United States Total		**164,754**	**413,7831**	**1561,995**	**188,277**	**438,453**	**1497,001**	**1147,142**	**5425,3**	**10836,7051**
Total		**7024,8745**	**13141,4126**	**13609,1899**	**6313,2778**	**4660,9462**	**21812,45**	**21738,4317**	**88588,273**	**176888,8557**

Table 8: Dataset for 2°C delayed scenario

Below 2°C imemdiate

Geography	**Year**	**Bioenergy**	**Coal**	**Gas**	**Hydro**	**Nuclear**	**Oil**	**Renewables**	**Total**	**Total immediate**
Africa	**2020**	**155,018**	**45,909**	**46,492**	**11,347**	**0,1314**	**71,662**	**0,2753**	**334,495**	**665,3297**
	2025	153,023	29,31	55,845	11,791	0,1405	79,048	0,6346	336,768	666,5601
	2030	152,027	0,6572	57,063	12,678	0,2994	70,263	0,9714	311,312	605,271
	2035	150,422	0,4083	40,118	16,195	0,3368	59,389	40,142	313,717	620,7281
	2040	150,554	0,1858	16,268	17,65	0,4253	46,323	130,439	367,345	729,1901
	2045	142,727	0,0836	15,784	17,966	0,6644	30,546	134,968	349,472	692,211
	2050	139,997	0,0365	10,123	18,92	13,925	20,27	137,841	341,441	682,5535
Africa Total		**1043,768**	**76,5904**	**241,693**	**106,547**	**15,9228**	**377,501**	**445,2713**	**2354,55**	**4661,8435**
Canada	**2020**	**0,0953**	**0,5418**	**34,346**	**34,635**	**0,8946**	**52,542**	**0,528**	**142,12**	**265,7027**
	2025	0,1078	0,3909	34,047	34,764	0,8333	48,86	0,8462	139,452	259,3012
	2030	0,1235	0,1262	31,37	35,226	0,8038	44,411	14,556	136,097	262,7135
	2035	0,1354	0,1141	25,756	35,51	0,7693	40,531	22,928	134,914	260,6578
	2040	0,173	0,1007	18,8	35,796	0,7557	35,027	36,385	136,302	263,3394
	2045	0,2057	0,0835	13,916	36,238	0,7492	29,839	43,237	133,614	257,8824
	2050	0,236	0,0585	0,9184	36,403	0,746	23,713	50,52	130,225	242,8199
Canada Total		**1,0767**	**1,4157**	**159,1534**	**248,572**	**5,5519**	**274,923**	**169,0002**	**952,724**	**1812,4169**
China	**2020**	**40,404**	**800,229**	**82,466**	**118,336**	**22,665**	**293,992**	**50,088**	**1408,18**	**2816,36**
	2025	45,785	781,756	70,43	123,361	33,307	311,102	114,354	1480,095	2960,19
	2030	47,57	591,735	97,441	138,197	47,855	316,748	246,672	1486,218	2972,436
	2035	48,672	460,917	89,162	154,336	50,611	286,975	446,134	1536,807	3073,614
	2040	50,727	332,954	90,909	166,779	56,394	262,244	614,885	1574,893	3149,785
	2045	49,528	245,57	78,845	174,637	56,607	242,016	627,414	1474,616	2949,233
	2050	49,981	155,775	44,09	179,754	58,529	230,994	686,71	1405,831	2811,664
China Total		**332,667**	**3368,936**	**553,343**	**1055,4**	**325,968**	**1944,071**	**2786,257**	**10366,64**	**20733,282**
Europe	**2020**	**18,082**	**77,267**	**144,264**	**51,634**	**73,903**	**264,973**	**55,968**	**686,092**	**1372,183**
	2025	22,791	55,353	157,457	52,67	66,828	247,792	79,174	682,065	1364,13
	2030	24,921	41,04	167,696	53,569	61,383	230,701	90,552	669,863	1339,725
	2035	25,506	33,815	143,812	54,716	54,631	210,011	104,865	627,355	1254,711
	2040	26,233	16,079	128,144	56,552	53,144	178,309	127,54	586,001	1172,002
	2045	29,119	0,7725	106,672	58,199	54,202	145,667	160,227	561,811	1116,6695
	2050	33,101	0,4197	61,965	60,156	57,418	119,47	199,326	535,632	1067,4877
Europe Total		**179,753**	**224,7462**	**910,01**	**387,496**	**421,509**	**1396,923**	**817,652**	**4348,819**	**8686,9082**
Global	**2020**	**474,32**	**1511,34**	**1228,12**	**381,449**	**238,211**	**1847,804**	**189,966**	**5871,21**	**11742,42**
	2025	485,956	1391,645	1289,076	394,279	247,056	1892,619	357,108	6057,739	12115,478
	2030	493,233	961,837	1208,241	429,325	270,872	1800,333	640,925	5804,766	11609,532
	2035	498,948	685,059	1022,371	465,559	285,212	1650,342	1308,868	5916,36	11832,719
	2040	511,949	435,348	840,053	497,221	364,216	1428,663	2264,16	6341,61	12683,22
	2045	502,783	301,019	676,924	521,982	447,707	1207,781	2632,436	6290,632	12581,264
	2050	515,08	184,128	420,249	543,127	533,375	977,429	3256,067	6429,456	12858,911
Global Total		**3482,269**	**5470,376**	**6685,034**	**3232,942**	**2386,649**	**10804,971**	**10649,53**	**42711,773**	**85423,544**
India	**2020**	**75,873**	**177,189**	**24,37**	**12,114**	**0,4395**	**98,475**	**10,446**	**402,863**	**801,7695**
	2025	76,758	157,974	27,625	12,738	0,5828	103,716	40,324	424,963	844,6808
	2030	77,506	106,154	26,629	16,576	0,9894	101,328	112,087	450,175	891,4444
	2035	78,687	59,835	24,136	18,53	21,592	95,534	283,305	581,618	1163,237
	2040	80,563	21,498	19,172	19,705	44,658	83,232	507,54	776,368	1552,736
	2045	79,452	0,8079	13,071	20,387	59,851	62,89	653,265	896,994	1786,7179
	2050	80,386	0,2163	0,4952	21,279	82,963	35,916	867,026	1094,685	2182,9665
India Total		**549,225**	**523,6742**	**135,4982**	**121,329**	**211,0757**	**581,091**	**2473,993**	**4627,666**	**9223,5521**
Japan	**2020**	**0,0115**	**41,795**	**37,858**	**0,753**	**0,5601**	**68,612**	**0,5683**	**167,194**	**317,3519**
	2025	0,0122	42,575	37,833	0,7625	10,241	64,987	0,8484	171,868	329,1271
	2030	0,0121	32,955	34,633	0,7744	16,43	59,93	0,9019	160,833	306,4694
	2035	0,0123	25,966	31,598	0,7872	16,057	55,354	14,361	151,331	295,4665
	2040	0,0128	19,689	27,693	0,8012	14,602	49,758	24,196	144,078	280,83
	2045	0,0133	13,64	23,551	0,8173	12,571	48,452	29,845	136,366	265,2556
	2050	0,0136	0,8275	17,682	0,8329	10,58	42,891	30,781	118,674	222,282
Japan Total		**0,0878**	**177,4475**	**210,848**	**5,5285**	**81,0411**	**389,984**	**101,5016**	**1050,344**	**2016,7825**
Others	**2020**	**166,298**	**230,276**	**582,087**	**121,193**	**51,27**	**688,308**	**20,707**	**1860,138**	**3720,277**
	2025	166,483	205,112	619,007	126,133	56,141	751,299	39,206	1963,381	3926,762
	2030	168,02	118,623	502,51	139,184	62,662	724,152	84,504	1799,655	3599,31
	2035	170,655	71,997	385,37	151,581	76,15	677,418	298,972	1832,143	3664,286
	2040	176,614	35,043	270,479	165,052	135,271	600,453	705,342	2088,254	4176,508
	2045	173,372	19,238	207,927	177,672	204,129	508,477	856,236	2147,05	4294,101
	2050	180,625	0,8914	132,58	188,395	245,144	386,124	1044,001	2185,783	4363,5434
Others		**1202,067**	**681,1804**	**2699,96**	**1069,21**	**830,767**	**4336,231**	**3048,968**	**13876,404**	**27744,7874**
United States	**2020**	**17,576**	**133,257**	**276,237**	**24,66**	**70,117**	**309,24**	**39,041**	**870,129**	**1740,257**
	2025	19,916	115,656	286,833	25,195	64,973	285,816	60,759	859,148	1718,296
	2030	21,833	63,495	290,898	26,151	61,616	252,799	73,82	790,614	1581,226
	2035	23,53	27,304	282,419	26,819	55,111	225,13	98,162	738,475	1476,95
	2040	25,401	0,7221	268,588	27,675	48,336	173,317	117,832	668,369	1330,2401
	2045	26,395	0,5096	217,158	28,71	46,211	139,894	127,245	590,709	1176,8316
	2050	28,495	0,3855	139,674	29,891	57,356	118,051	239,863	617,185	1230,9005
United States Total		**163,146**	**341,3292**	**1761,807**	**189,101**	**403,72**	**1504,247**	**756,722**	**5134,629**	**10254,7012**
Total		**6954,0595**	**10865,6956**	**13357,3466**	**6416,1255**	**4682,2045**	**21609,942**	**21248,8951**	**85423,549**	**170557,8178**

Table 9: Dataset for 2°C immediate scenario

Net zero 2050

Geography	Year	Bioenergy	Coal	Gas	Hydro	Nuclear	Oil	Renewables	Total	Total net zero
Africa	**2020**	**155,018**	**45,909**	**46,492**	**11,347**	**0,1314**	**71,662**	**0,2753**	**334,495**	**665,3297**
	2025	153,023	0,9183	56,583	12,094	0,1421	68,054	0,6017	306,375	597,7911
	2030	152,916	0,4673	33,735	16,128	0,3163	52,846	22,249	285,71	564,3676
	2035	152,178	0,0844	11,225	17,59	0,3536	32,873	68,172	286,417	568,893
	2040	156,312	0,0311	0,4833	17,699	0,4704	16,134	116,803	316,796	624,7288
	2045	149,931	0,0254	0,4486	18,657	0,8116	16,05	114,067	311,561	611,5516
	2050	146,066	0,0235	0,4427	18,459	17,611	17,338	110,68	314,816	625,4362
Africa Total		**1065,444**	**47,459**	**149,4096**	**111,974**	**19,8364**	**274,957**	**432,848**	**2156,17**	**4258,098**
Canada	**2020**	**0,0953**	**0,5418**	**34,346**	**34,635**	**0,8946**	**52,542**	**0,528**	**142,12**	**265,7027**
	2025	0,108	0,1782	32,717	35,086	0,8314	48,092	0,9639	136,71	254,6865
	2030	0,121	0,1145	18,64	35,903	0,8333	41,638	22,002	128,872	248,1238
	2035	0,1383	0,0858	13,662	36,347	0,8097	35,368	30,82	126,536	243,7668
	2040	0,2194	0,0679	0,8438	36,927	0,8251	28,839	46,659	131,985	246,3662
	2045	0,4954	0,0551	0,5903	37,515	0,8192	23,724	51,171	132,01	246,38
	2050	13,989	0,0465	0,5067	37,267	0,7606	19,854	47,265	131,513	251,2018
Canada Total		**15,1664**	**1,0898**	**101,3058**	**253,68**	**5,7739**	**250,057**	**199,4089**	**929,746**	**1756,2278**
China	**2020**	**40,404**	**800,229**	**82,466**	**118,336**	**22,665**	**293,992**	**50,088**	**1408,18**	**2816,36**
	2025	45,23	650,463	92,801	124,49	33,623	319,816	130,215	1396,638	2793,276
	2030	46,712	388,218	208,642	140,645	49,325	315,408	314,692	1463,642	2927,284
	2035	48,441	278,277	152,53	157,054	50,284	279,76	523,599	1489,945	2979,89
	2040	50,73	221	144,13	170,442	56,668	252,317	564,137	1459,424	2918,848
	2045	49,761	152,123	45,331	178,89	57,518	228,809	646,858	1359,291	2718,581
	2050	50,846	82,685	30,052	182,926	61,313	201,359	731,908	1341,09	2682,179
China Total		**332,124**	**2572,995**	**755,952**	**1072,783**	**331,396**	**1891,461**	**2961,497**	**9918,21**	**19836,418**
Europe	**2020**	**18,082**	**77,267**	**144,264**	**51,634**	**73,903**	**264,973**	**55,968**	**686,092**	**1372,183**
	2025	22,729	55,318	147,541	52,895	66,914	246,658	78,725	670,78	1341,56
	2030	24,837	10,444	90,443	55,212	61,981	210,675	145,758	599,351	1198,701
	2035	26,611	0,6061	68,259	56,956	56,769	186,475	166,743	567,874	1130,2931
	2040	29,701	0,3936	51,896	59,177	59,39	144,848	182,462	531,41	1059,2776
	2045	32,057	0,1284	23,973	62,025	61,367	99,855	204,421	484,982	968,8084
	2050	34,14	0,0566	11,822	63,454	62,961	71,204	225,297	469,444	938,3786
Europe Total		**188,157**	**144,2137**	**538,198**	**401,353**	**443,285**	**1224,688**	**1059,374**	**4009,933**	**8009,2017**
Global	**2020**	**474,32**	**1511,34**	**1228,12**	**381,449**	**238,211**	**1847,804**	**189,966**	**5871,21**	**11742,42**
	2025	484,783	1164,726	1255,623	401,969	247,839	1858,158	370,488	5783,587	11567,173
	2030	493,801	654,37	1060,805	445,119	274,007	1710,681	836,969	5475,754	10951,506
	2035	515,332	437,934	779,33	482,993	291,863	1503,479	1602,977	5613,908	11227,816
	2040	875,42	303,202	595,762	514,366	383,629	1289,048	2305,864	6267,29	12534,581
	2045	815,027	189,61	345,467	542,394	476,098	1109,43	2834,191	6312,218	12624,435
	2050	857,536	105,088	257,803	555,456	546,898	991,314	3176,378	6490,475	12980,948
Global Total		**4516,219**	**4366,27**	**5522,91**	**3323,746**	**2458,545**	**10309,914**	**11316,833**	**41814,442**	**83628,879**
India	**2020**	**75,873**	**177,189**	**24,37**	**12,114**	**0,4395**	**98,475**	**10,446**	**402,863**	**801,7695**
	2025	76,743	178,737	29,944	12,662	0,58	107,164	38,541	449,591	893,962
	2030	77,513	127,076	28,746	16,132	0,9806	104,83	104,412	468,515	928,2046
	2035	78,026	81,38	27,001	17,718	19,019	99,253	237,426	559,824	1119,647
	2040	79,65	38,858	23,604	18,658	40,174	90,501	446,978	738,424	1476,847
	2045	79,01	12,857	17,162	19,964	57,702	74,06	631,607	892,363	1784,725
	2050	78,824	0,5467	10,343	20,591	72,878	55,309	768,065	1011,476	2018,0327
India Total		**545,639**	**616,6437**	**161,17**	**117,839**	**191,7731**	**629,592**	**2237,475**	**4523,056**	**9023,1878**
Japan	**2020**	**0,0115**	**41,795**	**37,858**	**0,753**	**0,5601**	**68,612**	**0,5683**	**167,194**	**317,3519**
	2025	0,0122	32,985	35,616	0,7654	10,241	66,839	0,8084	161,542	308,809
	2030	0,0121	25,045	31,197	0,7788	16,43	61,987	10,351	152,92	298,7209
	2035	0,0122	16,655	26,186	0,7944	16,058	57,469	20,174	144,608	281,9566
	2040	0,0128	10,615	19,743	0,8115	14,603	48,527	29,893	131,624	255,8293
	2045	0,0131	0,378	0,9043	0,832	12,572	40,422	56,394	130,663	242,1784
	2050	0,0133	0,1829	0,4342	0,8525	10,581	33,378	70,33	129,117	244,8889
Japan Total		**0,0872**	**127,6559**	**151,9385**	**5,5876**	**81,0451**	**377,234**	**188,5187**	**1017,668**	**1949,735**
Others	**2020**	**166,298**	**230,276**	**582,087**	**121,193**	**51,27**	**688,308**	**20,707**	**1860,138**	**3720,277**
	2025	165,932	174,659	571,043	131,694	56,533	719,743	41,029	1860,632	3721,265
	2030	168,779	91,386	432,72	146,494	63,085	682,834	121,876	1707,174	3414,348
	2035	184,883	48,83	311,941	161,535	82,589	614,632	377,415	1781,824	3563,649
	2040	531,049	23,862	233,135	174,145	146,226	552,165	663,547	2324,129	4648,258
	2045	472,046	16,022	192,117	186,16	202,728	500,021	752,205	2321,298	4642,597
	2050	501,655	11,66	155,092	192,341	234,115	479,911	782,936	2357,711	4715,421
Others		**2190,642**	**596,695**	**2478,135**	**1113,562**	**836,546**	**4237,614**	**2759,715**	**14212,906**	**28425,815**
United States	**2020**	**17,576**	**133,257**	**276,237**	**24,66**	**70,117**	**309,24**	**39,041**	**870,129**	**1740,257**
	2025	19,924	61,598	289,379	25,395	64,994	281,792	58,238	801,32	1602,64
	2030	21,714	0,6383	216,682	26,817	61,884	240,463	95,628	669,571	1333,3973
	2035	23,687	0,503	168,526	27,849	55,511	197,648	178,629	656,88	1309,233
	2040	25,657	0,3941	109,984	29,201	53,612	155,718	255,385	633,499	1263,4501
	2045	27,137	0,2738	47,452	30,862	67,903	126,488	377,468	680,049	1357,6328
	2050	31,883	0,2181	36,658	31,894	79,833	112,962	439,896	735,307	1468,6511
United States Total		**167,578**	**196,8823**	**1144,918**	**196,678**	**453,854**	**1424,311**	**1444,285**	**5046,755**	**10075,2613**
Total		**9021,0566**	**8669,9044**	**11003,9369**	**6597,2026**	**4822,0545**	**20619,828**	**22599,9546**	**83628,886**	**166962,8236**

Table 10: Dataset for Net zero 2050 scenario

Table 11: NACE-ICP correspondence for fossil fuel sector

1. FOSSIL FUEL															
5. Mining of coal and ignite	**6.Extraction of crude petroleum**	**08.92. Extraction of Peat**	**19. Refined petroleum products**	**35.2. Manifacture of Gas**			**47.3. Retail sale of automotive fuel in specialized stores**								
E21C	C10L	C10F	C10G	A62C	G01K	F25D	B67D	F23D	F23L	B21K	H04N	B63B	D01D	A01F	B60T
F02B	A23L	E21C	C10L	C10B	B05B	F41A	F02C	F24B	B60N	B23K	D06H	C03B	G01K	B41M	B65B
F02C	C11B	C05F		F17B	H01J	F02G	F02M	E05B	H01F	B24D	E01B	B41J	E04B	B62M	C30B
F02P	C21D	A23L		C10H	H02B	F23R	F23B	B60W	A45D	B60J	G01G	B41L	A61F	B60R	G09G
F23Q	A23F	C11B		C03B	B01J	F21S	G06Q	F02B	F21S	E04D	A47K	A61J	A61H	G03F	E02D
B63G	A24B	B65B		C10L	G01N	F02K	F23C	G21F	A41D	E04G	F41C	B61G	B21C	G03B	
F42B	B01D	C21D		F23D	B65G	H01S	B60L	C10J	A63B	F01B	G01D	A61D	A47C	B62L	
F42D	G06V	A23F		B60K	F21V	F24B	B62J	B64F	B62K	F04C	A61B	A62C	G16H	B66B	
E21D	C22B	A24B		C06D	E21B	F42B	F23G	F24C	D05B	B23C	F41H	B21J	A61M	C09B	
F21K	G10L	B01D		B64B	F02M	F22B	F23K	C06B	B21B	A23K	F02K	D01F	H03L	C40B	
H01J	F41A	G06V		F02C	H01H	H01M	G21C	F16K	B21H	B44F	B64G	E05C	E01F	F04D	
E21F	C13B	C22B		F17C	B01D	F16F	B64D	A01B	F01L	F03D	C13B	A01C	G06V	B23F	
B66B	C10G	G10L		F41B	B02C	B60R	C10L	C21B	H02S	F16C	F21V	B41B	G11B	D21H	
F41H		F41A		F41H	B01L	C23C	B60K	B42D	F16B	E06B	G04D	B61C	H01J	F21K	
G16H		C13B		B63H	B63C	F02B	F23Q	F16L	A24F	G16B	B21F	F16M	B44D	B24B	
		C10G		F02D	F01N	G09G	F01M	F04B	C10N	H01L	B21D	G07F	B60P	B22F	
				B64D	B07B		H01M	A61G	E04H	G01R	B60Q	H04W	B61H	F15B	
				C10J	A62D		G01N	F01K	H04M	A61K	C23C	A24D	B65H	B08B	
				B43K	B22C		F23R	A47F	G05G	H01R	H04H	B23G	E21B	B28B	
				F26B	C21D		F02D	A63C	A47B	B65D	G01V	B25B	B23B	C12M	

Table 12: NACE-ICP correspondence for utility and electricity sector

2. UTILITY AND ELECTRICITY																						
35.11. Production of electricity									**35.12 Trasmission of electrocity**							**35.13. Distribution of electricity**						
C25B	C21B	D06M	C09D	F16K	H01R	B60T	G01K	H01G	B60R	H01T	H05F	G01P	F24F	B62M	B81B	B60K	F02D	G06M	F24H	G05D	G11C	F27D
B60R	A23B	H04N	C09J	B60L	G05D	F03D	B06B	B62M	B61C	F02D	G05F	B62J	G11B	H03K		E21F	F04B	G04C	F16K	A45D	F24C	H01G
B61C	C03B	G01N	D04H	H02P	A45D	F24V	E06B	H03K	G05B	H05B	G06G	F01L	H02N	F27B		H02J	A01C	H01J	B60L	D05B	B01J	B62M
D05C	G03G	G04C	C08L	F42C	D05B	B41L	H05C	F27B	F21K	B60Q	H02J	G01C	G01L	G12B		H02G	G01R	B05D	H02P	E05B	C10G	F27B
G05B	C30B	H01L	G10K	H02K	E05B	G01V	A24B	G12B	B23K	F02B	G01R	H01J	H05H	F25B		H02B	F16N	H05B	D06F	H01F	F02M	G12B
F21K	A01D	C22B	A61N	H05K	H01F	B23Q	B22D	C10M	G04C	F24H	H02H	H04N	A24F	F02N		F21V	F21S	H01Q	G03G	H01K	F24F	F25B
D03D	A23K	D04B	C21D	A43B	H01K	G11C	B23H	F25B	H01L	F16K	H01R	C23F	B06B	G01F		G06F	A61B	F24D	F42C	B05B	H03K	F02N
F02C	A23C	H05H	F16L	A63H	B05B	H01Q	A61J	F02N	B61G	B60L	G05D	B60T	E06B	G06K		H03H	H01T	B61G	H01P	F41A	G11B	G01F
B23K	C10J	C10B	G01J	F42D	B60K	H03H	C25D	G01F	F02P	H02P	A45D	C04B	G10K	H04M		F28F	H04N	F02P	H02K	G10H	H04L	G06K
A23L	H02H	G21C	G21K	G08C	F41A	F24C	A62D	G06K	H02S	F42C	D05B	F03D	H05C	F41J		G06G	H01L	H02S	H05K	H01H	H02N	F41J
C12F	C04B	B61G	H01T	B22F	G10H	B01J	G04F	H04M	H04R	H02K	E05B	G01V	C30B	H04Q		B61C	G08B	B61L	A43B	G02F	G01L	H04Q
B32B	F23M	F02P	F02D	H02G	H01H	F02M	F21S	F41J	B61L	H05K	H01F	B23Q	B23H	C03B		B41B	H04M	G01H	A63H	B41J	H05H	C03B
A23G	G03F	H02S	B29C	F21L	C23C	D01H	F27D	H04Q	G01H	A43B	H01K	G01N	G04F	G21H		E01C	H01S	B60W	F42D	G01P	A24F	G21H
G01R	B28B	C25C	C10G	G06M	G02F	F24F	H02B	G21H	F21V	A63H	B05B	G11C	F21S	G03G		B60R	H01M	A61N	G08C	B62J	B06B	B60M
A01K	C13B	H04R	H05B	B03C	G01P	G11B	B81B	B60M	A61N	F42D	B60K	H01Q	F27D	B60M		H04H	H04R	C21D	F21L	G01C	E06B	B66B
C11D	D01F	C10H	B60Q	H05F	B62J	B21B	G06F	B66B	C21D	G08C	F41A	H03H	H02B	B66B		G05B	B60Q	F16L	F15B	C23F	G10K	H02M
B41J	D06N	C06B	F02B	G05F	F01L	H02N	B01F	H02M	F16L	H02G	G10H	F24C	A61B	H02M		F03C	H01R	G01J	B03C	C04B	H05C	B66C
H01M	F17D	B61L	B65H	G06G	G01C	G01L	A61B	B66C	G01J	F21L	H01H	B01J	D06F	B66C		F21K	F01L	G21K	H05F	G01V	C30B	H05G
A21D	B65B	G01H	F24H	H02J	H01J	A24F	D06F	H05G	G21K	G06M	G02F	C10G	F24D	H05G		F23K	B60T	H02H	B05C	B23Q	B23H	A61F
B21C	C08J	F21V	F02G	A61K	C23F	B21K	F24D	A61F	H01M	B03C	B41J	F02M	H01G	A61F		B23K	F03D	F02B	G05F	G01N	G04F	B81B

Table 13: NACE-ICP correspondence for energy intensive sector

3. ENERGY INTENSIVE																
07.1Iron ores	07.29 Non metal ores	10.2 Processing and preservation of fish							10.41 Manifacture of oil and fats	10.62 Starching and starch production	10.81 Manifacture of sugar	10.86 Homogenized food and dietetic food	11.01 Disrtilling of spirtis	11.02 Manifacture of wine	11.06 Malt	13 Manifacture of textiles
E21C	B03D	A22C	H01M	B01D	C04B	C07K	B21D	C11C	C09K	C08B	C13B	A23L	H02H	C12G	A23L	D06Q
B03D	C22B	A23B	B65D	C08F	B22C	C10B	H04B	C11B	A23F	C08L	C07H	B01F	H02M	B01F	C12C	D06H
B01J		A23L	C12H	B23K	C21C	C21D	D06M	A23D	E21B	C09D	A47G	B65D	H01G			D04D
C21C		A01K	C22B	C08G	G03B	C08J	H01L	G01N	H01B	C09J	A61K	A23P	H02K			D06C
C22B		A23C	G06F	F24F	G03H	C12P	G01S	C12P	H01F	A23L		A47J	H01L			D06B
B63G		G16Y	B28C	C07C	G01T	C05F	G01R	C08L				C30B				D06F
F42B		B63B	G06G	C03B	C02F	D04B	A21C	C10M				B32B				D06J
D06F		C12N	C14B	G03D	C21B	G16H	D05B	F16N								D06P
C21B		B21F	B27K	B41C	C25F	H01S	G16B	C09D								D06M
C09C		G01N	D21C	G03C	G06T	B22F	B27D	C09J								B29D
E21D		A61K	G21F	B24B	G03F	C09J	H01J	C10N								G01N
B23K		B44D	A01H	B22D	G01Q	H05K		B27K								D06G
C21D		A21D	B21B	B41M	B42D	B32B		A23C								
E21F		E21B	C10G	C12Q	C01F	B29C		C09F								
A45D		A01N	C10L	F26B	B33Y	B81C		B09B								
B66B		C08C	C25D	G21C	G06V	B05D		C10G								
F41H		G06Q	C30B	G10L	D04H	D21H		A47L								
G01R		C25B	H01C	B01J	B41J	C23F		B61F								
G16H		C10J	C23C	H04N	C09D	H01G		C04B								
C08F		C11B	C01B	A62D	H01R	G03G		A61K								

Table 14: NACE-ICP correspondence for energy intensive sector (cont.ed)

3. ENERGY INTENSIVE								
14 Wearing apparels	**15 Leather and related products**	**16.29 Wood, corck and plaiting**	**17.11 Manifacture of pulp**	**17.12 MPaper and paperboard**	**20.12 Dyes and pigments**	**20.13 Inorganic pigments**	**20.15 Fertilizer nad nitrogen components**	**20.16 Manifacture of plastics in its primary forms**
D06J	D06P	B27L	D21C	A47K	C04B	C09C	A61P B01J H03K	E04G H04N C01B G02B B01D F27D
F16D	C14B	B27H	D21H	D21H	C09B	A61K	G21C D06M B60K	H01M E04D C09K C08J H01J B21B
F16L	C14C	B27K	D21D	G07F	A23L	C04B	A61K G04G B62D	B65D B29D C03B A01N E01F B07C
E21B	B68F	E04C		G09F	D06P	D21H	C06B B64F D06P	A43C B41C B21L G03G B03C B28B
B60W	D06L	B27C		D21F	B41M	C08K	B27B B29C C11D	E04C F16L B41F A61K B23H H02N
	D06N	B27G		B41M	D21H	C11D	C07H C09K B41M	F16F C07D E04B G11B B27D F16B
	D04H	B27M		G07D	C09C	C09D	C08G G01N F01B	B65B B41M A47C H01R G01L F23B
		B32B		D21G	C09D	D06P	C05C C10L C30B	B41D A41H B21D G01G B26F H05K
		B27B		B41J	G03C	C25B	C07C C08K G06F	H01Q B65G B31C B22D F16S B02C
		F16B		B31F	A61K	A23L	G02B G01R C08L	C07K A47B D01D F25C G03C B61G
				B42F	G11B	C05D	H02S F24F A23C	F42B A61J E01C C08G C10N D06P
				B65D	C03C	C06B	B01D H01H F24S	B29B F21Y G21C A01F G09F H01C
				B32B	B27K	C03C	H05K H04N H01S	C09J B65H B01J H01K F24S H02K
				G03C		C09K	C09B C08F B25F	F24F B42D B31B B01F D04H B23F
				B09B		A62D	B65D A01N B22F	A43B C10B C05G B05B B23G B82B
				B65H		B27K	C10M B01F F21K	B09B D21H F22B B61L C04B C08F
				B41L		A01G	C01B C09J C12P	B29C D06B H01L B26D G10G G06F
				A47F		A23B	C07D C09D	H01B B30B B41J A61F B23K C10M
				B41M		H01M	C07F F03D	F16G B41L C10G G09B H01H
				D21H		D06M	H01L C08B	B32B B21F G01D C12P A24B

Table 15: NACE-ICP correspondence for energy intensive sector (cont.ed)

3. ENERGY INTENSIVE

20.17 Manifacture of syntetic rubber in primary forms	20.20 Pesticides and otrher agrochemical products	20.42 Manifacture of perfumes and other toilet preparations	20.53Manifacture of essential oils	20.60 Manifcture of manmade fibres	21Pharmaciutical products
H01M A47C E04G H01L A61F A24B	C25B C04B D04H	A61Q B22C A23N	C11B C09D	D04H B27L	A61K
B41M C08F B60B B41J G09B B30B	B65D F23M C08L	A61K C01C A61P	G01N C09J	A43B H01H	A61K
B32B B01D C01B G01D C12P F27D	C09D G03F H04N	A45D B02B C12N	C10M B21C	D01G E04C	A61P
C10M E06B C09K G02B H01J B07C	B01F B28B F02G	C11B G03C B28C	F16N H01B	B27N B01D	C07D
B41D F16F C03B C08J E01F B28B	D05C C13B G03G	A47K C01B A47J	C10N B32B	D06M B29C	C07H
A43B C07D B21L A01N B03C H02N	A23L D01F A01N	G01N C08F C12Q	F23B H01F	D21H G01K	C07J
C08C A41H B41F G03G B23H F16B	C12F D06N C30B	C12C G03F C09C	B27K F16H	D03D D02G	C07K
C08L H01B F42B A61K B27D F23B	B32B F17D B22F	A23L C10N C08G	A23D C12P	C03C D01F	C12N
C10G B65G E04B G11B G01L H05K	A23G H01M B29C	F23K A61M	C11C B21D	D01B D06L	
C09J B29C B21D H01R B26F B02C	A01K B65B A61K	E01C C12P	C09F E05C	C22C C04B	
C09D A47B B65B B65H F16S E04C	C11D C08J H05H	C09H A21C	C10G B21H	D01H	
H01Q A61J B31C G01G G03C B61G	A21D D06M F24V	A23C C08B	A47L B23F	C03B	
B29K F21Y D01D B22D C10N D06P	B21C G01N F02C	C07C C07K	B09B F02M	D01D	
C07K B42D E01C F25C G09F H01C	C21B C22B B21B	C07D B01J	B61F B23P	G02B	
F16G C10B G21C A01F F24S H02K	A23B D04B C10G	C12G B41N	C04B C08K	D01C	
F24F D21H B65D H01K D04H B23F	C03B G21C A61J	A24B C01F	A61K B65H	D06P	
B60G D06B B01J B01F B23G B82B	A01D C25C C25D	C12J A23G	C09K	H04B	
B41C B41L B31B B05B C04B G06F	A23K C10H C10M	C12F C11D	A23F	B32B	
H04N B21F C05G B61L G10G	A23C C06B D03D	A23F C04B	E21B	B01J	
B09B C08G F22B B26D H01H	C10J C09J G10K	C09B A21D	C08L	D07B	

Table 16: NACE-ICP correspondence for energy intensive sector (cont.ed)

3. ENERGY INTENSIVE

22.1Manifacture of rubber products				23.1 Manifacture of glass and glass products				23. Manifacture of refracturing products						23.5 Manifacture of cements line and plaster			23.7 Cutting, shaping and finishing pf stone						23.91 production of abrasive products		
B32B	A23G	D01F	A61K	C03B	D05C	F17D	F24V	H04N	G03F	C08L	C04B	A01D	C09D	E04F	H04M	C21D	B23G	C14C	B26F	G03B	B21H	E21D	C25B	B28B	H04N
C10M	A01K	F17D	H05H	C03C	A23L	H01M	F02C	C25B	B28B	F02G	B32B	A23K	C09J	B28C	H04Q	B60L	E04B	A46D	A47H	B23Q	B60J	E03D	D05C	C13B	F02G
C09J	C11D	H01M	F24V	B09B	C12F	C08J	B21B	D05C	C13B	G03G	C25B	A23C	D04H	C04B	H01Q	F16C	A01D	D06C	B29C	B21G	C23C	B65B	A23L	D01F	G03G
C09D	E06B	B65B	F02C	D03D	A23G	D06M	C10G	A23L	D01F	C30B	G02F	C10J	C08L	E21B	B41J	F25B	B28B	E01C	B09B	G21C	F16F		C12F	D06N	C30B
A43B	F16F	C08J	B21B	B32B	A01K	G01N	A61J	C12F	D06N	B22F	G21C	F23M	H04N	A61K	B65D	F16H	B21D	B31B	D02J	F16S	C10M		B32B	F17D	B22F
C08C	C08F	G01N	A61J	B24B	C11D	C22B	C25D	B32B	F17D	B29C	B28B	G03F	F02G	A42B	B60M	H01J	B28D	B23K	A63B	A24B	F16L		A23G	H01M	B29C
C10G	A21D	C22B	C25D	D04H	A21D	D04B	B01F	A23G	H01M	A61K	B09B	C13B	G03G	A61L	F17D	E01B	B26B	B26D	B65D	A01F	C14B		A01K	B65B	A61K
C08L	B21C	D04B	B01F	G04B	B21C	G21C	C10M	A01K	B65B	H05H	C22C	D01F	C30B	F16L	H04B	B23D	B27G	B21C	A23L	H04L	B29B		C11D	C08J	B24C
C25B	C21B	G21C	D03D	E04F	C21B	C25C	G10K	C11D	C08J	F24V	D05C	D06N	B22F	B28B	B41G	H02H	A21C	D03D	G04B	B41J	F01L		A21D	D06M	H05H
B29K	A23B	C25C	G10K	C04B	A23B	C10H		A21D	D06M	F02C	A23L	F17D	B29C	C09K	H02G	H01H	B23B	F16K	H01M	B02C	H01Q		B21C	G01N	F24V
F16G	C03B	C10H		B65B	A01D	C06B		B21C	G01N	B21B	C12F	H01M	A61K	A01K	B41B	F16F	C04B	B41F	C30B	B65H	A61C		C21B	C22B	F02C
B60G	A01D	D04H		D02G	A23K	C09D		C21B	C22B	C10G	B23K	B65B	H05H	E21D	H01R	A61M	E04C	D05B	H03K	B01F	B23C		A23B	D04B	B21B
B09B	A23K	H04N		E04D	A23C	C09J		A23B	D04B	A61J	A23G	C08J	F24V	H01P	G08B		A23N	B44D	B23F	F16B	B62H		C03B	C09D	C10G
B29C	A23C	F02G		A47K	C10J	C08L		C03B	G21C	C25D	A01K	D06M	F02C	F16D	G01R		F21W	D06F	E21C	A23P	C08J		A01D	G21C	A61J
C06B	C10J	B41D		B08B	F23M	F02G		A01D	C25C	B01F	C11D	G01N	B21B	F23M	B29C		H01L	A43D	F42B	D21H	F02M		A23K	C25C	C25D
D06N	C04B	G03G		B60J	G03F	C30B		A23K	C10H	C10M	A21D	C22B	C10G	A41D	F21W		E04F	B23P	A61B	H01S	B21L		A23C	C10H	B24B
D05C	F23M	B60C		G03G	B28B	B22F		A23C	C06B	D03D	C03B	D04B	A61J	B09B	G01C		B24B	B23D	F21S	C10N	F02K		C10J	C06B	B24D
A23L	G03F	B41L		H04N	C13B	B29C		C10J	C09D	G10K	B21C	C25C	C25D	E03F	G01S		H01R	B27M	B24C	G11B	B41D		C04B	C09J	B01F
C12F	B28B	C30B		C25B	D01F	A61K		C04B	C09J		C21B	C10H	B01F	F27D	F16T		C03B	F02D	B67B	A47J	H02K		F23M	D04H	C10M
D06M	C13B	B22F		B23K	D06N	H05H		F23M	D04H		A23B	C06B	C10M	D06F	F26B		B29D	D06H	E21B	B21K	B32B		G03F	C08L	D03D

Table 17: NACE-ICP correspondence for energy intensive sector (cont.ed)

3. ENERGY INTENSIVE

24.1 Basic iron and steel and ferro-alloys	24.2 Tubes , pipes hollow profiles and steel	24.31 Cold drawing of bars	24.5 Casting of metals	25.4 Weapons and ammunitions	25.Cutlery, tools	25.94 Manifacture of fasteners and screw machine products	26 Manifacture of computer, electronic and optical rpoducts
C21C	B21D B21B E03C B42F F41A	B61G D05B	B22D C06B B21J B21K	F42B	B24B	A43B B62D H01C D04B A47G E06B	A61N G01V G06G H03F
C21B	B65G E03F F24S B05C H05G	B60D B29C	B22C C25C B23D C01D	F41B	B29L	A45D B62K H01H E01B A61C H01B	B81B G01W G06J H03G
B01J	B08B A24F A61M G01K F16H	B43L A47F	B41D E04B H01F C01G	F41A	B21D	B21B B65B F16L E21B B02C A61M	B81C G02B G06N H03H
B23K	E02D B61K E03D F24F F23J	F25J B60G	B21B C23G C01F E06B	F42C	B21K	B29C B66F A63G F04B B23C B04B	B82B G02C G06T H03J
E01B	F16L D01D H01P F28F B41B	G01K A47B	B22F C22B E01C B63B	F41G	A21D	B65G B67B A63H F16G B61F B61C	B82Y G02F G08B H03K
D06F	B21C B21K B60C E04D H04N	F25D E05F	B23P B21D C01C B23Q			F21V C10B B02B F24S B61G G11B	C30B G03B G08C H03L
D06P	C21C B60B B22C G09G B65H	C03B H02B	C21D C23F C09B B01D			F41G C10H B21D F28F B63B E04D	F15C G03C G09C H03M
H01H	B31C F28D F15C H02M B62J	B21D C21D	B29C B29K F16J C08C			F27D D21B B21H F41A E05C	G01B G03H G11C H04B
C09C	B01F E21B F22B G01P H05B	B23B B44D	C21C C10N C10G B24D			H01R E02D B21K G01B E21D	G01C G04B G12B H04H
C21D	E01B F17D C21D H02G E06B	D01H B41J	B41B C25B C22F B21H			A44B E02F B23B G01G F01C	G01D G04C G21K H04J
G10H	F16B D06G A23P H02P G10K	F23H B23Q	B28B C25D C04B E01B			A61B E05B B25G H02K F02N	G01F G04D H01C H04K
A45D	H04L E03B C10G G05F F22D	A01K A01D	C23C C25F C23D C12P			B01F E05F B29L A43D F04C	G01H G04F H01F H04L
F16F	C21B G01C H03F G11C G21C	E05B B65D	B01J B21F D21H			B23Q F01D B43K B23G H01M	G01J G04G H01G H04M
H03M	H01J B01D F23R H02J A47J	B43K H01R	C22C C08F D06M			B25B F04D B60B G03B F16J	G01K G04R H01J H04N
G01R	B23K A62C B65B H03K B23B	B21C H01H	C08K G01N F16H			B27L F16B B60N A47H A01C	G01L G05B H01L H04Q
H01J	C03B F02K F16K G01R A61B	C06F A61M	B62K B21C H01J			B28B F16D B60S B01J A62C	G01M G05F H01Q H04R
C08F	E21D B24B H03B B65D G01S	D01G F16B	C01B D03D H01L			B29B F16H B65D B23P B27B	G01N G06C H01S H04S
H01M	F42B G02B A45D F15D H01S	B65H	B23K C10M B21L			B30B F16K B65F B29D B65C	G01Q G06D H03B H04W
	B23F F16F B23D F24T	A47H	B32B A61K C03C			B41B F23K B65H D01H C03B	G01R G06E H03C H05G
	F24H B66C H03C H01H	G02C	B65D C07C B23H			B60P F25B C02F A43C E01F	G01S G06F H03D H05H

Table 18: NACE-ICP correspondence for energy intensive sector (cont.ed)

3. ENERGY INTENSIVE

27 Manifacture of electrical equioment			**28 Manifacture of machinery and equipment**												**32 Other manifacturing**	
A21B	F24B	H02N	A01B	B02C	B23B	B26D	B41J	B66B	D02H	E02C	F03D	F23D	G03G	A45F	A62B	F23Q
A45D	F24C	H02P	A01C	B03B	B23C	B26F	B41K	B66C	D02J	E02D	F03G	F23G	G05D	A61G	A63B	G01T
A47G	F24D	H02S	A01D	B03C	B23D	B27B	B41L	B66D	D03C	E02F	F04B	F23H	G05G	A63G	A63C	G03D
A47J	F25C	H05B	A01F	B03D	B23F	B27C	B41N	B66F	D03D	E05G	F04C	F23J	G06K	B62B	A63D	G03F
A47L	F25D	H05C	A01G	B04C	B23G	B27F	B42B	B67B	D03J	E21B	F04D	F23K	G06M	G10F	A63F	G09B
B01B	G08G		A01K	B05B	B23H	B27G	B42C	B67C	D04B	E21C	F04F	F23L	G07B	A41G	A63H	G09F
B60M	G10K		A01M	B05C	B23K	B27J	B43M	B68F	D04C	E21D	F15B	F23M	G07C	A42B	A63J	G10B
B61L	H01B		A21C	B05D	B23P	B27L	B44B	C10F	D05B	E21F	F15D	F23N	G07D	A44C	A63K	G10C
D06F	H01H		A22B	B06B	B23Q	B28D	B44C	C12L	D05C	F01B	F16C	F23R	G07F	A45B	B01L	G10D
E06C	H01K		A22C	B07B	B24B	B30B	B60S	C13C	D06B	F01C	F16D	F24F	G07G	A45C	B04B	G10G
F21H	H01M		A23N	B07C	B24C	B31B	B61B	C13D	D06G	F01D	F16F	F24H	G09D	A46B	B43K	G10H
F21K	H01P		A24C	B08B	B24D	B31C	B65B	C13G	D06H	F01K	F16G	F25B	G09G	A46D	B43L	G21G
F21L	H01R		A41H	B21B	B25B	B31D	B65C	C13H	D21B	F01M	F16H	F26B	G10L	A61B	B44D	
F21M	H01T		A42C	B21D	B25C	B31F	B65F	C14B	D21D	F01N	F16K	F27B	G11B	A61C	B65D	
F21P	H02B		A43D	B21F	B25D	B33Y	B65F1/*	C23C	D21F	F01P	F16M	F28B	H05F	A61D	B68G	
F21Q	H02G		A47K	B21H	B25F	B41B	B65F5/*	D01B	D21G	F02C	F16N	F28C		A61F	C06F	
F21S	H02H		A62C	B21J	B25G	B41C	B65F7/*	D01D	E01C	F02G	F16P	F28D		A61H	C12M	
F21V	H02J		B01D	B21K	B25H	B41D	B65F9/*	D01G	E01D	F02K	F22D	F28F		A61J	A61K	
F21W	H02K		B01F	B21L	B25J	B41F	B65G	D01H	E01F	F03B	F23B	F28G		A61L	D07B	
F21Y	H02M		B02B	B22C	B26B	B41G	B65H	D02G	E01H	F03C	F23C	G01G		A61M	F16L	

Table 19: NACE-ICP correspondence for building sector

4. BUILDINGS						
23.6 Concrete, cement and plaster	**41.2 Developement of bulding projects**	**42.2 Residential/non residential**	**43.3 Completion and finishing**	**55 Hotels**	**68 Real estate activity**	**71.1 Architectural and engeneering activities**
C04B	G03C	E04B H01S D04B	E04F A43D	G06Q	G09B C12N	E04B H01S F16S
E01D	G03G	E04H D03D H04M	E04G B41B	A47J	C23C C11D	E04H D03D D04B
E04F	G03B	B03C H04Q E06B	B63B D06C	E04H	G01R H01L	B03C H04Q H04M
B09B	G01N	B64C E01B G11B	G09B D01H	H04N	H04L F41J	B64C E01B E06B
B28C	B43K	C03B B01D B23Q	E04B E21D	G04C	H04N C05G	C03B B01D G11B
E01C	B65H	G02F H01L H01M	A21D G03B	A47G	C01B C09K	G02F H01L B23Q
E21B	B41J	B65D B63H F16B	C14C B66B		B60R B01J	B65D B63H H01M
E01B		F16H F16C	E04H H02S		H01M C07D	F16H F16C F16B
C21D		F16L B60K	E01C H02G		A61P C07C	F16L B60K
A61K		E01F B65H	B29C F24S		C04B	E01F B65H
A61L		G21C E01C	E06B B21B		H01S	G21C E01C
E02D		C25B E04G	A63H B65H		H03K	C25B E04G
C09K		B64D H03H	E04C		H01Q	B64D H03H
E04C		E05D B07B	B29D		C08G	E05D B07B
B28B		F24S C23F	H01L		C07K	F24S C23F
E04G		H05K B63B	B44D		A61K	H05K B63B
		F16F E02B	D06F		H03B	F16F E02B
		B66C A61M	E21C		H03C	B66C A61M
		B41L H04N	C04B		A01N	B41L H04N
		F01N F16S	B23P		G01N	F01N G10K

Table 20: NACE-ICP correspondence for transportation sector

5. TRANSPORTATION

29 Motor veichles, trailers and semitrailers	30 Transport equipment	33.15 Boats	33.16 Aircrafts	42.1 Roads, railways and bridges	45 Trade and repair of motor vehicles and motorcycles	49.1 Passenger rail transport	49.2 Freight rail transport	49.3 Other passenger land transport
B60K	B60F B64C	A63H	B64F	E01D H01H	B62D F03G E05F F41H E04H	B61J B60L	B61J A47B	B65G
B60L	B60V B64D	B29C	B29C	E01F G09D	B60S A63B A01D B61F B66D	E01B A23L	B64F E01H	G01C
B60N	B61C B64F	B63B	B64B	B61B C07K	E06C B63H F04B F16H H01H	A47H E21F	E01B E04H	B60P
B60P	B61D B64G	A24C	A43D	E01B F16H	B60L B41F G01C B60F B62B	B62J B65D	E05B F23B	B60V
B60Q	B61F B65F3/*	B64C	B64C	F42B B66C	B29C B66C B09B B60T B08B	B62D B61B	B60P G03G	B64F
B60R	B61G E01B	B64F	H02G	B60W G02C	H02P E04G G01M B60D B60H	B60N A47B	A47H G21F	E01F
B60T	B61H F03H	A43D	B60S	B61D B60L	A47L E01C B64G B60Q F21S	B60P E01H	B65G F03D	E01H
B60W	B61J B60G	H02G	E04H	E21B E01H	B61C G10K F41A B60J B21K	B60M E04H	B60M H01R	C03B
B62D	B61K B60H	B60S	F16L	B61L G07B	B61L A61G G05F B60C B60B	B64F E05B	B61H H04L	A61G
F01L	B62C B60J	F16L	B64D	B61K	F03D F16K F15B B66F E21B	B64G F23B	B65D B65H	A23L
F02B	B62H	E04G	A63H	B65G	B64F B01D H02N G01G E01F	B61H G03G	B60F F03D	E21F
F02D	B62J	E01C	G09B	E01C	A43D B62M A01G B65F H02J	B60W G21F	B61L H04L	B65D
F02F	B62K		E04G	C07D	H02G E05B F21W B61B G06V	B60F F03D	B61K B65H	B66B
F02M	B62L		E01C	A63H	B60M B60P F02N F01K F16F	B61L H01R	B61F	E04H
F02N	B62M		B63B	B60F	B61D G08G B61K B67D	B60R H04L	C03B	B61J
F02P	B63B		G01C	B61H	F16L B60V B60N G09B	B61K B65H	A61G	B64G
F16J	B63C		B60V	G08G	H02K A63H B61J F01B	B61F	B60L	F23B
G01P	B63H		B63G	E05B	B60R H04W G01S B60G	B65G	A23L	G03G
B60B	B63J			C07C	B60K B60W B61G F01D	C03B	E21F	G21F
B60D	B64B			G01R	B65G B62C B61H E06B	A61G		

Table 21: NACE-ICP correspondence for transportation and agriculture sector

5. TRANSPORTATION						6. AGRICULTURE		
49.4 Freight transport by road	**51 Air Transport**	**52 Wherehousing nad support activity for transportation**	**53 Postal and courier activity**	**77.1 Renting ond leasing of veivchles**	**77.35 Renting and leasing of transport equipment**	**1 Crop and Animal production**	**2 Forestry and logging**	**3 Fishery and acquaculture**
B64F F03D	B03C F24H B62J B01D	B65G H01M A61K F03D H01J E02B G03F	C23C	D02H A01G	D02H E04H A47J	C11D B32B D06N F02G	A01G	A01K
B65G G07B	B60P F02M C21B F16K	B60P A47H H04L F41J E01B F24S C07C	C01B	H02K F02N	B63C B61J B62J	A23K C12F F17D G03G	B27B	
G08G G06F	B65D F02D F41B B65H	B01J F16M H04M G11C G04D H05K C09K	H01M	B62D F16H	B60P A47G A45D	A23C B01F H01M C30B		
E05B E21B	E21F E04H A61H B05B	C23C B62J B41J B63B B41K B21B B01J	A61P	H02P F16K	B65G A63B A43D	A01K A23G B65D G06V		
B60P H04L	B65G B61J F02B B08B	B65H A43B H03B A61F H01B B23K C07D	C04B	F03G A47L	B64F B64D F03D	A01D A23N B65B B22F		
B60W B65H	C03B D06F G21F F04D	B66C B62H B60S E21D B62B D06F C07C	H01S	A63B B62M	A01K F23B B27C	A01G B62C C08J B29C		
E01C	F23B B60K F02C F23D	B65D E04G G21F F16J H01H F21V	H03K	B63H B66D	B63B B22D H04Q	A61D A61K D06M H05H		
E01F	A61G B60V A61C F16L	C03B H04N G10G G21C A47B C07D	H01Q	B41F H01H	C03B A63K B60W	A01L A63G G01N F24V		
B65D	A23L F23C F01N B60W	E04H A61P H03C H02S B23D B41F	C08G	B66C E21B	A61G E21B A21C	A23L A01N C22B F02C		
B60F	B64F F23L B60T F02P	A61G G03G A01N E04F C14B A23G	C07K	B60L	A47K B60L H04L	A01M B21C D04B B21B		
C03B	F24F B64D F01M E21B	A23L G09G G01N G11B H02K B23Q	A61K	G10K	A23L B22C B23B	C25B C21B C07K C10G		
A61G	F24D B41J H01H F21S	E21F F23B C12N A47C B60C H02G	H03B	B61C	E21F E01F B65H	A01B A23B G21C A61J		
A23L	B64B A43B F03D G06F	B64F C04B H01L B01F A47G F21S	H03C	F03D	B66B A45F G16H	G06T C03B C25C C25D		
E21F	C10J F24B F26B	C01B H01S C11D B24B C05G B65B	A01N	A01D	B65D B24B	C12N C10J C10H C10M		
E04H	F23R B63J B60R	F16L H03K F28F G12B G07F E02F	G01N	B60K	H04W G03G	A21D C04B C06B D03D		
B61J	A45D G03G E06B	G01V E01F F23H H03H C09K B60M	C12N	F04B	H04M B62B	G10K F23M C09D		
F23B	F01P A62B F22D	F21L H01Q G02C H01C B05B B60Q	C11D	B65G	B23Q B27B	A61L G03F C09J		
G03G	B60H A61L H04L	A46B E06C F16D H01R F26B E21B	H01L	G05F	B64G G21F	A63H B28B D04H		
G21F	F23M F42B G10D	E04B C08G H05B E03C H01K B41L	F41J	F15B	G06F A62C	D01C C13B C08L		
B61L	E03B A47L G06V	B61J C07K G06F G09B C40B B32B	C05G	H02N	E02F E21C	D05C D01F H04N		

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Summary

As the world prepares the transition to a low carbon economy to contrast the climate crisis, the backdrop of slowing growth and growing inequalities underscores the urgent need for a new approach to growth. In an economy that is increasingly knowledge based, innovation and intellectual property play a crucial role. This thesis analyses the role of innovation on growth and specifically its effect on climate transition risk management shedding light on the importance of innovation in mitigating the impact of climate transition risks. We present a financial stress test, and the assessment of Climate Value at Risk, applied to four bond portfolios that vary in terms of innovation and exposure to carbon-sensitive assets. Patent counting is used to measure innovation and a comprehensive code skimming methodology is employed to identify significant patents in environmental technology for economic modeling purposes.

Chapter 1

This chapter presents the broad concept of climate change and it prpovies an overview of type of risks it entails. Climate change refers to long-term shifts in temperature and weather patterns that have been accelerated by human activities (Weber & Stern, 2011). Climate change is not only a physical phenomenon, but also a public policy issue that has been studied for over 150 years through a continuous process of observational data collection, hypothesis formation and testing, and the construction of theories and models (Parmesan et al., 2022). Although it stems from natural solar cycles and is part of the planet's cyclical climatic eras, the current rapid acceleration of these changes is largely due to human activities.

According to Forbes, 2022 was marked by a significant increase in extreme weather events. For example, Pakistan was hit by an unusual monsoonal season that resulted in widespread flooding, landslides, and waterborne diseases, resulting in 1700 deaths, 1.7 million destroyed homes, and over $15 billion in economic damages. Europe was also affected by wildfires and droughts in Portugal, France, Romania, and Italy, leading to an estimated 60% loss for farmers in terms of annual returns (Lehnis, 2022). Heatwaves and meteorological events have been responsible for nearly half of the economic losses and over half of the fatalities related to adverse weather between 1970 and 2020 (Lehnis, 2022). The increasing frequency and severity of these extreme weather events highlights the urgency of addressing climate change and transitioning towards a more sustainable future.

The main trigger factor for climate change has been the extraction and use of fossil fuels such as oil and gas, which has led to the accumulation of greenhouse gasses in the atmosphere and disruption of the earth's ecosystems (United Nations, 2022). The international community has recognized the need for coordinated intervention.

The Paris Agreement, signed by UN member states at COP21, sets the goal of limiting the temperature increase to 2°C above pre-industrial levels, with efforts to limit it further to 1.5°C in the coming decades (Raikes et al., 2022). The COP monitors the progress of each member country every year to assess their response to the climate crisis. The world is at a critical point, and time is running out to take action. The COP 27 held in Sharm el-Sheikh last November discussed additional steps to fight the emergency and shift towards a cleaner economy (Raikes et al., 2022). The European Environment Agency projects a dramatic scenario if no intervention is taken to curb the rise in temperature. The report states that emissions must be reduced by 45% by 2030 to achieve net-zero emissions by 2050 (Raikes et al., 2022).

To implement international policies, financial solutions and innovative technologies are needed. Investments in renewable energies are sponsored to the tune of at least $4 trillion per year as the flow of green finance, currently at $803 billion, represents just 30% of what is needed to reach the temperature goal within the time limit (Raikes et al., 2022). The shift towards a low-carbon economy brings growing concerns among investors, who worry about the impact on financial stability (Stern & Valero, 2021). For this reason, quantifying the risks associated with sustainability is essential. The risks associated with the climate crisis are unique in nature since climate change is a global phenomenon with persistent impacts and a high degree of pervasive uncertainty (Batten, 2018).

The transition towards a new regime is a delicate process that requires careful timing. A delayed policy structure could lead to catastrophe, while an aggressive policy regime may result in a bigger drag on growth in the medium term due to insufficient means of mitigation (Batten, 2018). For example, a sudden shift away from fossil fuels could lead to an energy shortage, causing energy prices to skyrocket and leading to adverse macroeconomic outcomes. If assets in portfolios are heavily dependent on carbon and fossil fuel activities, a sudden shift towards a low carbon economy could result in heavy price adjustments, causing corporate defaults and financial instability (Stern & Valero, 2021).

This can come from two main channels: physical risks and transition risks. Physical risks arise from the interaction between climate-related hazards and the vulnerability of human and natural systems, including their adaptability (Batten, 2018). The main drivers of physical climate change are gradual global warming and extreme weather events, such as floods, water stress, and heat stress. This group of risks can affect both the assets and liabilities of financial agents, from damage to property and reduced productivity to business disruption and reduced ability to repay creditors (Batten, 2018).

Transition risks, instead, refer to all the dangers arising from the transition process to a low-carbon economy itself. This category of risks is more complex and difficult to identify compared to physical risks, and assessing and pricing them remains a challenge (Alogoskoufis et al., 2021). However, empirical evidence suggests that transition risks have a significant economic impact, affecting the economy on all fronts. On the demand side, they stem from the introduction of policies promoting low-carbon investments, which can lead to a decrease in private investment (Batten, 2018). On the supply side, they are seen as a reduction in near-term growth due to the costs of mitigation and emission reduction. Companies may need to allocate resources towards emission abatement, potentially reducing production (Batten, 2018). Additionally, asymmetrical climate policies can lead to disordered transitions and alter trade. As a result, investors are becoming more aware of the exposure of their investments to climate risks, leading to a shift in preferences towards lower returns for greener options (Monasterolo, 2020). However, the precise quantification of transition impacts to protect investors from unexpected negative outcomes is still limited.

Chapter 2

In this chapter the variable of innovation is theoretically introduced. It is outlined its dependence with economic growth and its role in the credit market.

Innovation can be defined as a successful upgrades of goods and services that are key to the longevity of a production system (Kahn, 2018). It stems from the synergistic combination of its three natures being simultaneously an outcome, a process, and a mindset. The the mindset refers to the culture's willingness to take risks in favor of change and is considered the key trait of successful innovation (Kahn, 2018).

The relation between innovation and economic growth has been established since the 1950s. Nonetheless, nowadays, the concept of growth has evolved to include the idea of sustainable growth, which is environmentally conscious and driven by the transition to zero-net carbon emissions (Cameron, 1996). Sustainability encompasses three main areas: social, economic, and environmental, and is defined as the ability to meet present needs without compromising future generations (Cameron, 1996). To achieve sustainable growth and the decarbonization of the economy, radical technological change is necessary. Innovation capacity, regulated by economic and institutional environment, is crucial for achieving this goal and to reach long-term growth and survival (Cameron, 1996).

Environmental sustainability is achieved by redirecting growth and not stopping it. Thus, sustainability can be accomplished by restructuring the R&D system and intangible asset valuation (Stern & Valero, 2021). The world is not moving quickly enough to meet the UNFCCC target set in 2015, and action on climate change must be accelerated to avoid catastrophic damage. The next decade is critical, and the choices made now on investments in infrastructure, innovation, and complementary assets will determine if we continue on a high-emissions path or steer towards a low-carbon growth path that is sustainable, inclusive, and resilient (Stern & Valero, 2021). The COP21 in Paris and COP27 in Sharm El-Sheikh in 2021 raised global ambition and will play a critical role in driving action (Stern & Valero, 2021).

Innovation owns vital importance in crisis management and in the ability of firms and systems to be resilient (Bar Am et al., 2020). The concept of resilience is here defined as the capacity of a system to transform and adapt to balance stability and adaptability (Bar Am et al., 2020). Innovation is at the core of both resilience and sustainability, and the latter is essential to achieve and maintain a sustainable system in a dynamic environment. A successful innovation process is one that recognizes opportunities and is resilient enough to deal with the uncertainties of the environment. Innovative assets are therefore strategic to overcome external shocks.

As a matter of fact, from the Great Financial Crises on, an increasing number of financial agents increased the intangible assets volume of their balance sheet (Bar Am et al., 2020). Specifically, companies now tends to prefer intangible assets as collateral. The ownership of patents, as a form of intellectual property, has provided companies with a new method to enhance their financial capability (Bar Am et al., 2020).

This is is particularly relevant in the context of climate transition, as the risk associated with it can lead to depreciation of physical collateral like real estate and infrastructure (Bar Am et al., 2020). This is due to the adverse effects of climate change, like rising sea levels, more frequent natural disasters, and extreme weather conditions, which can negatively affect the physical condition and value of these assets. In comparison, patents and other forms of intellectual property offer a distinct form of collateral that is immune to the physical risks.

The effect of patents portfolios over equity performance has long being studied, however the impact of patents on the creditworthiness of firms remain a grey area. Empirical evidence, show that the dimension of the patent portfolio hold by a firm impact the capability of the latter to access ante debt financing (Frey et al., 2020). Since creditors do not shares the upside of the investment, in this case the quality of patents become secondary to the quantity and the strategic contraction. Therefore, innovative firms, which hold a larger patent portfolio compared to their competitors, should benefit of an higher degree of creditworthiness and larger debet capability (Frey et al., 2020).

As a result, patents provide a sturdy form of collateral in the face of climate change as they offer a legally protected exclusive right to cutting-edge technologies that help mitigate its effects (Bloom & Van Reenen, 2002). These eco-friendly solutions are becoming more and more sought after as the world shifts towards a greener economy, making patents a highly valuable asset that can attract funding for continued research and advancement (Stern & Valero, 2021). The patent's legal protections also reduce the risk of intellectual property theft, thereby offering a safe return on investment for those financing the creation of environmentally conscious technologies.

Chapter 3

Chapter three introduces the theoretical models used to conduct our analysis. First the model used to compute scenario projections is presented, then the valuation frameworks for assessing the change in bond portfolio value following a policy shock is described and finally the concept of project-climate VaR is discussed.

Climate risk modeling is complex and challenging due to its forward-looking nature and the impact of risk perception and reaction of various agents'(Battiston & Monasterolo, 2020). Conventional methods of valuing assets fall short in this context. Our research models the economic transition risk in an economy with multiple companies and business sectors, each operating with a different energy technology. Each company issues corporate bonds for funding and investors choose these bonds as part of their portfolio.

To conduce climate transition scenario analysis, future economic output trajectories are needed. We used the class od Integrated Assessment Models (IAMs) which are a tool used to analyze the interaction between different regions and sectors and estimate their long-term economic output. They combine economic theory with data from the physical environment and are used to assess the impact of natural changes over time (Nordhaus, 2013). IAMs have a recursive approach and use a general economic equilibria while considering the impact of physical indicators such as air pollution and carbon emissions. The models convert economic activities into monetized values and allow policymakers to weigh the costs of transitioning from a carbon-intensive economy (Nordhaus, 2013). IAM models are divided into two groups: policy evaluation models, which describe selected variables of importance, and policy optimization models, which maximize an objective function such as a welfare function (Nordhaus, 2013). The welfare function is the discounted sum of population utility, which depends on per capita consumption and population volume over time. The models use a Cobb-Douglas function for production with inputs of capital, labor, and energy, which can be carbon or non-carbon based. Technology advancements are divided into overall progress and progress in reducing CO2 emissions. Carbon fuels become more expensive over time, leading to a shift towards non-carbon energy sources. Output is measured in terms of purchasing power parity (PPP) and regional outputs are projected using a partial convergence model. The final step combines all the regional outputs to give the total output for the world.

Among the class of IAM we adopted the the EPPA5 (Regional Integrated Assessment Model). It is a comprehensive, multi-region, multi-sector computational general equilibrium (CGE) model developed by the MIT Joint Program on the Science and Policy of Global Change. It uses the Global Trade Analysis Project (GTAP) dataset and simulates the global economy from 2005 to 2100, taking into account energy technologies, greenhouse gas emissions, air pollutants, and land use changes (Chen et al., 2015). The model take into account the interdependence of different economic sectors and markets and provides a comprehensive view of the economy. It can simulate the effect of various policy options on the economy and provide insight into their potential costs and benefits, such as the impact of a carbon tax on emissions and economic welfare or the impact of subsidies for renewable energy on energy production and consumption. The model is formulated and solved as a mixed complementary problem and uses a Constant Elasticity of Substitution production function (Chen et al., 2015). It maximizes profits while considering cost functions and the prices of goods and factors, taking into account the balance of supply and demand and the equality of income and returns to factor endowments.

In this model the representative household maximized a welfare function subject to a budget constraint in each region. The welfare function was based on a CES utility, and there was a single expenditure function or welfare price index that corresponded to each region (Chen et al., 2015). The equilibrium prices in various goods and factor markets were established through a closed system of market clearance equations. The GTAP dataset used in the EPPA5 model only included production activities that existed in the benchmark year, but it also added "backstop technology sectors" to account for advanced energy technologies that may become important in the future (Chen et al., 2015). The model considered 14 electricity generation technologies, including 5 traditional and 9 advanced technologies, and the relative cost of these technologies is determined endogenously. The input shares and markups for advanced electricity technologies are determined using a legalized cost of electricity calculation.

We assessed the risk exposure of financial intermediaries to climate transition impacts by introducing the concept of transition scenarios and climate policy shocks. The model classified different economic activities based on their greenhouse gas emissions, energy and technology profile, business model and policy relevance into Climate Policy Relevant Sectors (CPRS) such as utilities, transportation, agriculture, manufacturing, mining, and households. A financial actor was modeled as a portfolio of investments through bond contracts, each signed by a different borrower. The model used expectations to conduct the valuation of the bond project at three temporal steps: t_0,t^*, and Tj, where t_0 is the valuation time, t^* is the time at which a climate policy shock occurs, and Tj is the maturity of the bond. The financial valuation of an agent's investment in a specific project is represented by $Aij(t0, Tj)$, where i represents the agent and j represents the project. At t^*, a climate policy shock affects the bond issuer's revenue and leads to a shock in the value of the bond issuer's assets. The methodology was based on a climate stress-test aimed at evaluating the expected value of a bond portfolio affected by a balance sheet shock linked to the beneficiary's business operations due to a climate policy shock.

Then the default risk is modeled as a function of the borrower's assets at maturity and their liabilities, and is influenced by both an idiosyncratic shock (referred to as η_j) and a climate policy shock (ξ_j). The impact of the climate policy shock is modeled as a change in the market share of the borrower's sector, represented by $u_{S,R}$, which affects the borrower's profitability and net worth. The change in default probability is calculated based on the likelihood of the idiosyncratic shock being less than a threshold value that depends on the borrower's liabilities, initial net worth value, and the impact of the climate policy shock. The Climate Value-at-Risk (Climate VaR) of an investor's portfolio is defined as the amount at risk for a given transition scenario and confidence level (Monasterolo, 2020). Since the projected distribution of the idiosyncratic shock and the probability of occurrence of climate policy shocks are not available, we relied on the project-level Climate VaR which is defined as *"the value such that, conditional to the same climate policy shocks for all n projects, the fraction of projects leading to losses larger than the VaR is equal to the confidence level c* (Monasterolo et al., 2018).

$$|\{j|\Delta A_{ij}(t_0,T_j,P,B) \geq Var\}|/n = c \quad (2)$$

Chapter 4

Chapter 4 contains the empirical analysis. The analysis used data from the LIMITS dataset provided by the Bank of Canada and was based on four scenarios over a 30-year period from 2020 to 2050 (Hosseini et al., 2022). The scenarios were: the baseline scenario, which assumed no further policy action to limit global warming; the "below 2°C immediate" and "below 2°C delayed" scenarios, which considered a plausible path for global climate policy that limits the increase in global average temperatures to below 2°C by 2100; and the "net-zero 2050 (1.5°C)" scenario, which reached net-zero global carbon dioxide emissions by mid-century. The scenarios are not exhaustive or predictive in nature, but instead represent a range of plausible, challenging global transition pathways. Next, we quantified the market shocks for the same region and sectors by using the projected data up until 2050.

The introduction of climate policies had a negative impact on the market share of fossil fuel dependent sectors (Coal, Oil and Gas), with Africa and India being the most affected regions. India was particularly impacted by the introduction of policies in the coal and gas sectors, while China is impacted mainly by the gas sector. The market share shocks for the United States were robust until 2030, but started to decline after that. In the oil sector, Japan sees a positive impact from the introduction of low carbon transition policies until 2040.

To incorporate innovation into economic models, the we adopted the patent counting approach and use the Global Patent Index (GPI) provided by the European Patent Office (EPO). The GPI is a tool for collecting and categorizing global patent data and is updated regularly. We conducted their selection of patents based on International Patent Classification (ICP) codes, year of publication, and keywords. The process involved a fine-skimming of patent families and code mapping. A first coarse skimming was done using CPRS-NACERev2 correspondence to select the most relevant patent families. Then, we used the World Intellectual Property Organization portal to match NACErev2 classification with IPC categorization. Since, empirical evidence shows that key technological patents have a higher economic impact, we focused on these key technological patents by trimming the comprehensive dataset using OECD criteria for crucial environmental patents to obtain the final set of IPC codes.

We used the Global Patent Index database to find the most innovative companies in each energy sector. The database was searched to identify the most active companies in terms of the number of patents applied for and granted. This was the starting point for the innovative bond portfolio construction.

We then applied the theoretical model to four simulated bond portfolios that incorporated the innovation variable. The first portfolio consisted of bonds issued by innovative companies with a high carbon exposure, the second portfolio was made of bonds issued by innovative companies with a lower carbon footprint, the third portfolio was formed by bonds issued by non-innovative companies with a high carbon exposure, and the fourth portfolio was built on bonds issued by non-innovative companies with a lower carbon exposure. The portfolios had similar regional exposure.

To evaluate the project climate VaR we first found the change in value of each portfolio in each scenario due to climate policy shocks. We observed that there was a noticeable difference in trend between the portfolios that were dependent on carbon and those that were greener. The portfolios that focused on fossil fuels (portfolios 1 and 3) were expected to decrease in value over time in each climate change scenario, while the greener portfolios (portfolios 2 and 4) were expected to increase. The gap between the values of the carbon-intensive portfolios and the sustainable portfolios grew over time and was narrower in the Net-Zero 2050 scenario compared to the other scenarios.

Then, we calculated the quartiles of the variations in the portfolio value to assess the impact of the climate transition risk. Quartile graphs are used to represent the distribution of a dataset and provide insights about its distribution. The analysis of quartile graphs in the context of fossil fuels and green investment portfolios showed that portfolios focused on fossil fuels carried higher risk compared to portfolios with a focus on green investments, based on a more pronounced steepness. The sudden implementation of climate policy was also found to have a greater negative impact on fossil fuel-based assets. On the other hand, portfolios invested in sustainable assets had a higher level of returns compared to portfolios invested in carbon-based assets, as indicated by the upward slope of the third quartile and median in sustainable portfolios.

Finally, we computed the project-Climate Value at Risk (CVaR) to assess the effect of innovation on transition risk. CVaR is a financial risk management framework that evaluates the potential financial losses of an investment portfolio due to climate change impacts and takes into account the probability distribution of expected losses. The project-level CVaR was used in our reseaech as a way to summarize the tail risk of the portfolio and provide information about the potential loss that can be expected with a certain degree of confidence over a specific time horizon.

The research found that innovative portfolios resulted in a lower maximum expected loss for the 90% confidence interval of the project climate Value at Risk (VaR) compared to non-innovative portfolios. This indicates a lower level of uncertainty or volatility in the potential return of the investment. The introduction of policies had a negative impact on non-innovative portfolios, resulting in a higher level of climate VaR, while innovative portfolios were less affected. We also found that a delay in the adoption of the policies resulted in a higher potential loss, especially for non-innovative portfolios. The project climate VaR of sustainable portfolios was lower compared to their fossil-dependent counterparts. However, the research suffered from limitations such as a small sample size, which impacts the generalization of the results. Future research could benefit from a larger and more diverse sample, as well as objective measures to corroborate the findings.

Conclusion

To sum up, this thesis adds to the ongoing discussion about the importance of innovation for economic growth and crisis management, by assessing its role in the context of climate transition risk assessment. The transition towards a net zero emission economy implies a radical technological change which could impair portfolios performance and financial stability. In this research we notice how innovation has the ability to reduce the impact of climate transition risks. To do so, we ran a climate stress test over four different simulated bond portfolios each of which presented a different exposure to the fossil fuel sector and a different degree of innovation. We then evaluate risk exposure by adopting as risk measure the Climate Value at Risk (CVar). To apply our model we relied on the economic output trajectories computed by an Integrated Assessment Model (IAM), specifically, by the MIT Economic Projection and Policy Analysis project, the EPPA5 model. The scenario analysis data were projected out over a thirty year time window, 2020-2050, using 5 year steps.

We modeled innovation by patent application and granting counting. We took into consideration the Climate Policy relevant Sectors (CPRS) sectors and we draw the respective concordance with the NACERev2 framework. This enabled the selection of the ICP families of patents related to climate transition. We proceeded with a further skimming of patents families though the concept of "key technological patents", obtaining a final sample of significant ICP codes for patent identification. We then used the Global Patent Index database to draw up the most innovative companies for each energetic sector considered.

We then created four bond portfolios with a similar risk structure, two with a similar high carbon exposure and the remaining two more invested in alliterative cleaner energy source. One for each kind was labeled as innovative, and was therefore composed just of innovative bonds. Then the quartile disposition and the distribution of value change of each portfolio was computed. We then applied the concept of project-climate transition VaR, interpreted as the maximum expected loss over a given time horizon and confidence level, due to the impacts of climate change on a particular investment or project.

We have observed that for all possible climate scenarios considered in the model, the expected maximum loss has been lower for innovative portfolios with respect to the control group. The influence of innovation was more perceivable on the project Climate Value at Risk (VaR) for the 90% confidence interval. The findings show that innovative portfolios resulted in a lower maximum expected loss compared to non-innovative portfolios, reducing the level of transition risk associated with them. The reduction in project climate VaR became evident when comparing the project CVaR of green portfolios. Non-innovative sustainable portfolios performed poorly compared to innovative ones. Innovation was able to mitigate the effects of a delayed policy introduction in which the potential loss for both green and carbon intensive bonds increased. In all scenarios, the project climate VaR of sustainable innovative portfolios is lower than the respective counterpart. All in all, given all the limitations of this research, these findings have significant implications for financial institutions and policymakers and provide a foundation for future research in this field.