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A comparative study of the resilience of coal logistics chains in Australia, South Africa and Canada

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Résumé

Au cours des dernières années l'industrie du charbon a connu un essor important. L'importance du charbon dans l'économie mondiale provient d'une demande mondiale soutenue et de niveaux de production en hausse constante. De ce fait, le nombre élevé d'importateurs et d'exportateurs est à l'origine d'un système d'échange complexe où la compétition est féroce. En effet, un nombre grandissant de pays importateurs se partagent les sources d'approvisionnement tandis qu'un nombre limité de pays exportateurs s'efforcent de répondre à la demande tout en essayant de s'accaparer le plus de parts du marché mondial.

L'objectif de cette recherche s'inscrit dans ce contexte en démontrant les bénéfices associés aux chaînes logistiques résilientes pour tout acteur de l'industrie soucieux de devancer la compétition. Une analyse de la logistique de l'industrie du charbon permet entre autres de se pencher sur les questions suivantes: Comment les infrastructures influencent-elles la résilience d'une chaîne logistique? Quels risques est-ce que les catastrophes naturelles présentent pour une chaîne logistique? Comment la gouvernance influence-t-elle la résilience d'une chaîne logistique?

Une chaîne logistique représente le trajet effectué par un bien ou produit au cours de son cycle de vie, du point d'origine au point de consommation. Ceci étant dit, le meilleur moyen de régler les problèmes inhérents aux chaînes logistiques est de maintenir de hauts niveaux de résilience. Cette recherche évaluera donc la résilience de chaînes logistiques du charbon des industries australienne, sud-africaine et canadienne. Pour ce faire, trois variables seront étudiées: les infrastructures, les catastrophes naturelles et la gouvernance. La comparaison des trois cas à l'étude se fera par un nombre défini d'indicateurs (12 au total) pour chacune des variables étudiées. Les résultats de cette recherche démontrent que la résilience des trois cas à l'étude se ressemble. Cependant, certaines chaînes logistiques détiennent des avantages comparatifs qui améliorent grandement leur résilience et leur compétitivité. Plusieurs sujets de recherche pourraient être utilisés pour compléter cette recherche. L'analyse comparative pourrait être appliquée à d'autres chaînes logistiques pour vérifier la viabilité des résultats. Une analyse semblable pourrait également être entreprise pour le secteur en aval de la chaîne logistique. Finalement, une méthodologie basée sur des interviews pourrait ajouter un regard différent sur les questions abordées. *Mots-clés: Chaînes logistiques, industrie du charbon, résilience*

Abstract

In recent years, the importance of coal in the world economy has been put to the forefront by a strong demand and consequently, increasing levels of production. The increasing number of buyers and the limited number of sellers has created a system where competition is fiercer than ever. On one hand, importing countries are trying to secure sources of supply while on the other hand, exporting countries are striving to meet demand and secure as many export markets as possible.

In this context, the objective of this research paper is to demonstrate how resilient logistics chains can help decision makers of the industry to stay ahead of the competition. To do this, an analysis of the logistics chain of the industry is the best way to verify whether or not the industry is operating as well as it should be. Such an analysis allows us to tackle the following issues: How do infrastructure issues impact the resilience of the logistics chain? What risks do environmental hazards pose to the logistics chain? Does governance have a positive or negative influence on the resilience of the logistics chain?

"Logistics chain" designates the journey of any kind of product or commodity through the various steps of its life from its creation or point of origin to its point of consumption. This being said, the best way to solve problems in the logistics chain is to find ways to maintain high levels of resilience. This research paper will evaluate the resilience of logistics chains within the Australian, South African and Canadian coal industries. This evaluation will be based on three variables: infrastructures, environment and governance. The methodology necessary to accomplish this task is based on twelve indicators. As the main evaluation tool, these indicators are used to compare the case studies in the context of each variable. The results of this research paper show that the three case studies have similar levels of resilience. However, some case studies have areas in which they outperform their counterparts. While this research provides an in-depth look at the coal industry, several research avenues could still be explored. First of all, expanding the comparative analysis to different coal exporters could add nuance. This task could be undertaken in a different research paper providing decision makers with even more examples of how to improve resilience. A similar comparative approach could also be applied to the downstream section of the logistics chain. Furthermore, a methodology based on interviews with stakeholders could bring in a new perspective on the issue at hand.

Keywords: Logistics chains, coal industry, resilience

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Glossary

Mt : Million tonnes

Mtoe: Million tonnes of oil equivalent

Gt: Billion tonnes

RBCT: Richards Bay coal terminal

KPI(s): Key performance indicator(s)

II(s): Infrastructure indicator(s)

RI(s): Risk indicator(s)

GI(s): Governance indicator(s)

Tph: Tons per hour

Washing process: Washing coal is a technique used throughout the industry. The objective is to upgrade the quality of specimens by reducing the amount of unwanted substances found in raw coal. "Coal is first ground into smaller pieces so that it can be more easily processed. The pulverized coal is then washed in water or in fluids with densities that cause the coal to float so that unwanted impurities can sink to the bottom. Coal washing reduces its ash content by over 50%, resulting in less waste. About 25% of the sulphur content is reduced, lowering the amount of sulphur dioxide emissions released upon combustion. Coal washing also improves the heating value of coal, known as the thermal efficiency, which reduces carbon dioxide emissions as well" (http://climatelab.org/Coal_Washing).

Tectonic plates[1]: A tectonic plate (also called lithospheric plate) is a massive, irregularly shaped slab of solid rock, generally composed of both continental and oceanic lithosphere. Plate size can vary greatly, from a few hundred to thousands of kilometers across; the Pacific and Antarctic Plates are among the largest. Plate thickness also varies greatly, ranging from less than 15 km for young oceanic lithosphere to about 200 km or more for ancient continental lithosphere (for example, the interior parts of North and South America).

[1] U.S. Geological Survey. "What is a tectonic plate?," U.S. Geological Survey, http://pubs.usgs.gov/gip/dynamic/tectonic.html (accessed February 2 2012).

Acknowledgements

From start to finish, working on this research has been a real pleasure. What started as an attempt to bridge research interests in the fields of energy and maritime transportation quickly transformed into an in-depth analysis of the coal industry and logistics chains.

There is no doubt in my mind that the person most directly responsible for my passion in the fields of transportation and logistics is no other than my teacher, director and mentor, Professor Claude Comtois. Mr. Comtois, the first class I took with you when I was still an undergraduate student changed me. Your teachings allowed me to embark on a path that will certainly lead me to a gratifying and motivating career. As a student, I was literally blown away by your knowledge and Oh so refreshing and captivating way of teaching! These last two years, your help and guidance have allowed me to write this research with confidence in my abilities. On the other hand, you have also allowed me to work with independence, refusing to hold my hand, but rather pointing me in the right direction. For that, I cannot thank you enough!

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Chapter 1: An overview of the research project

1.1 Context

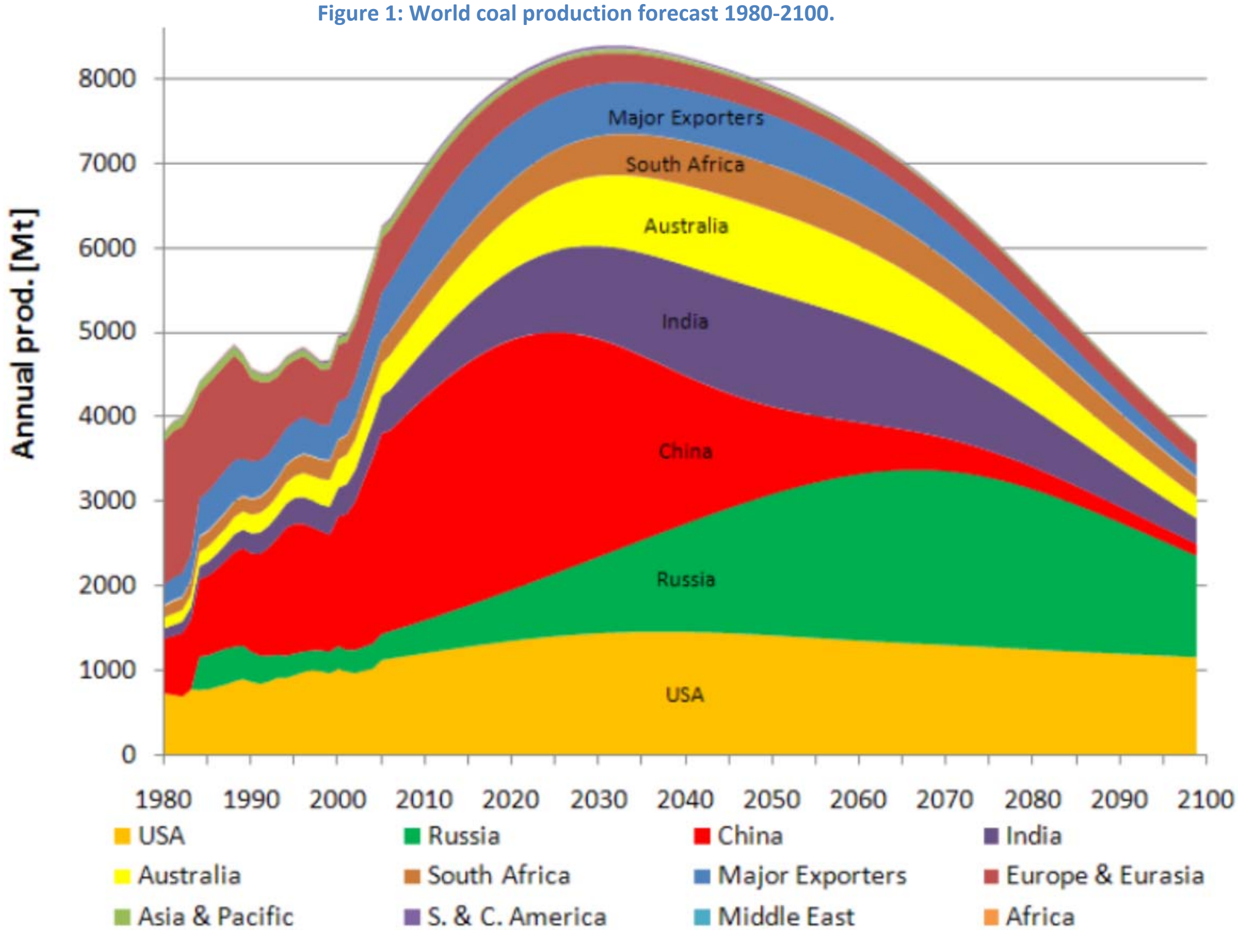
Coal, like most natural resources exploited by man, is a none-renewable commodity. Indeed, dead vegetation is only transformed into coal after millions of years of heat and pressure. In other words, the rhythm at which we consume coal is notably faster than the rhythm at which the resource renews itself. However, as the world population grows and societies develop, the need to find and secure supplies of coal is becoming increasingly important. Furthermore, as a major source of energy and main component of steelmaking, coal is a very sought and valuable commodity representing 29.6% of global energy needs and 42% of the world's electricity[2].

Several indicators demonstrate the importance and size of the coal industry. To begin with, production levels which had dropped because of the world's dependence on oil during the XX[th] century have been increasing quickly over the last decades. Furthermore, as figure 1 demonstrates, world coal production is expected to keep on growing rapidly for the next twenty years (Hook, Zittel and Aleklett, 2008, 43).

The world's major producers of coal, the *Big Six* (United States of America, Russia, China, India, Australia and South Africa) have been and will continue to be the main catalysts of this recovery (Hook, Zittel and Aleklett, 2008, 3). The sharp increase in coal production is also underlined by BP stating that from 2000 to 2010, total world production has jumped from 2352.5 to 3731.4Mtoe (BP, 2011, 32).

[2] World Coal Association, “Coal Statistics,” World Coal Association, http://www.worldcoal.org/resources/coal-statistics/ (accessed may 08, 2012).

Figure 1: World coal production forecast 1980-2100.



Source: Hook, Zittel and Aleklett, 2008

The second indicator of the importance of coal is its demand on world markets. As supply and demand are always trying to balance themselves, the increase in production mentioned previously is a clear indication of the strong and sustained demand for coal. The demand for coal has been increasing rapidly since 2000. Driven by the development of emerging countries like China and by the sustained needs of Japan and the European Union, the coal industry is having a hard time meeting demand. For example, the demand for coal products went from around 2750Mt per year in 1980 to more than 5000Mt per year in 2005 (Kavalov and Peteves, 2007, 14). According to the forecasts presented in table I, the demand for coal will grow more rapidly than any other source of energy in the years to come (with the exception of the other renewable category). In 2030, the demand for coal will even allow it to overtake oil as the world's most important source of energy.

Table I: World energy demand by type, 1980-2030 (Mtoe).

	1980	2000	2007	2015	2030	2007-2030
Oil	3107	3655	4093	4234	5009	0.9%
Coal	1792	2292	3184	3828	4887	1.9%
Natural gas	1234	2085	2512	2801	3561	1.5%
Biomass	749	1031	1176	1338	1604	1.4%
Nuclear	186	676	709	810	956	1.3%
Hydroelectricity	148	225	265	317	402	1.8%
Other & renewable	12	55	74	160	370	7.3%
Total	**7228**	**10018**	**12013**	**13488**	**16790**	

Source: International Energy Agency, 2009

Again, BP presents similar conclusions when stating that world consumption of coal as gone from 2399.7Mtoe in 2000 to 3555.8Mtoe in 2010 (BP, 2011, 33).

The importance of coal can also be seen through the evolution of the price of coal on international markets. Following sustained demand over the years, coal prices have been steadily increasing. The price of coal is a very important indicator because more than production or demand, it gives a precise evaluation of the value given to coal. On all markets studied by BP during a 20 years period from 1990 to 2010, coal prices have gone up by more than 100%. On the Northwest Europe market, average prices went from 43.48$ to 92.50$ a tonne, on the US Central Appalachian coal spot market, average prices went from 31.59$ to 71.63$, on the Japan coking coal import market, average prices went from 60.54$ to 158.95$ and finally, on the Japan steam coal import market, averages prices went from 50.81$ to 105.19$ (BP, 2011, 30).

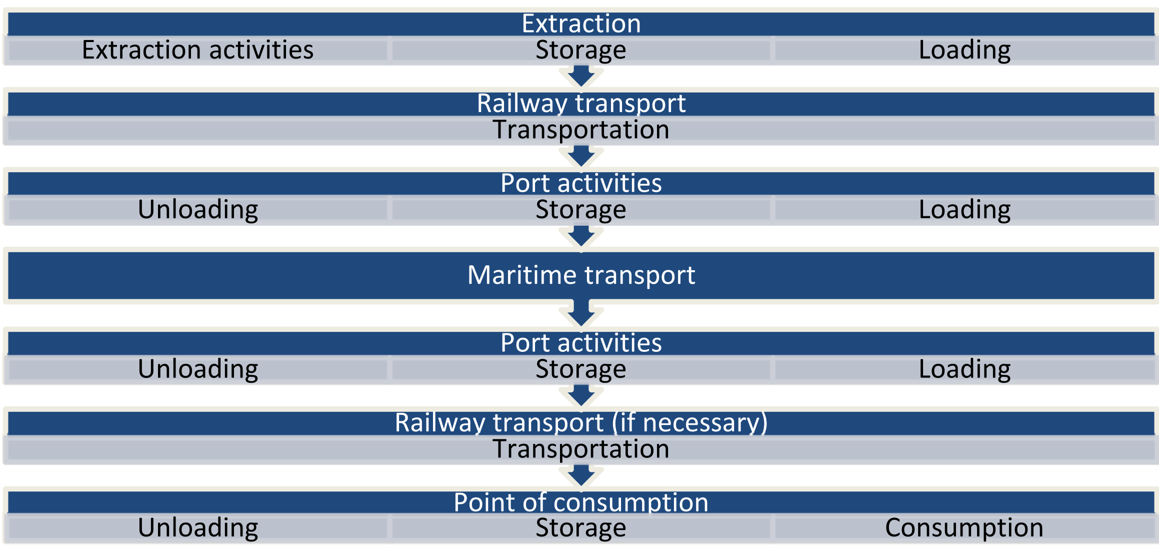
The last indicator of the growing importance of the coal industry is the growing level of complexity in the coal trading business. The growth in both production and demand has brought new players in the business. Countries like China who had once been exporters are now entering the import market to satisfy their enormous needs for coal. Furthermore, recent natural disasters that have underlined the risks associated with nuclear power plants meltdowns have also increased the demand for coal as a cheap and safe fuel to provide electricity. Those changes have modified the system of the coal trading business. As the number of players active in coal trading has increased, a multi-partner system has emerged where exporters have more clients and importers have more suppliers than before.

These four indicators: increasing production levels, increasing demand, increasing prices and a new multi-partner trading system have had important consequences for the coal industry in general. Competition is now stronger than ever in the industry for both suppliers and buyers. Indeed, coal exporting countries are engaged in fierce competition to secure new markets and attract new customers. On the other side, coal importing countries with increasing needs for coal are competing for contracts with suppliers struggling to meet demands. Such competition has been particularly difficult for coal exporting countries, forcing them to maintain high standard and levels of efficiency to keep up with demands and avoid losing market shares to competitors. In this context, logistics has become extremely important. As efficient operations depend first and foremost on effective logistics systems, the key to success for all coal exporting countries is high quality logistics systems.

1.2 Objectives

While the current reality in which the coal industry is operating offers many opportunities for growth, profits and success, high levels of competition make it necessary for coal exporters to rethink their operations and invest in their logistics sector. According to the Council of Logistics Management, "logistics is that part of the supply chain process that plans, implements and controls the efficient, effective flow and storage of goods, services and related information from the point-of-origin to the point-of-consumption in order to meet customers' requirements" (Brewer, Button and Hensher, 2001, 101). Despite its complexity, the coal industry's logistics chain can be summarized by the linking of seven stages as shown in figure 2. As mentioned in section 1.5, only the first three stages of the chain will be considered by this paper.

Figure 2: The coal industry chain of logistics.



Competition can have negative impacts on the activities of coal exporters. For instance, decreasing levels of demand and losses of market shares will result in decreasing levels of production and profitability. A possible way to deal with those negative impacts is to improve the logistics sector through better supply chain management practices. The improvement of the logistics sector is not only a matter of investing more money and building more infrastructures. It is, first and foremost, a question of measuring, monitoring and maintaining the system's resilience. Resilience is one of the most important factors in the success of a system because, more than anything, a high level of resilience is the best way to make sure that the logistics chain will function at full capacity as often as possible for as long as possible. A system's resilience is defined as follows: «Given the occurrence of a particular disruptive event (or set of events), the resilience of a system to that event (or events) is the ability to efficiently reduce both the magnitude and duration of the deviation from targeted system performance levels» (Vugrin, Warren and Ehlen, 2010, 3). It can also be defined as a system's capacity to foresee and anticipate the changing nature of potential risks and its ability to defend itself against those risks before negative consequences can happen (Therrien, 2010, 155). In other words, the first definition refers to the concept of recovery while the second definition refers to prevention.

Therefore, the hypothesis of this paper is that if resilience is taken into consideration and actions undertaken to maintain it, the logistics chain of the industry can create benefits that will reduce the negative impacts of competition and help coal exporting operations to remain ahead of their competitors.

The main objective will be to show examples, based on the operations of three important coal exporting countries, of resilient logistics operations that decision makers will be able to use as *up-to-date* and efficient tools to remain ahead of the competition. To do so, the following three core variables will be studied: infrastructure, environmental hazards and governance.

The whole idea will be to show whether or not the coal logistics chains in Canada, Australia and South Africa are based on the concept of resilience. For the infrastructure variable, this will be done by analyzing the impacts of capacity of ports and railways on the fluidity and resilience of the chain. For the environment variable, this will be done by analyzing the impact of seismic, hydrologic and atmospheric hazards (Mansouri, Nilchiani and Mostashari, 2010, 1127) on the fluidity and the resilience of the chain. For governance, this will be done by evaluating the impacts of planning and development, corporate concentration and market segmentation on the resilience of the chain. In the end, the situations where the logistics chain showed the highest level of resilience will be identified as the most effective ways of improving logistics and remaining ahead of the competition. The method used to measure resilience levels will be explained in section 1.5.

1.3 Research questions

This paper includes three research questions that help present an accurate picture of the industry in the context of the three variables identified previously. Accordingly, each variable is analyzed by its own research question.

The first research question refers to the first variable: infrastructure.

- How do infrastructure issues impact the resilience of the logistics chain?

The second research question refers to the following variable: environment.

- What risks do environmental hazards pose to the logistics chain?

The last research question touches the third variable: governance.

- Does the governance of the industry have a positive or negative influence on the resilience of the logistics chain?

For each question, answers will be provided for all three case studies. As stated in section 1.2, the situations that will prove to be the best examples of resilience will be selected as examples to follow. Thus, these examples will be vital to present realistic guidelines on what can and must be done to ensure the on-going development and well-being of the coal industry despite increasing levels of competition.

1.4 Review of literature

Among the various scientific articles, governmental reports, none-governmental organizations reports, private company's annual reports and other articles that have been written on the coal industry, the topic at hand has rarely been thoroughly tackled. Furthermore, a comparative, in-depth study concerning the logistics sector of three of the most important coal producers is hard to find. Comparative studies of this kind represent, at best, a fraction of the publications found in the literature. Therefore, this paper not only brings a new look into the international coal industry, it also acts as a pioneer in an unexplored topic of the literature, namely: What examples of resilient logistics chains do decision makers of the coal industry need to follow to face the challenges of the coal trading business? The various articles that form the literature are grouped in five categories: one for the core concept of resilience, one for the concept of performance indicators and for each variable.

1.4.1 Resilience

The idea of resilience or improving resilience has been the main focus of an increasing number of scientific articles since 2001. The literature has become more abundant following the September 11th 2001 terrorist attacks in the United-States. This trend can, to some extent, be explained by the importance given to the protection of our societies' essential infrastructure systems (Therrien, 2010, 154). U.S. governmental publications are common throughout the literature since many of the country's institutions are now paying close attention to the study of resilience. Thanks to the initiative of the Department of Homeland Security's Critical Infrastructure Task Force, resilience "became a national priority as the task force made critical infrastructure resilience its top-level strategic objective. [...] As a result of this shift, the federal government has started a coordinated set of resilience initiatives to understand what features create resilience in critical infrastructures/key resources and has initiated calls to agencies to start measuring the resilience of their infrastructure systems" (Vugrin, Warren and Ehlen, 2010, 2).

The concept of resilience is a broad term that can be applied to various systems, networks, infrastructures or industries. For instance, resilience has been studied in publications concerning financial systems, telecommunication systems, emergency response systems, transport systems and many more (Therrien, 2010, 160). Closer to the themes addressed by this research paper is the study of the relationships between *Maritime Infrastructure Transportation Systems* (MITS) and resilience. Here, the literature is both abundant and exhaustive, but seems to focus on container terminals more than bulk terminals. Nevertheless, in the field of maritime transportation, most of the recent literature on resilience tries to develop a Risk Management-based Decision Analysis. Such publications "guide the decision-makers to identify, analyze, and prioritize risks involved in PIS (Port Infrastructure Systems) operations; to define ways for risk mitigation, plan for contingencies, and devise mechanisms for continuously monitoring and controlling risk factors and threats to the system; and to value the adopted resilience investment plans and strategies" (Mansouri, Nilchiani and Mostashari, 2010, 1125). Again, these publications usually analyze the resilience of MITS in a similar way. For instance, robustness, flexibility, adaptability, agility and alignment are mentioned by many specialists as the most important qualities of a resilient system (Lee, 2004, 1). Likewise, the framework used to improve resilience is also a common theme of the literature; it consists of the following steps: assessing vulnerabilities, devising resilience strategies and valuing investment strategies (Mansouri, Nilchiani and Mostashari, 2010, 1126). In the first step, risks or threats to the systems are often separated in four groups: natural disasters, organizational factors, technological factors and human factors (Mansouri, Mostashari and Nilchiani, 2010, 7).

1.4.2 Infrastructure

The literature centered on infrastructure issues is by far the most abundant. Unlike the governance and environment questions, sources of information that deal directly with matters of infrastructure capacity can easily be found. The vast majority of this literature is made of reports published by the private sector or of scientific articles published by specialists or interests groups. In today's literature, scientific articles and company reports focus on three sub-topics.

The first theme is the increase in the East-Asian demand for coal and the effect of that demand on the logistics sector of the exporting countries. As a result of the Chinese demand for coal, exporting countries will have to invest massively in the development of every link of the chain to keep up with it. According to most sources, production is expected to grow more slowly than demand resulting in higher prices on global markets over the next years (Eby Konan and Zhang, 2008, 397).

The second theme is the whole question of capacity and inventory problems that affect the fluidity of the logistics chain due to delays, traffic or poor supply chain management. Even if all coal producers are affected by such problems now and then, Australia's industry seems to be particularly touched by delays and traffic. According to specialists from the Griffith University in Australia, "unanticipated demand, especially from Asia, and the lack of investment in infrastructure within all of the components in the Hunter Valley coal chain has resulted in bottlenecks and capacity constraints leading to an extensive vessel queue off the port of Newcastle" (Zacarias, Fisher and Gapp, 2008, 2).

The third theme that dominates the literature is the dwindling of coal reserves due to increased levels of consumption and numerous downgrading assessments of reserves and resources in many countries. In an article entitled *The end of cheap coal*, the authors mention how "recent studies suggest that available, useful coal may be less abundant than has been assumed – indeed that the peak of world coal production may be only years away" (Heinberg and Fridley, 2010, 367). While this statement might be true, some countries, Russia for instance, still have large reserves and will not hit peak production for many years. Nevertheless, most articles forecast a possible restructuring of the logistics chain. Such changes will have a direct impact on the necessary capacity of present and future storage sites.

1.4.3 Environment

The relationship between the environment and the coal industry is also the topic of many publications. Among the many reasons that explain the rising levels of concern and interest for the protection of the environment, global warming and its harmful impacts on the coal industry and on society in general have been the central topic of a growing number of publications. For this reason, many scientific articles have been written on topics related to the environment and the coal industry. Governments, research groups and private companies have also published their share of articles, owing to a generalized concern for the importance of sustainable development and sustainable practices. The relationship between the coal logistics chain and the environment touch the following themes.

First of all there is an important amount of publication on new environmentally friendly technologies, but more precisely, greenhouse gas mitigation measures. Hence, carbon capture and storage (CCS) has become one of the most promising new technologies. “According to the International Energy Agency, widespread deployment of CCS could account for one-fifth of the needed global reduction in emissions by 2050” (Bowen, 2009, 6). CCS is currently used in many countries in an effort to reduce the negative environmental impacts of the coal using industries. For instance, “coal forms 65% of South Africa’s primary energy supply as well as 95% of the electricity. As the principal indigenous energy source [...] the use of coal is forecast to increase. Therefore, carbon capture and storage is being investigated as a mitigation measure for carbon dioxide emissions. Such a measure is seen as a transition until renewable and nuclear energies can displace fossil fuel energy” (Surridge and Cloete, 2009, 2744). While CCS does not directly involve the upstream part of the coal logistics chain, it is nevertheless pertinent. If CCS establishes itself as a proven effective method of reducing greenhouse gas emissions, a growing number of countries might turn to coal fired thermal plants for the production of electricity. As a result, worldwide demand would increase and coal exporters would need to invest in the development of their infrastructures to keep up.

Similarly, the literature also includes many publications that focus on more indirect methods of reducing greenhouse gas emissions. In this regard, emissions trading and tax policies are the most frequently cited methods. The first method, emissions trading, has been implanted in many regions and is believed to be “theoretically more efficient than regulation. However, there is a strong argument in the literature that emissions trading is less efficient than taxes in the reality of high levels of uncertainty and incomplete information” (Tyler, du Toit and Dunn, 2009, 11). On the other hand, other studies underline the importance of other regulations such as “pure carbon tax [...] on energy-intensive sectors like transport and basic metals. In general, the more targeted the tax to carbon emissions, the better the welfare results” (Devarajan, Go, Robinson and Thierfelder, 2009, II). Besides, one of the most serious and recent studies on this matter was published in June 2011 by the Centre for International Economics. The research considers “in detail the extent to which key coal (sea borne) exporting countries have either imposed, or plan to impose a constraint on fugitive emissions from coal mining as part of their overall approach to greenhouse gas mitigation policy” (Centre for International economics, 2011, 6). While those methods are in effect in many parts of the world, some countries like South Africa appear “to be caught in a time warp with a weak environment policy and a power sector that continues to plan its future in the traditional way. The consequences are: a continued environmental degradation and a high-energy intensive economy with intermittent power supplies" (Sebitosi and Pillay, 2008, 2513).

Finally, the relationship between climate change and the industry is also an important theme in the literature. To be more accurate, the negative repercussions of climate change on the infrastructures are the focus of many publications. The underlying idea is that "by identifying and understanding vulnerabilities, stakeholders, practitioners and regulators can take pro-active approaches to reduce risk. However, our understanding of the implications of climate change for major industrial activities in Canada remains limited" (Pearce, Ford, Prno, Duerden, Pittman, Beaumier, Berang-Ford and Smit, 2011, 348). Recent natural catastrophes like the floods that hit Australia in 2010-2011 add to the importance of studies concerning the repercussions of climate change on coal infrastructures.

1.4.4 Governance

Governance is not a theme that is easily found in the literature. In fact, the publications that actually discuss this issue do so indirectly. The sources that only deal with matters of governance of the infrastructure and its impacts on the logistics chain are almost non-existent. Nevertheless, information on this issue can be found in some publications from the private sector and research groups. To be more accurate, when the governance of infrastructures is mentioned, two topics are usually discussed.

Governance is often studied with a financial approach. In this respect, it is mostly mentioned when new infrastructure projects are launched. For example, when the construction of a third coal exporting terminal on Kooragang Island for the port of Newcastle was announced in 2009, governance was an important aspect of the project. Actually, the project was to be led by Newcastle Coal Infrastructure Group (NCIG), a partnership of fourteen coal producers whose intention was to address capacity problems of the entire industry (Swanepoel, 2010). Furthermore, since the financing of the project will be shared by the government of New South Wales on one side and the partnership on the other, the ownership of the terminal will be split between the parties involved.

On the other hand, governance is also studied because of its impacts on capacity issues of port and railway infrastructures. The literature shows that a debate exists about whether shared use and shared governance of infrastructures is a good thing or not. For example, Port Warath Coal Services (PWCS) who operates two coal terminals in the port of Newcastle argues that "the CUP[3] is constraining coal capacity because new entrants are diluting the volume of capacity from existing companies. But the industry argues that PWCS is obligated to produce increases in capacity of coal throughput at the port to meet the demands for their services" (Zacarias, Fisher and Gapp, 2008, 7). On the other hand, some publications also provide good examples of shared governance. Indeed, the network of infrastructures can sometimes be a good example of cooperation between small mining companies and major transporters like Canadian National (CN) or Canadian Pacific Railway (CP). As stated in *Coal resources in British Columbia: opportunities, logistics and infrastructure*, the governance of the infrastructure in the province is an example of a shared system that has proved its efficiency (British Columbia Ministry of Energy, Mines and Petroleum resources, 2010, 14).

1.4.5 Key performance indicators[4]

Throughout the literature, the most commonly studied indicators of performance are the Key Performance Indicators (KPIs). Similar to other performance measurements such as the result indicators, performance indicators and key result indicators, KPIs are more frequently used and analyzed than their counterparts. In many industries, KPIs have become effective ways of assessing a company's performance. The usefulness of key performance indicators has helped them become a common theme of discussion and study. Many publications have analyzed the applications of Key Performance Indicators KPIs in various industries, organisations or companies. Since KPIs can be used by any given group in any given field of activity such as education, healthcare, transportation, the construction industry or sales & marketing, they have become a valuable set of tools in the eyes of many. The most relevant publications usually

[3] The common-user provision (CUP) is a condition under the lease agreement between the Minister of Public Works and Services of New South Wales and PWCS (Lease 844348K under the Real Property Act 1900 (NSW)). The CUP requires that PWCS "(M)ake available its services to any and every shipper of coal through the Port of Newcastle…under conditions and at a cost for like services that are not discriminatory as between user…" (Zacarias, Fisher and Gapp, 5)
[4] A detailed definition of Key performance indicators is given in section 1.5 of this paper.

include a section on the goals and requirements of effective KPIs. For example, organisations often evaluate their performance using indicators or data that are based on past events and measures. The problem is that such indicators offer little insight on the organisation's future situation. In this sense, winning indicators are useful because “they can not only illuminate where the organization is today but project where the organization will be and provide stability into where key individuals can engage to correct the course for the organization if the forward-looking KPIs are off-track” (Paulen and Finken, 2009, 38). Publications on the subject usually agree on the characteristics and the definition of KPIs which should be, first and foremost, a non-financial data (Vance, 2009, 145). In the case of the coal industry, KPIs are commonly published in internal publications. However, there seems to be a lack of scientific publications based on the use of KPIs analyzing the performance of the industry.

In conclusion, this review of literature has made it clear that the various publications that concern the coal industry do not really study the importance of resilience. In fact, the majority of the literature is more concerned about the environmental impacts of the coal industry or the infrastructure's ability to sustain the rising levels of demand. While publications on resilience exist, they usually only concern the maritime industry and, more specifically, container transportation. The issue of resilience throughout the coal industry's logistics chains remains to be studied. For this reason, this paper can be considered as a first step in that direction.

1.5 Methodology

The international coal industry is a vast and complex system where the increase in activity has allowed logistics networks to be increasingly connected to one another. For this reason, it is almost impossible to study the industry in one country without mentioning or noticing outside influences. Keeping this in mind, this research is limited to three case studies. The three countries studied in this research have been chosen because together, they represent the most common examples of coal exporting countries. Canada, Australia and South Africa are very different coal producers and exporters. Canada's reality is that of a minor player on the world stage with export levels inferior to most coal exporting countries. South Africa represents a player of medium importance. Even if the country is part of the Big Six, it only has 8.6% of world reserves (Hook, Zittel and Aleklett, 2008, 3). On the other hand, Australia is a much bigger and important player on the world stage. With 233 million tons exported in 2006, it «is by far the world's leading coal exporter» (Hook, Zittel and Aleklett, 2008, 3). In other words, these countries have different realities and, based on the size of their coal industry, they may have different problems or success stories. Furthermore, the dynamic of the logistics chain and its relation with outside influences are consequently not the same in each of the three countries. By selecting them, it is more likely to have an accurate view of what the logistics sector looks like in most of the coal producing countries.

Concerning the links of the logistics chain that were chosen for this research, it is important to realize that only the activities of the upstream section of the chain have been considered. Because coal production and exportation are the focus of this research, what happens after the coal has been exported by seaborne transport is irrelevant. Hence, only the issues that touch the following three links will be tackled: extraction, railway transport and port activities.

Geographic framework

The coal industry is usually made of a large and complex network of companies and operations scattered over large geographic areas. In exporting countries, more than one cluster of mines, rail networks and ports of exportation can usually be found. For the sake of clarity, this research uses geographic frameworks based on the idea of corridor. The reality of each country will be studied through the limits of these corridors. Table II summarizes the basic geographic features of corridors that will be studied in this research. It is also important to mention that while most countries have more than one major port of exportation, the case studies of this research include the most important mining networks and port of exportation in terms of volume exported.

Table II: The coal exporting corridors.

Country	Location of major mining networks	Location of the associated ports of exportation
Australia	Hunter Valley coal logistics network in New South Wales[5]	Port of Newcastle (NCIG coal terminal, Kooragang coal terminal and Carrington coal terminal)
South Africa	Mpumalanga province	Richards Bay Coal Terminal (RBCT)
Canada	British Columbia and Alberta	Port Metro Vancouver (Westshore Terminals and Neptune bulk terminal)

Data Collection

The information and data used in this paper come from various sources, including scientific articles, publications from experts groups, annual reports and other publications from the private sector. The process of collecting and analyzing relevant data has been one of the most important tasks of this research. Due to the comparative nature of this research, the need to find comparable data for all three case studies was ever present. Furthermore, since each of the core chapters is based on very different variables, relevant data and information had to be collected from sources related to many fields of study. For example, most of the data contained in chapter 3, which is centered on the question of infrastructures, was found in annual reports, scientific articles and special publications by port authorities, service providers and consultants. This data usually contained technical information or operational data of various transport or

[5] While as a whole, the state of Queensland might produce and/or export more coal than the state of New South Wales, the largest Australian coal exporting logistics chain is the Hunter Valley coal logistics chain which is found in New South Wales. For this reason, logistics networks in Queensland have not been considered in this paper.

terminal infrastructures. For chapter 4, most of the relevant data came from scientific articles in the fields of meteorology, seismology and hydrology. National scientific institutions such as *Environment Canada*, *Geosciences Australia* and the *Council for Geosciences of South Africa* also provided a wealth of valuable information. Again, chapter 5 was written with information taken sources containing data on corporate planning and development strategies, industrial assets and international coal markets. Here, annual reports and special publications of the private and public sectors on development strategies were the most useful sources of information. This being said, the task of gathering data from various sources of information was, in itself, not sufficient. To answer the needs of a comparative study, the collected information also needed to be sorted. This second step was necessary to ensure that all case studies could be evaluated and compared on similar criteria. The process of comparing and analyzing data was the final task of this research. The core research chapters of this paper were constructed thanks to this collect, sort and compare process.

Measuring resilience

A system's ability to avoid failures caused by disruptive events and its ability to protect itself against potential risks before they happen is a notion that needs to be measured before it can be implemented. Furthermore, since the concept of resilience refers to the flexibility, robustness and efficiency of a system, the criteria used to measure it must be chosen accordingly. In many companies, performance levels of a system are measured using KPIs. Acting as operational level measurements, they help "achieve the overall objective of reducing costs within the supply chain" (Berman, 2006, 72). KPIs can be defined as "a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization" (Parmenter, 2007, 141). To be effective, they need to be kept to a manageable number. Moreover, KPIs need to be measured on a regular basis and need "to be reported in a timely manner". By nature, they can be expressed as absolute numbers or ratios (Berman, 2006, 81). Hence, in the context of this research, the most critical aspects of organizational performance are:

1- **The need to operate close to full capacity (without reaching it) as often as possible.** While operating close to full capacity, the industry maximizes revenues. Therefore, an industry operating close to full capacity will gain positive outputs and comparative advantages over its competitors.

2- **The need to maintain the level of fluidity[6] of the logistics chain as high as possible**. By taking the necessary steps to maintain fluidity in the chain, the industry reduces the likelihood and the impact of disruptive events on the system.

Both of those aspects are signs of a system's resilience. By focusing on those two needs, the coal industry may take positive steps towards a more resilient system of operations and will increase its chances of success in the current economic context. However, KPIs can only be used to measure variables that are related to the productivity of logistics chain, but cannot be used when analyzing environmental hazards and governance. To be accurate, it is important to understand that analyzing natural hazards is in fact a way to assess the risks of external factors on the logistics chain and, as stated in section 1.4.1, assessing risks to a logistics chains is an important step in analyzing and improving resilience. In the same way, studying governance is in fact a way to assess the impacts of decisions, segmentation within the industry and the handling of power.

Therefore, the task of measuring resilience will not be based on KPIs as is usually the case since. The three core variables of this research cannot be studied by a single family of indicators. Since KPIs must be evaluated and reported on a daily or weekly basis, they are actually not designed to study the indicators chosen for this variable. For infrastructures, the indicators chosen (as seen further on in this section) must be reported on a monthly or quarterly basis which prevents the use of KPIs. For the second variable, assessing the impacts of environmental hazards on the logistics chain has nothing to do with performance or productivity. Such an assessment actually comes down to analyzing the risk that such hazards pose on the logistics chain and requires risk indicators. For the third variable, the relationship between governance and logistics chains has nothing to do with performance or productivity. It is in fact a way to measure the impacts of power structure, decision making and industry segmentation. In other words, in the third chapter of this paper, when the resilience of infrastructures will be analyzed, infrastructure

[6] Fluidity refers to the ability of a system to move products through the various links of the chain without disruptions or delays.

indicators (IIs) will be used to analyze productivity and performance. In the fourth chapter, risk indicators (RIs) will be used to analyze the risk of environmental hazards for the logistics chains. Finally, in the fifth chapter, governance indicators (GIs) will be used to study the impacts of decision making, segmentation and power structure on the resilience of logistics chains.

The role of three groups of indicators will be to show how each variable affects the resilience of the logistics chain. Taken individually, they only analyze one side of resilience. However, taken as a whole, these indicators offer an accurate and much more complete understanding of the elements that affect a system's resilience.

To measure resilience, each II, RI and GI will be worth a maximum of three points. Each corridor will be given a score of one, two or three points depending on how resilient it proved to be for a given indicator. Points will be assigned in accordance to ranges and values that will be established for each indicators. The actual methodology is explained in detail in chapters 3,4,5 where the following indicators are used. The indicators used in chapters three, four and five are the following:

a) Infrastructure (IIs):
   - Train capacity;
   - Capacity utilization of port infrastructures;
   - Stockyard capacity; and
   - Loading equipment operating rates.

b) Environment (RIs):
   - The vulnerability of the logistics chain to seismic hazards;
   - The vulnerability of the logistics chain to hydrologic hazards; and
   - The vulnerability of the logistics chain to atmospheric hazards.

c) Operational environment (GIs):
   - The efficiency of planning and development strategies;
   - The industry's corporate concentration in the extraction sector;
   - The industry's corporate concentration in the railway transportation sector;
   - The industry's corporate concentration in the port activities sector; and
   - The diversity of the industry's portfolio of clients on world markets.

One of two different marking systems will be used to award scores for each indicator. Each indicator will either have two or three possible values as shown in table III. The indicators and ranges of table III are only random examples, but its value system will be used for all indicators[7]. Concerning the possible categories of ranges, the literature has provided the necessary data to establish ranges for each indicator.

Table III: The possible marking systems used to award scores in each of the indicators.

	Range	**Value**
Marking system# 1 **Example #1:** **Indicator X**	1: From 1 to 10 hours 2: From 11 to 30 hours 3: More than 30 hours	3 2 1
Marking system# 1 **Example #2:** **Indicator Y**	1: More than 91% 2: From 71 to 90% 3: From 0 to 70%	3 2 1
Marking system# 2 **Indicator Z**	Yes or no type of indicator: Yes No	 2 0

[7] Depending on the wording of the question, the value system for "Yes or No" questions could also be reversed i.e. Yes=0 No=2 .

1.6 The scope and limits of this study

As one of the most dynamic sectors of the mining industry, the coal industry has to be examined on a worldwide scale. Moreover, the nature of this industry can be explained by geographic and economic factors. Unlike other fossil fuels, such as oil or natural gas, coal reserves are still abundant and spread in many regions of the globe. Accordingly, the various activities associated with the coal industry take place in many regions and countries around the world giving it a global and international character. Likewise, the nature of the coal industry, based on the activities of the various actors at every level of the logistics chain, also needs to be approached on a world-wide scale.

World coal transactions amongst the various actors located all around the world are possible by the use of large bulk carriers. The business of trading and moving coal has become a matter of global importance. “Since 1970 world coal demand has increased by more than 60 percent, which is even faster than the increase of world demand for oil, but the most significant increase has though been on the world market of traded coal, which increased by over 230 percent during the same period. This development has, during recent years, led many analysts to consider the international coal market as an essentially unified global market” (Warell, 2006, 1). For this reason, the coal industry cannot be studied by using only a local, regional or even national scale. The mechanisms that are inherent to this industry’s logistic chain are more often than not, influenced by worldwide factors.

For any undertaking, the improvement of the logistics sector is a logical procedure because it allows a permanent reduction in costs and time wasted due to inefficiencies. In other words, the improvement of the logistics sector is just like optimizing of a computer or repairs on a car after a maintenance check. It is a useful operation because it has the ability to improve performance and reduce costs in the long-term. In this regard, this research paper will not only be useful because it will contribute to the advancement of the research in the logistics sector for the coal industry, but mainly because it will be a useful tool for governments and private companies to plan future investments and modifications in the logistics sector of the industry.

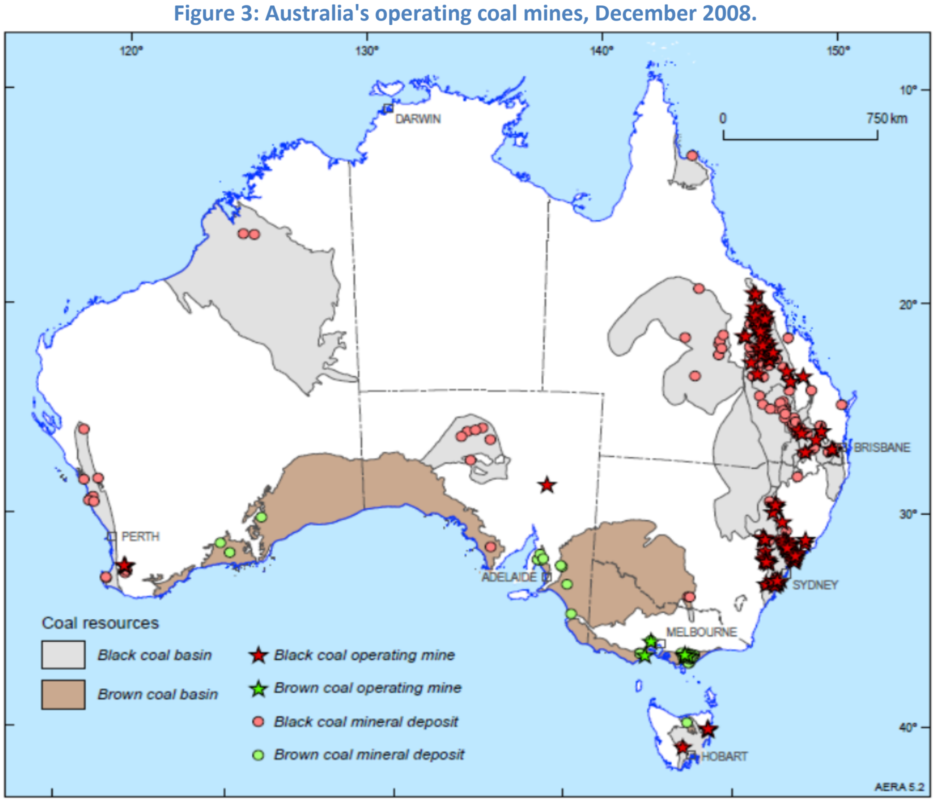
The difficulty to find and use indicators that can evaluate every variable of a system's resilience is the most important limit of this study. Since performance, risk and governance cannot be evaluated by a single family of indicators, the resilience of logistics chain can only be evaluated separately for each variable. In the same way, the inability of KPIs to evaluate variables other than performance has made it more difficult to analyze the second and third core variables. To overcome this limit, indicators suited to the nature of each variable have been created. The lack of scientific research on the resilience of logistics chains in the coal industry has also been a limit to this study since the methodology and results of this paper cannot be compared to previous comparative studies of resilience in the coal industry.

Chapter 2: Australia, South Africa and Canada's export corridors.

2.1 First Case Study: Australia's export corridor.

As the fourth largest producer and largest coal exporting nation in the world, Australia is a major player in the world coal market. The country's rise to the top can be explained by the abundance of low-cost high quality reserves of both metallurgical and thermal coal. Based on 2010's assessments, the country's reserves of black coal were evaluated at 44 billion tonnes or 7% of the world's total (Australian Coal Association, 2011, 1). Similarly, Australia's coal resources were estimated at 308.1 Gt. Therefore, the importance of the nation's reserves could allow it to remain a major player for many years to come (Australian Bureau of Agricultural and Resource Economic Sciences, 2011, 142).

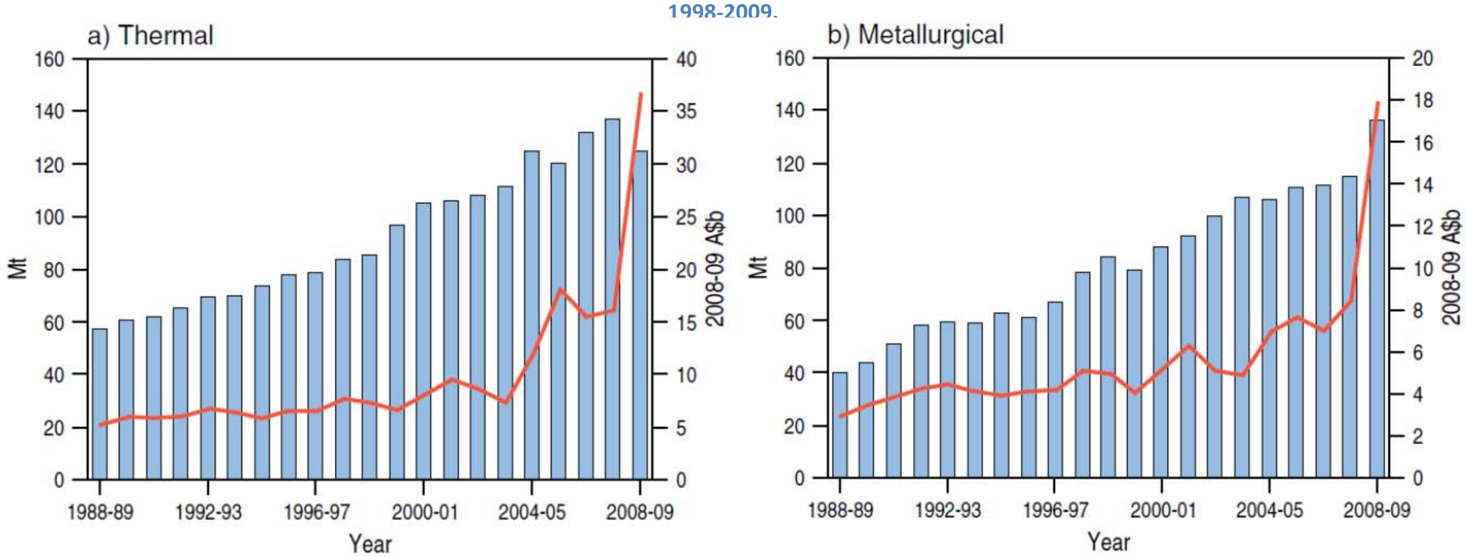
Figure 3: Australia's operating coal mines, December 2008.



Source: Australian Bureau of Agricultural and Resource Economics and Geoscience Australia, 2010

In 2007-2008, Australia produced a total of 421Mt of black coal of which it exported 252Mt on the world market (Hook, Zittel and Aleklett, 2008, 34). Similarly, Australian coal exports in 2008-2009, which amounted to 262Mt, went to Japan (40%), South Korea (16%), India (10%), Taiwan (10%), China (10%) and the European Union (6%) (Australian Coal Association, 2011, 1). The quality of the country's reserves of both thermal and metallurgical coal[8] has allowed the industry to export high volumes of both types of coal over the years. Figure 4 shows how export volumes and value (the red line represents the value of exports in A$b) have been constantly rising for twenty years between 1988 and 2009.

Figure 4: Australia's export volumes of thermal and metallurgical coal, 1998-2009.

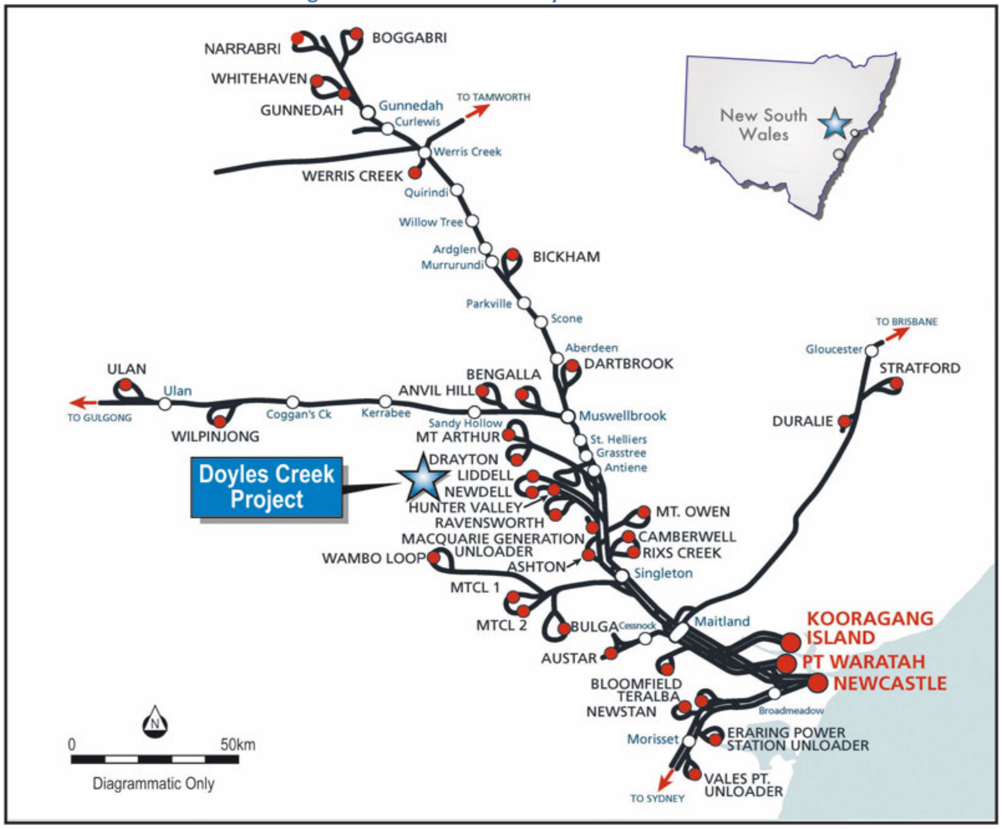


Source: Australian Bureau of Agricultural and Resource Economics and Geoscience Australia, 2010

The states of Queensland and New South Wales accounted for the majority of this production: 57 per cent and 41 per cent respectively (Australian Bureau of Agricultural and Resource Economic Sciences, 2011, 146). The concentration of Australia's coal mines in those two states is clearly shown in figure 3. The first case study of this research is based on a segment of the New South Wales mining cluster commonly referred to as the Hunter Valley Coal Network. Located in the Sydney basin, one of the largest coal basins of the country, the Hunter Valley Coal Network, as shown in figure 5, is controlled by the Hunter Valley Coal Chain Coordinator Limited (HVCCC).

[8] Steam coal and thermal coal are synonyms that designate coal that will be used in power plants to create electricity. Similarly, coking coal and metallurgical coal are synonyms that designate coal that will be used in steel mills to create steel.

Figure 5: The Hunter Valley Coal Network.



Source: NuCoal, 2011

Made up of coal producers and service providers, it is "the largest coal export operation in the world"[9] whose major highlights are:

- Approximately 35 coal mines owned by 13 coal producers;
- Two Coal Terminals with a 3rd Terminal under construction; and
- The movement and loading of more than 1000 coal vessels/year from the Coal terminals through the Port of Newcastle[10].

This dense network of mines and railways stretches several hundred kilometres inland with its base at the Port of Newcastle which is the busiest coal exporting port in the world. Figure 5 gives a general overview of the mining sites and railways under the jurisdiction of the HVCCC.

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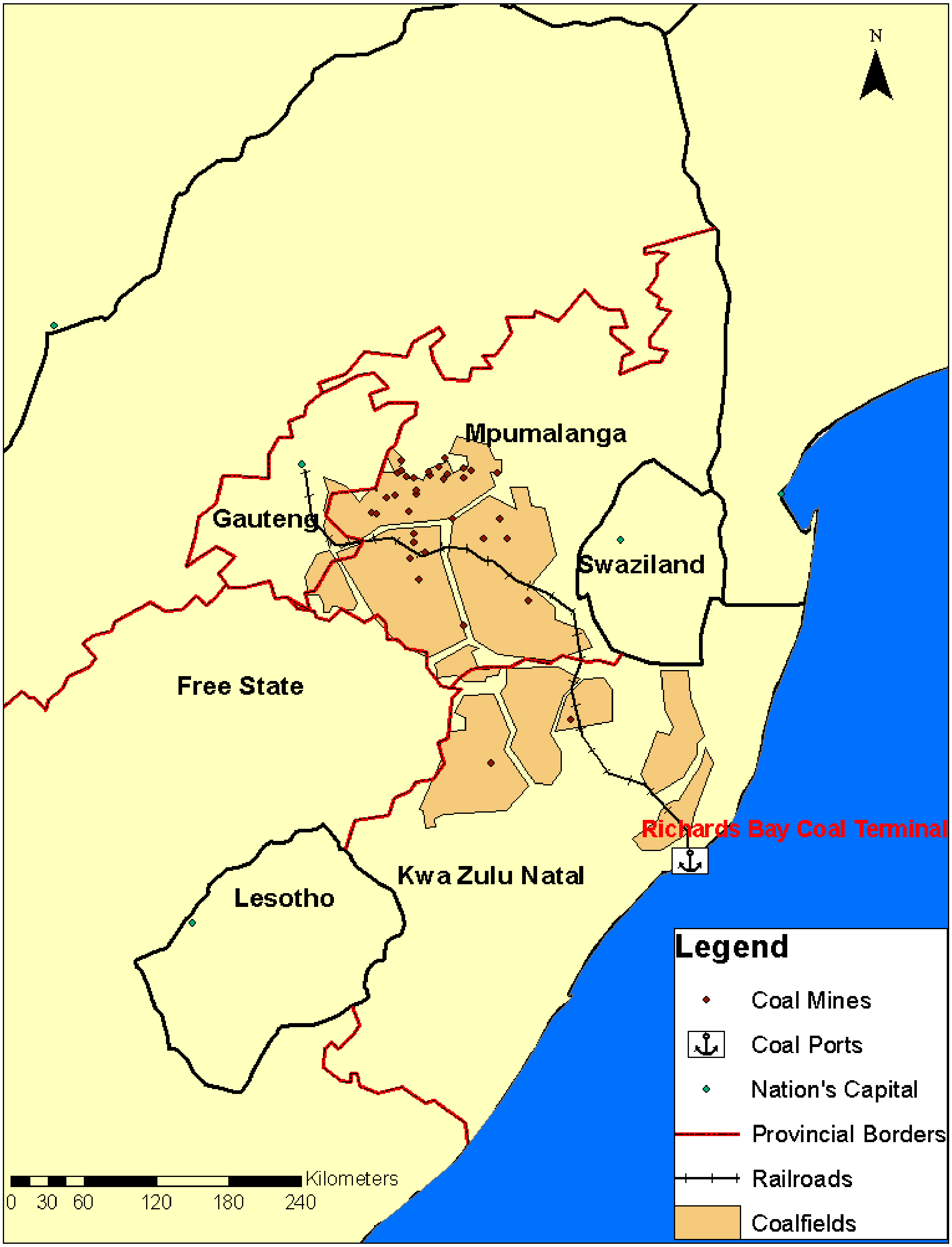
[9] Hunter Valley Coal Chain Coordinator, "History," Hunter Valley Coal Chain Coordinator, http://www.hvccc.com.au/AboutUs/Pages/History.aspx (accessed November 2, 2011).
[10] Ibid.

2.2 Second case study: South Africa's export corridor.

According to a 2010 report published by the Department of Energy of the Republic of South Africa, the country's proven coal reserves are estimated at 48Gt or 5.7% of the world's total coal reserves (Moses Maleka, Mashimbye and Goyns, 2010, 22). However, even if the country's reserves seem abundant, South African coal suffers from a certain number of disadvantages. First, the industry has access to average quality deposits since "South African coal is nearly all bituminous, with very little anthracite. It is generally of low quality with high ash content" (Moses Maleka, Mashimbye and Goyns, 2010, 22). Furthermore, the remaining low-grade reserves are more difficult to mine compared to past decades. Since the biggest sites have already been exploited, current and future mining operations will be "smaller and more complex" (Hook, Zittel and Aleklett, 2008, 36). Finally, South Africa's low grade coal usually goes through a washing process to improve its quality for the international market. However, such a process is problematic since coal washing results in a portion of the production being transformed into unusable coal discards. Moreover, since coal discard is essentially made of impurities it cannot be used and is therefore stockpiled (Hook, Zittel and Aleklett, 2008, 36). While the washing of coal has allowed the industry to overcome the disadvantage of low-grade coal, low pit head costs and low sulphur levels add to its competitive advantages (Moses Maleka, Mashimbye and Goyns, 2010, 29).

As shown in figure 6, the country's main mining cluster is located in the Mpumalanga province which accounts for 83.8% of South Africa's production (Winkler, 2006, 46). This mining cluster, the railway network used by coal trains and the port of Richards Bay which exports most of the country's coal represent the geographic framework of the corridor studied in this research. Although the number of mining operations exceeds 50, a small number of key players control most of the production. The country's main market for exportation is Europe, which accounts for approximately 60% of total exports, while the remaining exportations go to countries located in the Pacific region. The main product of exportation is bituminous grade steam coal since South Africa's production of coking coal is almost non-existent (Maleka, Mashimbye and Goyns, 2010, 25). Production of coal in South Africa is expected to keep on growing until 2020 at a production peak of 284Mt / year (Hartnady, 2010, 1).

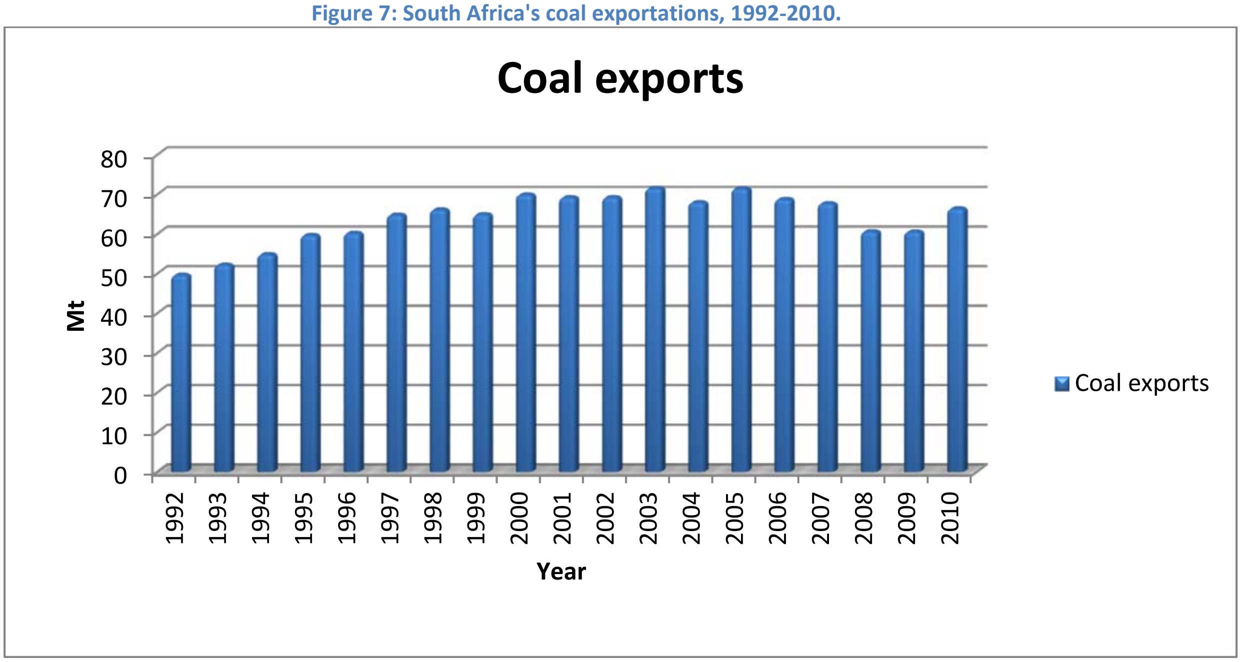
Figure 6: An overview of the Mpumalanga coal corridor.



Source: Sefiane Benyahia, 2012

As shown in figure 7, coal exports have risen from 50Mt in 1992 to more than 70Mt in 2005. Since then, export levels have dropped and remained stable between 60 and 68Mt. Since total production volume in 2010 had already reached 254.52Mt (Chamber of mines of South Africa, 2011, 17), South Africa's production is expected to grow slowly until it reaches peak production in 2020. Thus, export levels should also keep on growing slowly until 2020.

Figure 7: South Africa's coal exportations, 1992-2010.



Sources: (Subramony, Jeff *et al*, **2009) and (Chamber of mines of South Africa, 2010)**

2.3 Third case study: Canada's export corridor.

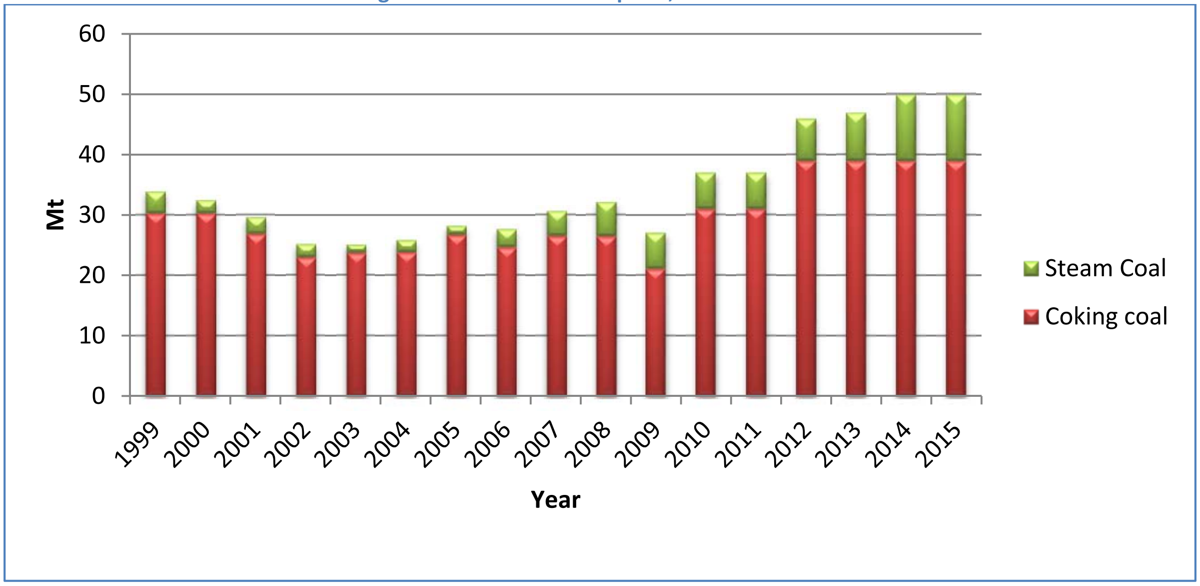
According to BP's statistical review of World Energy 2011, Canada is currently the 13th most important coal producing nation in the world (BP, 2011, 32). With productions of 69.1 Mt in 2007 and 67.8 Mt in 2008, Canada has managed to keep its position among the world's top coal producing countries (Stone, 2010, 25). Canada can be seen as a small to medium coal producer and exporter. The country possessed about 6.6 billion tons of proven recoverable coal reserves (0.74% of the world's 2008 proved recoverable reserves (World Energy Council, 2010, 10)) and 193 billion tons of resources[11] (Stone, 2010, 2). With such abundant resources, the Canadian coal industry could remain in operation for many years to come. However, as stated in «*A supply driven forecast for the future global coal production*», «the last assessment of the coal reserves was conducted in 1987» (Hook, Zittel and Aleklett, 2008, 39). The industry could therefore benefit from updated assessments of coal reserves for future planning and development.

Coal production in Canada is mainly used for domestic purposes. In 2008, only 40% of the country's production was exported. Coking coal represented more than 80% of the exports since Canada's energy demands required most of the national production of thermal coal (Stone, 2009, 5). Figure 8 shows two important realities linked to Canadian coal exportations. First, coking coal has always accounted for most of the exports. Second, overall export levels have been rising since 2003 and are expected to follow this trend until at least 2015.

In 2008, Canada exported coal to three major markets namely Asia (63% of total exports), Europe & the Middle-East (22% of total exports) and Americas (15% of total exports) (Stone, 2009, 14). In 2009, there were 22 operating mines in Canada located for the most part in the provinces of British Columbia and Alberta. Furthermore, a few mining companies have ongoing mine development projects that should increase the number of operational mines and the national production capacity in the upcoming years.

[11] «The logic of distinguishing between *reserves*, which are defined as being proved and recoverable, and *resources*, which include additional discovered and undiscovered inferred/ assumed/ speculative quantities, is that over time production and exploration activities allow to reclassify some of the resources into reserves» (Energy Watch Group, 2007). In simpler terms, the word *resources* is used for coal we think we have while *reserves* is used for coal we know we have.

Figure 8: Canada's coal exports, 1999-2015.



Source: (Kevin Stone, 2009 Coal report, 2009) and (Kevin Stone, Coal in Canada, 2009)

Most coal mines extract thermal coal which is sent to power plants across the country. As a result, not all mines in operation are active on the export market. Stretching across the provinces of British Columbia and Alberta, Canada's coal corridor includes 11 of the country's 22 mines. As shown in figure 9, two main coal railways link the corridor's mines to Westshore Terminals and Neptune Bulk Terminals, both located in Port Metro Vancouver.

Figure 9: An overview of Canada's coal corridor.

Source: Sefiane Benyahia, 2012.

Chapter 3: Analyzing the relationship between the infrastructures and the resilience of the logistics chain.

Infrastructures have a direct impact on the resilience of a logistics chain. Infrastructures that are numerous, adapted to the chain’s level of activity, in good condition and answer the needs of its users often indicate higher levels of resilience. While a high level of resilience allows an industry to absorb or prevent the negative impacts of harmful events, it also plays a major role in the performance, success and profitability of the system. On the contrary, infrastructures that are old or overloaded will reduce the resilience of the entire system. In this respect, the goal is to get “supply chain management right. This means resolving issues around infrastructure development, [...]and ongoing management to allow the minerals industry to expand and get as many commodities to market as possible” (Access Economics, 2008, vi). However, maintaining high levels of resilience through better supply chain management practices is not an easy task: accurate methods of measurement, evaluation and analysis must be used in order to achieve that goal. A set of carefully chosen IIs that study the effects of coal mining infrastructures on the resilience of the logistics chain is the best tool available for such a task. In this section, infrastructures will be evaluated with the help of the following four IIs:

- Train capacity (Mine to port measurement);
- Stockyard capacity (Stock yard measurement);
- Capacity utilization of port infrastructures. (Stock yard measurement); and
- Loading equipment operating rates (Waterside measurement).

Each II will have its own evaluation system which will be explained at the beginning of each section. At the end of each section, the logistics chain of each corridor's coal industry will receive a score based on its performance.

3.1 II#1: Train capacity.

The first II of this research measures the performance and resilience of the railway transportation link of the logistics chain. In the coal industry, railway transportation plays a vital role as the main and often only suitable method of transporting coal from mine to port. As demand for coal grew, so too did the need to move larger quantities of coal. The concept of economies of scale provided the solution and much like maritime transportation, led to the emergence of gigantism. For railway transportation, gigantism led to the creation of longer and heavier trains with cars capable of carrying more and more raw materials. For railway transportation, the application of economies of scale has the following four advantages:

1. Trains with more capacity can transport higher quantities of raw materials each run.
2. By increasing the capacity of a train, the industry reduces the number of journeys or the number of trains necessary to transport the required quantity of coal.
3. By reducing the number of journeys or trains required to transport a certain quantity of coal, the industry also reduces transportation costs.
4. These advantages allow the industry to save money by maximizing profits and reducing operating costs.

Therrien's definition of resilience underlines the reason why trains with increased capacities improve the industry's resilience. Bigger trains allow the industry to keep up with demand and avoid shortages caused by the industry's inability to get the necessary amount of coal to the client in time. Furthermore, bigger trains allow the industry to reduce congestion problems and reduce the likelihood that disruptive events caused by congestion (i.e. delays and derailments) ever happen.

For II#1, the capacity of coal trains is measured for each of the three case studies. The trains with the highest capacities can be seen as the most efficient in maintaining high levels of resilience in the railway transportation link of the industry. Table IV shows how the marking system of KPI#1 identifies which case study is the most resilient.

Table IV: Marking system for II#1.

Corridor	Value
Corridor in which coal trains have a capacity superior to 15 001 tons.	3
Corridor in which coal trains have a capacity between 9001 and 15000 tons.	2
Corridor in which coal trains have a capacity between 1 and 9000 tons.	1

Hunter Valley coal corridor

According to the "Australian Rail Track Company" which owns the Hunter Valley's coal railway infrastructure, six different train configurations are used to transport coal. The configurations range from 2000 tons for the smallest trains to more than 10000 for the largest. The configuration which has the highest capacity is made of 91 cars with a capacity of 120 tons each (Australian Rail Track Corporation, 2008, 6) for a total capacity of 10920 tons.

Mpumalanga coal corridor

South Africa's coal moving company, "Transnet Freight Rail", has a monopoly on all coal transportation in the country. The company operates "two 100 wagons trains coupled to form one 200 wagons train[12]". Transnet's trains use cars with a capacity of 104 tons (Thompson, 2009, 9) for a total capacity of 10400 tons for each 100 cars train and 20 800 tons for the 200 wagons train actually being used.

Canadian coal corridor

Canada's coal trains are operated by CN and CPR. Both companies have somewhat similar transportation procedures. According to Richard, transportation economist at Transport Canada, CPR currently operates trains of 142 cars with cars from 110 (for the older steel cars) to 120

[12] Transnet, "Coal," Transnet, http://www.spoornet.co.za/Website/coal.html (accessed December 1, 2011).

tons(for the new aluminum rotary gondolas which have almost entirely replaced the smaller steel cars)[13]. CPR's coal trains have a total capacity of 17040 tons. In the same way, CN currently runs trains of 145 cars using new aluminum cars of 110 tons for a total train capacity of 15950 tons (Gurpreet, 2009, 10).

However, although train capacities are important, their benefits can be nullified by external factors. For example, railway capacity constraints in Australia and South Africa have cancelled out some of the benefits of operating high capacity coal trains. In Australia, railways “have not kept up with the growth demand for new coal mines” (Rademacher, 2008, 78). As a result, rail capacity utilization remains high despite plans to eliminate bottlenecks and traffic problems. In such a context, resilience levels are low due to inherent risks and permanent strain on the systems, which favours the occurrence of disruptive events. Similarly, Transnet's 200 wagon trains have not been able to raise resilience levels because chronic and repetitive train derailments plague the industry. In South Africa, “derailments are not uncommon” (Eberhard, 2011, 22). Frequent and numerous train derailments are caused by “unreliable infrastructure, such as signal failures, [...] cable theft and [...] locomotive reliability problems” (Creamer, 2011). Another consequence of these problems is that operations in coal terminals are often suffering from the backlash of the rail sector's issues. Port terminals in Newcastle and RBCT are not operating as well as they could be because of the rail sector's inability to transport enough coal to the terminals (this issue will also be mentioned in section 3.3). On the other hand, the Canadian coal industry's resilience exceeds that of its competitors because of CN and CPR's ability to operate high capacity trains, but also because of few traffic and derailment problems made possible by the country's “well developed, reliable and efficient” (Ritschel and Schiffer, 2007, 85) infrastructures. For all those reasons, the II scores of section 3.1 must not be considered as an indicator of the efficiency of railway transportation, but as a strict indicator of transport capacity. If the goal of this II was to evaluate the efficiency of the overall railway transportation sector, the Canadian corridor would be first, followed by the Hunter Valley corridor and finally, the Mpumalanga corridor.

A likely explanation to Canada's ability to run longer trains and its competitors’ inability to do so relies in part in the quality and support capacity of its railways. When traveling on a track segment, trains create impacts that are a result of weight and/or speed. As speed and/or weight

[13] Rod Richard, e-mail message to author, January 27, 2012.

increases, the level of impact also increases which, in time, can damage tracks and provoke derailments. Each track of a railroad can support a certain level of impact which is known as axle load (Australian Rail Track Corporation, 2008, 25). For bulk transportation, this is particularly important since “increases in axle load (while holding speed constant) can obviously increase tonnage carried per wagon” (Australian Rail Track Corporation, 2008, 25).

In Australia, coal trains travel on the Hunter Valley rail network. According to the Australian rail Track Corporation, Hunter Valley's network has a 21 to 25 tons axle load with a few small sections at 30 tons (Australian Rail Track Corporation, 2008, 25). South Africa's coal railroads which link the Mpumalanga province to Richards Bay have a 25 axle load (according to Thompson, 2009, 9) or a 26 axle load (according to Kuys, 2011, 7). Finally, Rod Richard of Transport Canada states that Canada's coal lines have a maximum gross weight (combined weight of the tare of the railcar plus loaded product) of 286 000lbs which is worth 32.5 tons (Australian Rail Track Corporation, 2007, 32). The Australian, South African and Canadian standards for axle load explain why CPR and CN can successfully operate trains with higher capacity. Track segments in Canada can sustain higher levels of impact without danger which allows train operators to operate longer, heavier and higher capacity trains.

3.2 II#2: Stock yard capacity.

The capacity of a terminal's stock yard has a direct influence on the resilience of the chain. Resilience is, by definition, based on the ability to reduce both the magnitude and duration of a disruptive event. Large stock yards have that ability by allowing a terminal to operate even if disruptive events interrupt the flow of coal to the port. In other words, a terminal with large stock yards will use its on-site reserves and will be able to operate normally until the disruptive event such as a train derailment or a mine accident is resolved. Thus, the effects of any unwanted event that affects the logistics chain will be less problematic and less damaging. Stock yards are buffers necessary to the well-being of the industry. However, the size of a terminal's stock yard is linked to its level of activity. Terminals which export high quantities of coal have higher stock yard capacities than stock yards which export less coal. For this reason, RBCT and the three coal terminals of Newcastle Port have larger stock yards than those found in Port Metro Vancouver. Comparing stock yards capacity in absolute numbers can therefore be misleading and give a false impression of a terminal's stockyard's usefulness as a buffer. A much more accurate way of evaluating the role of stock yards on the resilience of the industry is to analyze the ratio between stock yard capacity and total exports in a year. This ratio indicates how much of total coal exports a terminal's stock yard could store at all times. A higher percentage is a sign of higher resilience levels. Table V shows how this result will be calculated.

Table V: Marking system for II#2.

Port	Exports (Mt) to stockyard capacity ratio (Mt).	Value
Port with an export to stock yard capacity ratio superior than 11%.	(Total exports/stock yard capacity)*100	3
Port with an export to stock yard capacity ratio between 6% and 10.99%.	(Total exports/stock yard capacity)*100	2
Port with an export to stock yard capacity ratio between 0% and 5.99%.	(Total exports/stock yard capacity)*100	1

The table's range of ratios were established to reflect the export to stock yard capacity ratio usually found in large coal terminals. Table VI includes the stock yard capacity of Newcastle Port's three coal exporting terminals, (Newcastle Coal Infrastructure Group's terminal (NCIG), Kooragang Coal Terminal and Carrington Coal Terminal) South Africa's RBCT and Port Metro Vancouver's Neptune Bulk Terminals and Westshore Terminals. The stockyard capacity to export ratio (both in tons) is expressed in percentage.

Table VI: Stockyard capacity to export ratio[14].

Ports	2010 stockyard capacity to export ratio.
Newcastle Port	((3.5+1+6)/108.26)*100 = 9.7%
Richards Bay Coal Terminal	(8.2/62.86)*100 = 13%
Port Metro Vancouver	((2.2+0.6)/30.3)*100 = 9.2%

Richards Bay Coal Terminal ranks first with a score of 3 because its stockyards could hold 13% of all exported coal in 2010 giving the industry a higher resilience. Newcastle Port, with 9.7% comes in second place for a score of 2. Finally, Port Metro Vancouver follows closely behind its Australian counterpart with 9.2% and a score of 2. It is important to note that recent development projects at Newcastle Port and Richards Bay have had a great impact on the results presented above. Indeed, NCIG's terminal and Richards Bay Coal Terminal's Phase V expansion projects were completed in 2010, adding extra stockyard capacity to both ports and boosting the ratio of their stockyard capacity to export. On the other hand, no new development project has been recently completed at Port Metro Vancouver.

[14] For the source of table 5's export volumes, see section 3.3. For stock yard capacities data:

- Newcastle Port Corporation, "Facilities," Newcastle Port Corporation, http://www.newportcorp.com.au/site/index.cfm?display=111681 (accessed January 31 2012).
- Woolaston, Andrew, "Development of the NCIG coal export terminal," Australian Bulk handling review, http://www.bulkhandling.com.au/pdfs/abhr-novdec34-37.pdf (accessed January 31 2012).
- Richards Bay Coal Terminal Company Proprietary Limited, "Welcome," Richards Bay Coal Terminal Company Proprietary Limited, http://www.rbct.co.za/ (accessed January 31 2012).
- Westshore Terminals, "Equipment," Westshore Terminals, http://www.westshore.com/stackers.html (accessed January 31 2012).
- BRITISH COLUMBIA MINISTRY OF ENERGY, MINES AND PETROLEUM RESOURCES, *Coal resources in British Columbia: Opportunities, logistics and infrastructure* Vancouver: British Columbia Ministry of Energy, Mines and Petroleum Resources, 2010, 17.

3.3 II#3: Capacity utilization of port infrastructures.

Capacity utilization reflects many features of a port's infrastructure and performance. It is an indication of a port's level of activity since it represents the ratio between the total amount of coal exported in a year and a port's total capacity at a given year. Thus, two pieces of information are needed to assess a port or terminal's capacity utilization. First, this II requires the maximum capacity (in millions of tons) that a port can process in a year. Second, it requires the volume of coal (in millions of tons) that is exported by the port in any given year. The ratio, expressed in percentage, shows the level at which the infrastructures are used in a year. Evaluating an ideal capacity utilization level is a subjective task. In the present case, the need to maintain resilient port infrastructures will determine the desired values of capacity utilization in accordance with the following condition. A port must have excess capacity that can be used to react to any disruptive event or any sudden spike in demand levels. This condition will allow a port to raise capacity utilization without overusing the infrastructures (more than 100% capacity utilization).

An ideal capacity utilization level would therefore mean that the infrastructures are being used to high levels without ever going over their maximum capacity. A percentage too close to 100% is also not desirable since any disruption affecting capacity or operations would result in an overuse of the infrastructure. On the other hand, a capacity utilization percentage that would be too low means that the infrastructures are not being used to their full potential. Therefore, a capacity utilization ranging from 85% to 90% is ideal for the following two reasons. First, it shows a high level of activity and appropriate use of the infrastructures. Second, it leaves enough flexibility to allow operations to continue normally even with a loss in capacity due to unforeseen disrupting events. Average capacity utilization ranging from 85% to 90% will be considered as the best possible result with a value of 3. Average capacity utilization below 75% and 85% will be considered as an average result with a value of 2 because it indicates lower levels of activity and/or underused infrastructures. Finally, the worst result, with a value of 1 will be given to a port whose average capacity utilization is above 90% or below 75%. Above 90%, infrastructures are being used almost to the point of saturation and to a point where there is no more flexibility to allow operations to continue normally even with a loss in capacity due to unforeseen disrupting events. Below 75%, infrastructures are underused resulting in less business opportunities for the industry.

Since the annual capacity utilization can vary greatly depending on the various events that affect the industry, a port's true capacity utilization is more relevant on a long term analysis. Therefore, the marking system for this II will be based on the average capacity utilization for the years 2010, 2009, 2008 and 2007, as shown in table VII.

Table VII: Marking system for II#3[15].

	Port capacity utilization 2007	**Port capacity utilization 2008**	**Port capacity utilization 2009**	**Port capacity utilization 2010**	**Average**	**Value**
Average capacity utilization between 85% and 90%.	(Total exports/Total capacity)*100	(Total exports/Total capacity)*100	(Total exports/Total capacity)*100	(Total exports/Total capacity)*100	((2007 to 2010 capacity utilization)/4)*100	3
Average capacity utilization between 75% and 85%	(Total exports/Total capacity)*100	(Total exports/Total capacity)*100	(Total exports/Total capacity)*100	(Total exports/Total capacity)*100	((2007 to 2010 capacity utilization)/4)*100	2
Average capacity utilization above 90% or below 75%	(Total exports/Total capacity)*100	(Total exports/Total capacity)*100	(Total exports/Total capacity)*100	(Total exports/Total capacity)*100	((2007 to 2010 capacity utilization)/4)*100	1

[15] Total exports and capacities are expressed in Mt.

Hunter Valley coal corridor

The infrastructures capacity has been rapidly expanding over the years at the port of Newcastle. As the largest coal exporting port, Newcastle's rapid expansion aims at meeting the growing demand for coal on world markets. As a result, Newcastle is one of the busiest coal exporting ports in the world.

Table VIII: Newcastle port's capacity utilization[16].

	Port capacity utilization 2007	Port capacity utilization 2008	Port capacity utilization 2009	Port capacity utilization 2010	Average
Newcastle Port	(88.96/102)*100= 87.2%	(90.5/102)*100= 88.7%	(97/113)*100= 85.8%	(108.26/143)*100= 75.7%	(87.2+88.7+85.8+75.7)/ 4 = 84.35%

Table VIII shows that for the period stretching from 2007 to 2010, the average capacity utilization at Newcastle Port was 84.35%. Therefore, Australia's coal industry for II#3 is 2, which is an average result.

The port of Newcastle has some of the busiest coal exporting infrastructures. As section 3.4 will explain, several dozen vessels wait in queue to be serviced at all times. Considering this reality alone, the port's capacity utilization should logically be higher. Two reasons explain why capacity utilization for this period is slightly below 85%. First of all, the port has been rapidly developing its infrastructures during the last few years. The current phase of development is expected to continue at least until 2015. Approved in 2007 by the government of New South Wales, the port's development should bring total capacity to 211Mt (Boyle, 2010, 6). In other words, from 2007 to 2010, the port's capacity has been growing faster than the volume of coal exported. From 2007 to 2010, exports increased from 88.96Mt to 108.26Mt; a difference of 19.3Mt,. On

[16] The data presented in this table comes from the following sources:

- Newcastle Port Corporation. *Annual report 2010-2011*. Newcastle: Newcastle Port Corporation, 2011.
- Bayer, Arne K., Maggi Rademacher and Andrew Rutherford. “Development and perspectives of the Australian coal supply chain and implications for the export market.” *Zeitschrift Für Energiewirtschaft* vol.33 (2009): 255-267
- Australian Rail Track Corporation. *Hunter Valley corridor 2007-2012 capacity strategy consultation document*. Australia: Australian Rail Track Corporation, 2007.

the other hand, port capacity went from 102Mt to 143Mt, a difference of 41Mt. The fact that capacity has grown faster than export volumes is the first explanation of Newcastle Port's capacity utilization of 84.35%. The second explanation is that infrastructure problems present in other links of the logistics chain affect the system as a whole and prevent port infrastructures from being used at their full potential. In Australia, as in most coal exporting countries, investment in rail capacity "has not kept up with the growth demand from new coal mines" (Rademacher, 2008, 78). Accordingly, the problems in rail transportation have been slowing down coal exports through Newcastle Port. This problem is made even more apparent when comparing general rail capacity utilization to port capacity utilization in Australia. In 2006 and 2007, port capacity was at 85% and 90% while rail capacity utilization was at 99% and 105% (Rademacher, 2008, 78). In brief, the bottlenecks at the port are a consequence of the rail sector. Because of the "lack of wagons and locomotives, the railway system is increasingly choked" and overused (Ritschel and Schiffer, 2007, 51). In conclusion, solving the rail infrastructure's problems would allow the coal terminals to reach higher operational and productivity levels while maintaining a high resilience level.

Mpumalanga coal corridor

South Africa's RBCT is the largest coal exporting terminal in terms of volume handled. Exports of coal out of Richards Bay have declined in the last few years, "mainly because of rail constraints" (Eberhard, 2011, 22). New capacity projects and sustained demand on the world market are expected to increase South African exports in the years to come (Ritschel and Schiffer, 2007, 67). Table 9 shows that RBCT has had an average capacity utilization of 82.9% from 2007 to 2010. For this II, this score is worth a value of 2 since it falls in the second category.

Table IX: Richards Bay Coal terminal's capacity utilization[17].

	Port capacity utilization 2007	Port capacity utilization 2008	Port capacity utilization 2009	Port capacity utilization 2010	Average
Richards Bay Coal Terminal	(67.7/72)*100= 94%	(61/76)*100= 80.3%	(67/76)*100= 88.2%	(62.86/91)*100= 69.1%	(94+80.3+88.2+69.1)/4 = 82.9%

Table IX contains interesting information that is worth mentioning. First of all, we can see how the port's expansion projects have helped to lower capacity utilization levels that were dangerously high in 2007. Back then, both rail and port capacity utilization were at 94% (Rademacher, 2008, 80). The world's largest coal terminal has followed a utilization and development pattern similar to Newcastle Port where capacity has grown faster than export volumes. The South African and Australian coal industries also show similarities since in both cases the rail sector is frequently identified as the most important source of infrastructure problems. The South African case shows how poor supply chain management and lack of coordinated development projects between mining, rail and port actors have prevented exports from growing in the last few years despite strong demand on the world market. The best explanation of this problem comes from a 2011 report published by the Program on Energy and Sustainable Development of Stanford's University.

> There is an apparent lack of planning and investment coordination between Transnet, coal producers and ports. While port capacity at Richards Bay has increased, coal exports have actually decreased in recent years. Rail capacity needed to increase to 76 Mtpa by 2008 and 91 Mtpa by 2010 to match expansions at the Richards Bay Coal Terminal; however current rail capacity remains below 68 Mtpa, and actual performance has been even lower with some costly derailments. Shortages of locomotives, wagons and skills are also cited as problems (Eberhard, 2011, 21).

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[17] The data presented in this table comes from the following sources:

- Eberhard, Anton. *The future of South African coal: Market, investment and policy challenges*. Stanford: Stanford University, 2011.
- Richards Bay Coal Terminal Company Proprietary Limited. “December 2010 operating statistics.” Richards Bay Coal Terminal Company Proprietary Limited. http://www.rbct.co.za/default.asp?id=1173#2010 (accessed December 14, 2011).

In short, capacity utilization could keep on falling if infrastructure problems in the railroad transportation link of the logistics chain are not solved. Even with Phase V of the port's expansion plan concluded, the South African industry will not be able to grasp the opportunities created by a growing and sustained demand on world markets as long as issues in the rail sector are not solved.

Canadian coal corridor

Canada has been a relatively small coal exporting nation on world markets. However, "the infrastructure available to the Canadian coal industry is very well developed, reliable and efficient, but nonetheless remains the sector's weak point on account of the transport distances involved" (Ritschel and Schiffer, 2007, 84). Table X shows that from 2007 to 2010, the average capacity utilization at Port Metro Vancouver reached

Table X: Richards Bay Coal terminal's capacity utilization[18].

	Port capacity utilization 2007	Port capacity utilization 2008	Port capacity utilization 2009	Port capacity utilization 2010	Average
Port Metro Vancouver	(26.4/34)*100= 77.7%	(25.9/37)*100= 70%	(24.2/37)*100= 65%	(30.3/38)*100= 79.7%	(77.7+70+65+79.7)/4= 73.1

73.1%. For this II, this score falls in the third category which is worth a score of 1. Consequently, port capacity utilization in the Canadian coal industry has the lowest possible score and the lowest average of all three case studies. The information presented in table X has to be put in perspective. As mentioned above, the industry benefits from one of the most efficient logistics chain among coal exporting nations. However, the geographic factor, especially the problem of long distances is a drag to the success of the industry. "Due to long transportation routes, West Canada's hard coal-mining has a considerable cost disadvantage compared with Australian [...]coal" (Ritschel and Schiffer, 2007, 84). To be more accurate, Canada's coal corridor stretches

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[18] The data presented in this table comes from the following sources:

- Port Metro Vancouver, *Statistics Overview 2010*. Vancouver: Port Metro Vancouver, 2011.
- De Place, Eric. *Coal exports from Canada*. Seattle: Sightline Institute, 2011.
- Westshore Terminals. "Background 2000 and beyond." Westshore Terminals. http://www.westshore.com/beyond.html (accessed December 15, 2011).

for 1100km from the furthest mines in Alberta to Port Metro Vancouver on the west coast. In contrast, Australia's Hunter Valley mines are situated in a radius of no more than 300 km away from Newcastle (Gurpreet, 2009) while coal trains leaving from the Mpumalanga coalfields to Richards Bay travel 588km (Kuys, 2011). The Canadian coal industry has the infrastructures needed to handle more volumes. However, "the high cost for inland rail transport due to long distances " (Rademacher, 2008, 78) has led buyers to favor other exporters thus reducing activities and restricting Port Metro Vancouver's capacity utilization to low levels. Despite an average capacity level under 75%, the results for 2010 show the first signs of a rise of activity which is expected to last for many years to come. According to most analysis, "the outlook for Canada's coking-coal exports are vastly improving thanks to higher world market prices" and because "many consumers prefer not to cover their needs with Australian coal only" (Ritschel and Schiffer, 2007, 84). Hence, while port average capacity utilization is currently low, strong demand on the world market and good transport infrastructures will raise this port capacity utilization to higher levels in the years to come.

In conclusion, the scores for II#3 for each case study are the following. None of the three case studies have received the best score since average port capacity utilization for the period 2007-2010 has not reached a score between 85% and 90%. Australia and South Africa both received an average score of 2 on this KPI with respective scores of 84.35% and 82.9%. Finally, the Canadian coal industry had the worst results with average capacity utilization of 73.1% and a score of 1.

3.4 II#4: Loading equipment operating rates.

Traffic and congestion on transport networks explain the occurrence of many of the industry's disruptive events. In fact, "delays have the potential to cause significant difficulties that span continents. In some industries, the window for construction, manufacturing or selling is short, and delays result in missed opportunities or major increases in cost" (Archibald and Rutten, 2010, 1). Consequently, reducing traffic and maintaining high levels of fluidity in the system reduces the likelihood of such disruptive events happening. Since fluidity and resilience are so closely related to one another, the entire logistics chain benefits, both in terms of performance levels and resilience levels, from reduced congestion in the system. For this reason, measures such as the use of rail tracks with higher axle loads and the use of trains with more capacity not only reduce traffic and congestion, but also raise the logistics chain's resilience level. However, measures that effectively improve resilience are not only found within the railway transport link of the industry. Traffic can also be reduced by allowing ships to be loaded quickly. Reducing the number of hours needed to load a ship is achieved by using equipment that can handle high volumes of coal in few hours. Coal terminals use machines known as *loaders* whose efficiency are determined by the maximum amount of tons they can load in a ship in one hour. Table XI explains how II#4 will be used to identify which case study has the best performance in this area. The idea behind II#4 is that loaders with higher tons per hour (tph) operating rates can load more coal, allowing more ships to be serviced, ultimately helping reduce both inland and seaside traffic levels. Likewise, since more efficient equipment brings fluidity to the logistics chain, the most efficient loaders reduce the likelihood of disruptive events and increase the ability of a port to recover from such events.

Table XI: Marking system for II#4.

Port	Value
Terminal average loading rate superior to 8001tph.	3
Terminal average loading rate between 3001tph and 8000tph.	2
Terminal average loading rate between 1tph and 3000tph.	1

Coal terminals in Port Newcastle, Richards Bay and Port Metro Vancouver all operate more than one loader. As technology progresses, loaders become more efficient enabling higher tons/hour operating rates. Therefore, loaders have different operating rates, which means that, for example, a ship can be loaded at a speed of 5000tph while another ship in the same terminal can be loaded at a faster speed of 9000tph depending on the operating rate of the loader being used. Evaluating loading rates can sometimes lead to misunderstandings. The best way to correctly assess the operating rates of a port's equipment is to evaluate the average operating rates of all its loaders. However, assessing the average loading rate of an entire port can be misleading. Since some ports, like Port Metro Vancouver and Newcastle Port have smaller coal terminals with slower loading equipment, the average port operating rate does not properly reflect the performance of the bigger, more efficient terminals. Therefore, the average operating rate of an entire port's ship loaders is not the most accurate way to evaluate the performance of the loading equipments. In fact, it is much easier to have an accurate picture of a terminal's loading efficiency by assessing and comparing the average operating rate of each terminal's ship loader. II#4 will use this method to determine which terminal is the most efficient.

Hunter Valley coal corridor

On May 3rd 2010, a third coal terminal was officially opened in the port of Newcastle. Owned and operated by a group of six companies, the terminal currently has a capacity of 30 Mtpa with expansion projects underway to achieve 53Mtpa[19]. The original two terminals, Kooragang Coal Terminal and Carrington Coal Terminal, both belong to Port Warath Coal Services (PWCS). The ship loaders of each terminal and their operating rates are found in table XII. The average operating rate of all six ship loaders located in the port's coal terminals is decreased by slower, less efficient ship loaders in the Carrington Coal Terminal. The loaders in operation in Newcastle Port's three coal terminals have an average operating rate of 7 833tph. What's more, NCIG and Kooragang Coal terminals are the two fastest loaders with a rate of 10 500tph.

[19] NCIG. "About NCIG," Newcastle Coal Infrastructure Group, http://www.ncig.com.au/AboutNCIG/AboutNCIG/tabid/110/Default.aspx (accessed January 10, 2012).

Table XII: Port of Newcastle's shiploaders operating rates.

Terminals	Shiploaders	Operating rates in tons per hour (tph)
NCIG	Shiploader#1	10 500
Terminal average		10 500
Kooragang Coal Terminal	Shiploader#1	10 500
	Shiploader#2	10 500
	Shiploader#3	10 500
Terminal average		10 500
Carrington Coal Terminal	Shiploader#1	2 500
	Shiploader#2	2 500
Terminal average		2 500
Average port operating rate		(10 500*4 + 2 500*2)/6 = 7 833

Source: http://www.newportcorp.com.au/site/index.cfm?display=111681 and http://www.ncig.com.au/Portals/2/files/General%20Information%20Pres_May%202008.pdf

Mpumalanga coal corridor

The port of Richards Bay houses the world's largest export coal terminal in the world[20]. As a result, it operates more ship loaders than its Australian and Canadian rivals. RBCT operates four ship loaders whose operating characteristics are shown in table XIII. The four loaders in operation in the terminal have an average operating rate of 9 625tph.

[20] Richards Bay Coal Terminal. "Welcome," Richards Bay Coal Terminal, http://www.rbct.co.za/ (accessed January 31 (2012).

Table XIII: Richards Bay Coal Terminal's ship loaders operating rates.

Terminals	Ship loaders	Operating rates in tons per hour (tph)
Richards Bay Coal Terminal	Shiploader#1	11 000
	Shiploader#2	10 500
	Shiploader#3	8 500
	Shiploader#4	8 500
Average port operating rate		(11 000 + 10 500 + 8 500*2)/4 = 9 625

Source: http://www.kzntransport.gov.za/public_trans/freight_databank/kzn/ports/Richards_Bay/index_xml.html

Canadian coal corridor

Port Metro Vancouver's coal terminals are smaller than their Australian and South African counterparts. Both in terms of volume exported and size of their infrastructures, Westshore Terminals and Neptune Bulk Terminals operate on a smaller scale. Westshore Terminals operate three ship loaders two of which have a combined operating rate[21]. Neptune Bulk Terminal is made of three different berths. However, only Berth#1 handles coal products while the other two usually handle potash and fertilizers[22]. For this reason, only Berth#1's two ship loaders can be considered as coal loaders. The operating rates of those ship loaders are presented in table XIII. The average operating rate of the entire port is relatively low because Neptune Bulk Terminal's slower loaders have a negative effect on the port's results. Nevertheless, Westshore Terminal's loaders show better results with an average loading rate of 7 000tph.

[21] Westshore Terminals. "Equipment," Westshore Terminals, http://www.westshore.com/berths.html (accessed January 11, 2012).

[22] Neptune Terminals. "Terminal Operations," Neptune terminals, http://www.neptuneterminals.com/terminal-operations/ (accessed January 11, 2012).

Table XIV: Port Metro Vancouver's ship loaders operating rates.

Terminals	Ship loaders	Operating rates in tons per hour (tph)
Neptune Bulk Terminals	Shiploader#1	2 700
	Shiploader#1	2 700
Terminal average		2 700
Westshore Terminals	Shiploader#1	7 000
	Shiploader#2 & 3 combined	7 000
Terminal average		7 000
Average port operating rate		(2 700*2 + 7 000*2)/4 = 4 850

Source: http://www.westshore.com/berths.html and http://www.neptuneterminals.com/terminal-operations/

With two coal terminals with average ship loading rates at 10 500tph, Australia's Newcastle Port receives a score of 3 for the best results in II#3. Richards Bay Coal Terminal also receives a score of 3 since the average loading rate of the terminal (9 625tph) is superior to 8001tph. Finally, with a loading equipment average operating rate of 7 000tph, Canada's Westshore Terminal receives a score of 2.

3.5 Cumulative scores of chapter 3.

In this chapter, the relationship between the resilience of the logistics chain and the infrastructures of the coal industry has been analyzed with the help of four infrastructure indicators. The first II of this chapter measured the capacity of coal trains. The analysis showed that the Mpumalanga coal corridor's coupled trains were the biggest, followed by those of the Canadian coal corridor's and those of the Hunter Valley. The second II measured stock yard capacity in Newcastle Port, RBCT and Port Metro Vancouver. Stock yards in Richards Bay proved to be the most resilient, followed by those in Newcastle and Vancouver. The third II measured the capacity utilization of port infrastructures. In this case, both the Australian and South African case studies received average scores while Canada received the lowest. Finally, the fourth II measured the operating rates of the port's loading equipments. As the largest coal exporting port, Newcastle came in first, followed by Richards Bay and finally Vancouver. The final scores for this chapter are presented in table XV.

Table XV: Cumulative scores for chapter 3.

Case studies	II#1	II#2	II#3	II#4	Cumulative Score
Hunter Valley coal corridor	2	2	2	3	9
Mpumalanga coal corridor	3	3	2	3	11
Canadian coal corridor	3	2	1	2	8

In conclusion, the infrastructure indicators of chapter 3 were chosen to demonstrate how infrastructures have the potential to improve or hinder the resilience of the industry. Carefully designed and well-operated infrastructures can prevent disruptive events from happening. When such events cannot be avoided, they can also dampen negative effects.

On a personal note, I believe that the final scores as shown in table XV have been influenced by a certain number of factors that need to be mentioned and understood. For Australia, the sheer size of the coal industry, the relatively high efficiency of its operations and the high level of activity explain the country's score. The Hunter Valley coal corridor has long been the first exporter of coal and its high II score is no surprise. The Mpumalanga's first place can be explained, to a certain degree, by the fact that RBCT is probably one of the most efficient coal terminals in the world. However, the incapacity of the industry to solve infrastructure problems, especially on the rail side has led the industry on a declining path. If nothing is done to permanently solve this situation, the South African coal industry could miss several business opportunities and lose its first position. Canada's third position must be put in perspective. As mentioned before, Canada's coal industry is not as big as Australia's or South Africa's. As a result, most of its infrastructures are not being used at their full potential. Canada's problem is not that its coal industry is not resilient or competitive enough; the problem is that demand for Canadian coal has not allowed the industry to operate as well as it could have. With an increasing demand for coal on world markets, the industry's best days are probably ahead. With a few years of strong demand on international markets, the industry will operate at a higher level of activity which will, in time, significantly improve the resilience and the efficiency of the infrastructures. As mentioned by Ritschel and Schiffer, “the outlook for Canada's coking coal exports are vastly improving, thanks to higher world market prices and a tightening of the supply range due to China's withdrawal from exporting coking coal, since many consumers prefer not to cover their needs with Australian coal only. Hence, Canada's exports are on the up again at present” (Ritschel and Schiffer, 2007, 84). Nonetheless for decision makers, the most important conclusions to remember and understand are the following.

1. Rail and port infrastructures are vital components of the industry. Their performance impacts the entire upstream and downstream sections of the logistics chain. As a result, their performance needs to be constantly monitored.
2. Infrastructure problems will easily and quickly affect the system's resilience. Taking steps to prevent problems or to reduce the magnitude of such problems will add or restore resilience in the system and reduce wastes of time and revenues. Consequently, the ability to anticipate and forecast capacity and traffic issues yield high benefits and rewards.
3. Investing in existing infrastructures is as beneficial if not more than investing in new infrastructures. Building new infrastructures to increase the system's resilience will not always solve the issues associated with existing infrastructures.

Chapter 4: Analyzing the resilience of the logistics chain to environmental hazards.

The first four indicators of this research analyzed the relationship between the infrastructures and the resilience of the coal industry. Analyzing this relationship revealed how resilience levels can be controlled and improved by measures designed to improve the effectiveness and performance of infrastructures. On the other hand, the three risk indicators of this chapter evaluate the resilience of the industry to factors that cannot be controlled and whose consequences are usually devastating. For this reason, improving the resilience of the industry to environmental hazards is a much harder task to accomplish.

The environment is an important external factor to consider when assessing the resilience of an industry. Environmental hazards can have disastrous consequences and their impacts can affect the industry longer and more seriously than any infrastructure problem. "Transportation routes and mining infrastructures are susceptible to structural weakening and failure due to increased frequency and severity of extreme weather events and climate variability" (D. Pearce *et al*., 2011, 349). Therefore, high levels of resilience are essential and must be maintained at all times if possible. To do this, each stakeholder of the industry must be informed about the geographic and climatic reality of the area in which the logistics chain is situated. However, since some regions of the world are more likely than others to be affected by environmental hazards, the environmental features of each country have to be taken into account. Therefore, the evaluation process of RIs# 1, 2 and 3 determines how likely environmental hazards are to happen based on the geographic features of each corridor. This evaluation will be based on the following three RIs:

- The vulnerability of the logistics chain to seismic hazards.
- The vulnerability of the logistics chain to hydrologic hazards.
- The vulnerability of the logistics chain to atmospheric hazards.

4.1 RI#1: The vulnerability of the logistics chain to seismic hazards.

Seismic hazards include natural phenomenon caused by the movement and collisions of the Earth's crusts. Among the various manifestations of this type of hazard, earthquakes and tsunamis are the most susceptible of having negative consequences on coal logistics chains around the world. Thus, this RI will analyze how likely coal logistics chains are to stop functioning or suffer damages from tsunamis and earthquakes. Table XVI shows how each country will be evaluated on the following 4 criteria:

Table XVI: Marking system for RI#1.

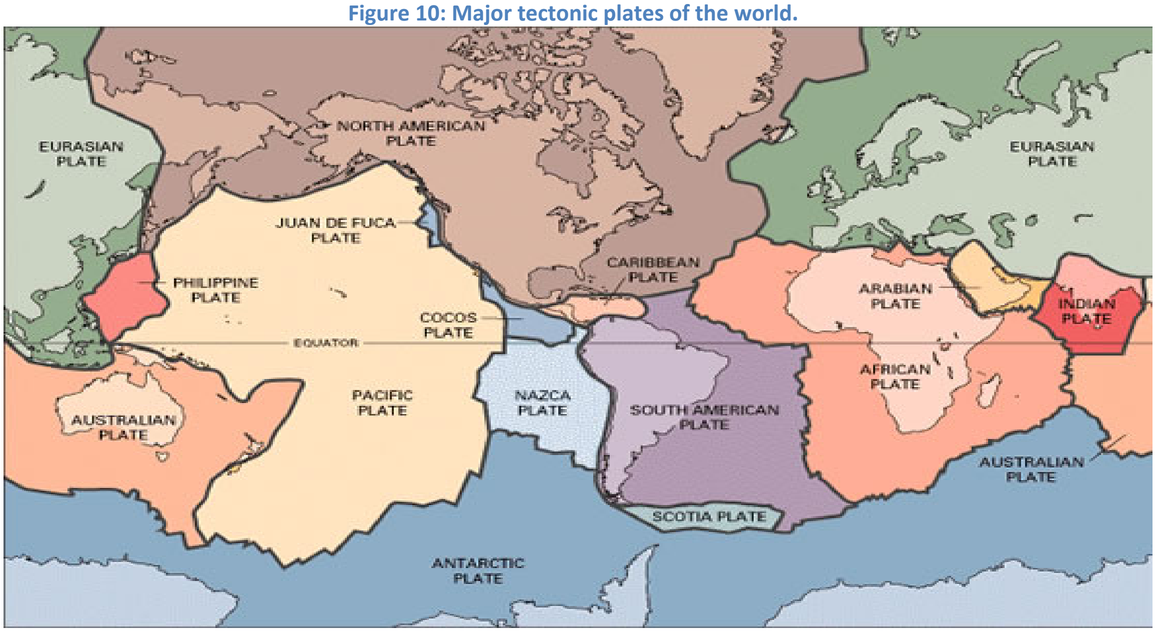
Criteria	Value
The corridor is situated in an area where earthquakes are likely to cause minor damages to the infrastructures and interrupt activities for a short period.	Yes=0
	No=1
The corridor is situated in an area where earthquakes are likely to cause major damages to the infrastructures and interrupt activities for a long period.	Yes=0
	No=1
The corridor is situated in an area where tsunamis are likely to happen.	Yes=0
	No=1
The corridor is situated in an area where tsunamis are not only likely to happen, but also likely to damage infrastructures and interrupt activities.	Yes=0
	No=1

Small earthquakes (generally under 6 on Richter's scale)[23] are likely to happen in many regions of the world that are not necessarily considered as regions of high seismic activities. Nonetheless, small earthquakes can still affect the logistics chain for a few days or a few hours and must consequently be taken into account when evaluating seismic hazards. The first criterion of RI#1 evaluates this possibility. The second criterion evaluates the likelihood that a more important earthquake (generally above 6 on Richter's scale) happens where the corridor is situated. This type of event usually happens in regions where seismic activity is high. The third criterion evaluates the likelihood that a tsunami happens where the corridor is situated. The final criterion evaluates the likelihood that, in the event of a tsunami, the infrastructures would be damaged and activities interrupted. To have a clear understanding of the vulnerability of a given region to seismic events, it is important to look at the geography of the Earth's tectonic plates. "Most earthquakes occur along plate edges (inter-plate), where the plates meet and are forced against each other. Some 95% of earthquakes are inter-plate, with 80% of all recorded earthquakes occurring around the edge of the Pacific" (Middelmann, 2007, 135). Earthquakes are triggered "when the stresses caused by the plates movements result in rocks fracturing along fault planes. The energy released when the rocks fracture generate seismic waves, and these cause ground shaking when they reach the surface of the Earth" (Middelmann, 2007, 135). Figure 10 shows that, among the three case studies of this research, the Australian and South African coal industries are relatively far away from tectonic plate edges while Canada's coal industry is much closer. In comparison tsunamis are also created by the movement and collision of the Earth's tectonic plates. They are the result of undersea earthquakes.

> To be more accurate, tsunamis are waves generated by sudden movement of the sea floor, usually caused by undersea earthquakes, but sometimes caused by landslides, volcanic eruptions or meteorite impacts. A tsunami is very different from a typical wind-generated wave. Wind-generated waves cause movement of water only near the sea surface, and have wave lengths measured in meters. In contrast, tsunamis involve water movement to the sea floor, and can have wavelengths of 100 kilometres or more (Middelmann, 2007, 149).

[23] Events that caused some minimum level of damage or could have caused damage had they occurred close to inhabited regions. See: Lamontagne, M., S. Halchuk, J.F. Cassidy and G.C. Rogers, "Significant Canadian earthquakes of the period 1600-2006," *Seismological Research Letters* vol. 79 number 2 (March/April 2008): 211.

Figure 10: Major tectonic plates of the world.



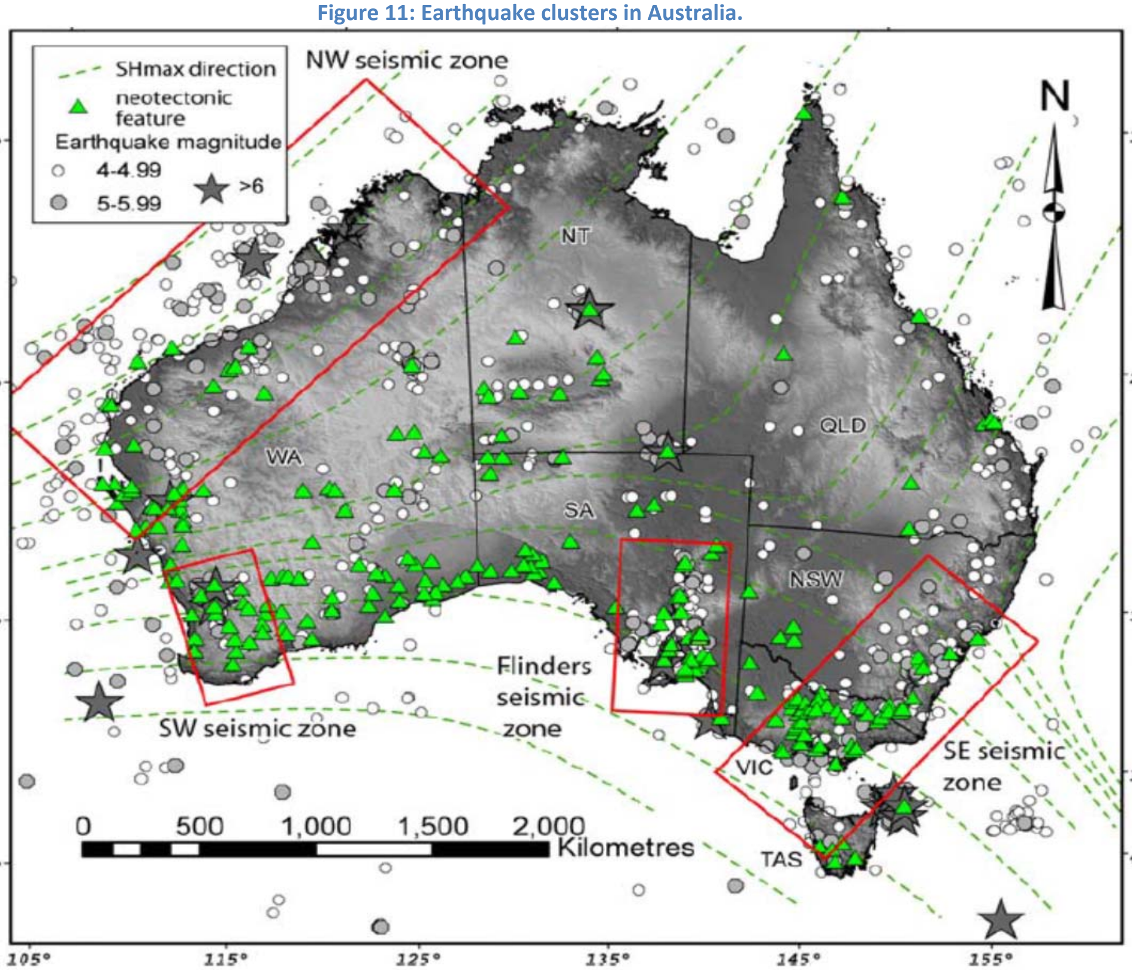
Source: Geology.com, 2012

Hunter Valley coal corridor

Historically, Australia has never been a very active seismic region. When they do happen, earthquakes are either not felt by the population or create little to no damage. Records of past earthquakes show that four regions have higher seismic activity. Located in the south-east part of New South Wales, the Hunter Valley is part of one of these regions. However, figure 11 shows that even if numerous earthquakes happened in that region over the years, none of them have had a higher magnitude than 6 on Richter's scale. The most important earthquake recorded in Australia both in terms of destruction and lives lost happened in Newcastle in 1989. This earthquake caused the death of 13 people and caused serious building damage. Furthermore, including Newcastle's earthquake of 1989, a total of 5 earthquakes of a magnitude higher than 5 have occurred in the Hunter region since 1804 (Dhu and Jones, 2002, 3).

Until now, Australia has been spared from the destructive effects of tsunamis. In recent history, large tsunamis have not threatened Australian cities or densely populated areas (Middelmann, 2007, 151). The high seismic activity zone where the Pacific and Australian plates meet, have not yet created threatening tsunamis for the East coast of Australia. Likewise, the last volcanic eruption was the 1883 Krakatau eruption which is not likely to happen for another 21 000 years. (Middelmann, 2007, 150).

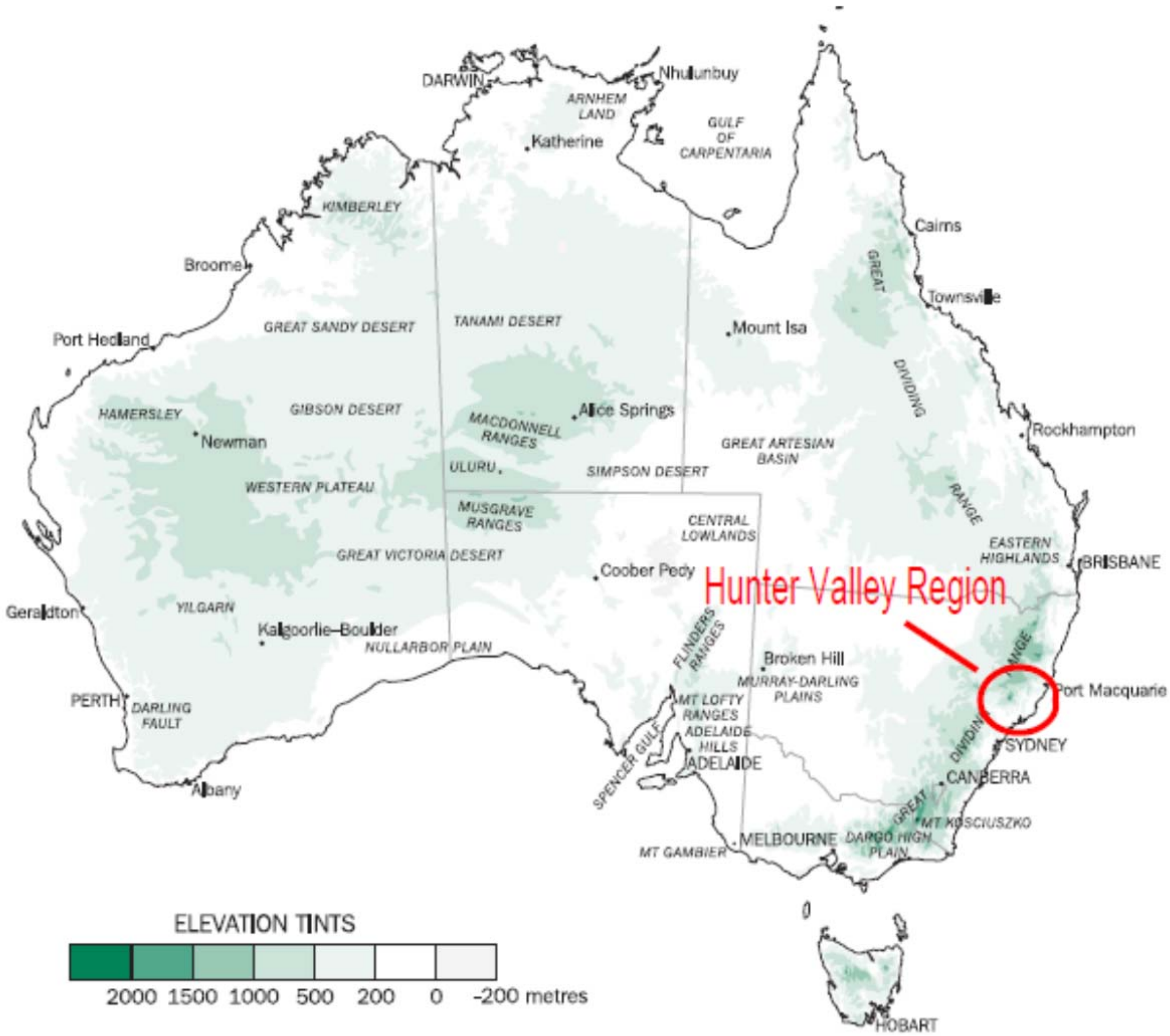
Figure 11: Earthquake clusters in Australia.



Source: Quigley, Clark and Sandiford, 2010

However, in the unlikely event of a tsunami happening between the South-East coast of Australia and the Western coast of New-Zealand, the Hunter Valley region would be vulnerable to damages caused by high waves. When looking at figure 12, two geographic features of Australia's Eastern coastal plains can be identified as potential reasons for the area's vulnerability to tsunamis. First, the elevation on Australia's East coast is low. The entire region located East of the Great Dividing Range (see figure 12) is at or slightly above sea level and no other mountain ranges act as natural barriers. In other words, if a tsunami did happen, nothing could stop it from reaching inland mining and railroad networks. Second, no significant island is situated close enough to protect Hunter Valley's coal corridor. If a tsunami were to happen between New Zealand and Australia, nothing could stop it from reaching the coast.

Figure 12: Elevation of the Australian continent.



Source: Trewin, 2006

Accordingly, the Hunter Valley coal corridor is situated in an area where small scale earthquakes are likely to happen, but not in an area where earthquakes are likely to cause major damages to the infrastructures and interrupt activities for a long period. Hunter Valley is also situated in an area where tsunamis are not likely to happen, but likely to create serious damage if they were to happen. Consequently, this case study has a score of 0 for the first criterion, 1 for the second, 1 for the third and 0 for the last criterion worth a final RI score of 2.

Mpumalanga coal corridor

Like Australia, South Africa is not located close to tectonic plate edges. According to the South African Council for Geosciences, "the stable tectonic setting of South Africa means that large earthquakes are comparatively rare"[24]. However, smaller earthquakes still happen on occasions and are created by natural seismic activity and mining-related activities. The strongest earthquake to occur in South Africa reached a magnitude of 6.3 on Richter's scale. Since that event in 1969, no earthquakes exceeded this magnitude (Mayshree, Kijko and Durrheim, 2009, 73). As shown in figure 13, the coal corridor stretching from the Mpumalanga province to the port of Richards Bay is located in a region where earthquakes have been numerous, but of lesser magnitude. Located next to the Wits basin earthquake cluster, seismic activity in the corridor is a mix of both natural earthquakes and "tremors and blasts from the gold, manganese, platinum, diamond and coal mines" (Mayshree, Kijko and Durrheim, 2009, 72). To be more accurate, the concentration of earthquakes in the Northwest section of the corridor is almost entirely due to explosions in the coal fields (Mayshree, Kijko and Durrheim, 2011, 8).

In an interview given to a firm of investment consultant, Dr. Kijko, seismologist at the South African Council for Geosciences, stated that "the probability of a tsunami striking the coast of South Africa is zero. [...] the South African coast basically does not fulfill a range of requirements for a tsunami"[25] including the need for an earthquake of magnitude 7 or higher. As mentioned above, earthquakes of that magnitude have never occurred in or around South Africa. Nevertheless, if such a tsunami did happen, the coal industry could suffer severe damage. Similar to the Australian East coast, the South African east coast is not protected by islands or high mountains on the coast. However, altitude rises quickly and highlands start no more than 50 kilometers off the coast. The Mpumalanga coal corridor stretches far away inland in an area located beyond the Great Escarpment mountain range with average altitudes greater than 1000 meters. In other words, the entire mining complex would not be endangered by a tsunami. The Port of Richards Bay and stretches of the railway located close to the coast would, on the other hand, suffer serious damage.

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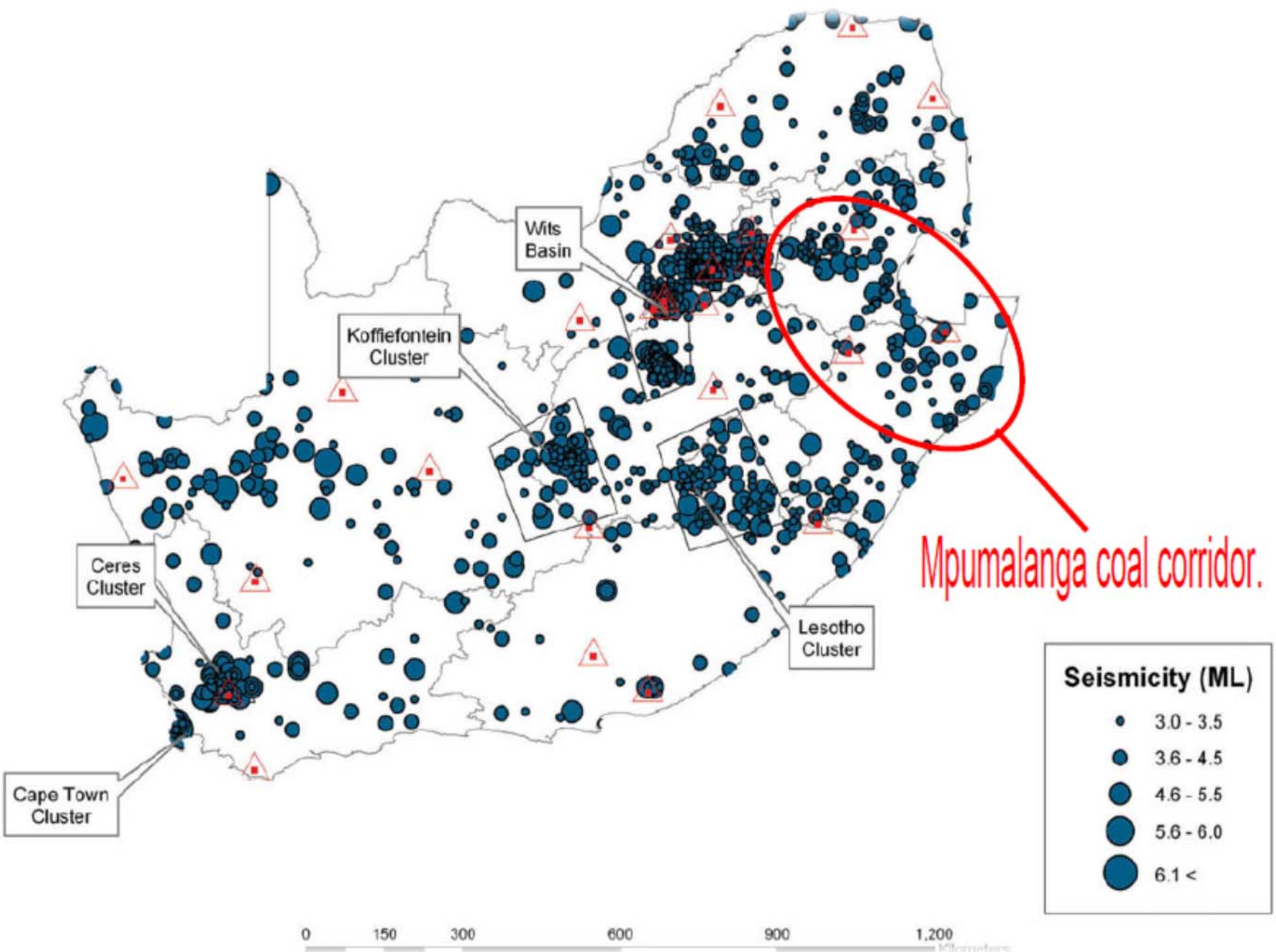
[24] South African Council for Geosciences, "Hazard assessments," South African Council for Geosciences, http://www.geoscience.org.za/index.php?option=com_content&view=article&id=1616:seismic-hazard-assessment&catid=141:seismology&Itemid=615 (accessed February 3 2012).

[25] Garden Route Investments, "Could a Tsunami ever hit the Cape?," Garden Route Investments, http://www.gri.co.za/51029.html (accessed February 3 2012).

Figure 13: Location of South African earthquakes from 1620 to 2008.



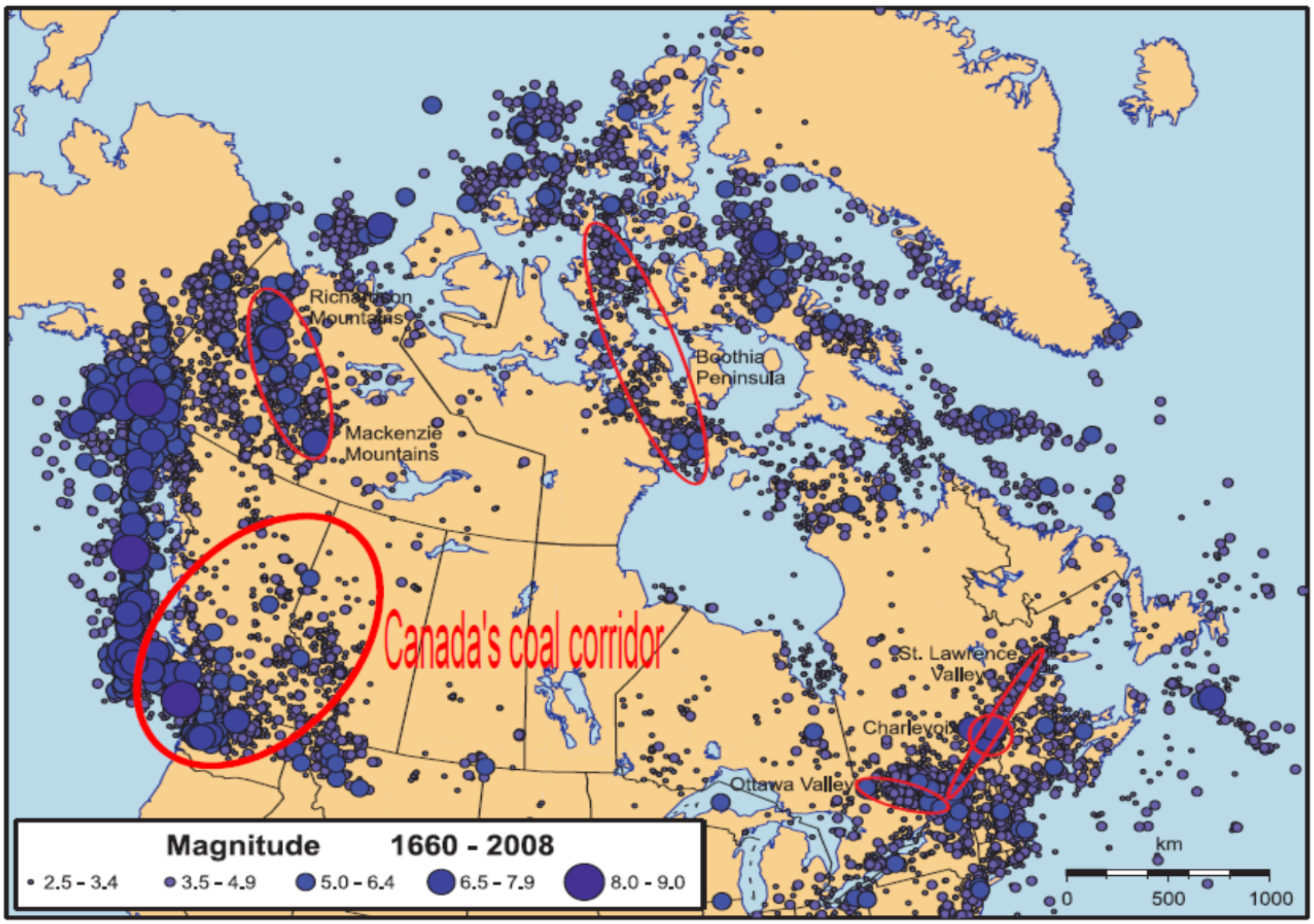
Source: Mayshree, Kijko and Durrheim, 2009

In conclusion, the Mpumalanga coal corridor is located in a region where earthquakes happen on a relatively frequent basis. On the other hand, large scale and destructive earthquakes have never been recorded in the region or in the rest of the country. Tsunamis are also not likely to happen. Yet, if they ever occurred they could seriously damage the port of Richards Bay and sections of the railroad. Therefore, this case study has a score of 0 for the first criterion, 1 for the second, 1 for the third and 0 for the fourth for a total RI score of 2.

Canadian coal corridor

Canada is a country of high seismicity. Canadian earthquakes have been recorded by natives and European colonists since the 17th century. As shown in figure 14, Canada has several active seismic zones spread in all regions of the country with the exception of the stable Craton, a geological region that stretches from central Quebec to Manitoba and southern Nunavut.

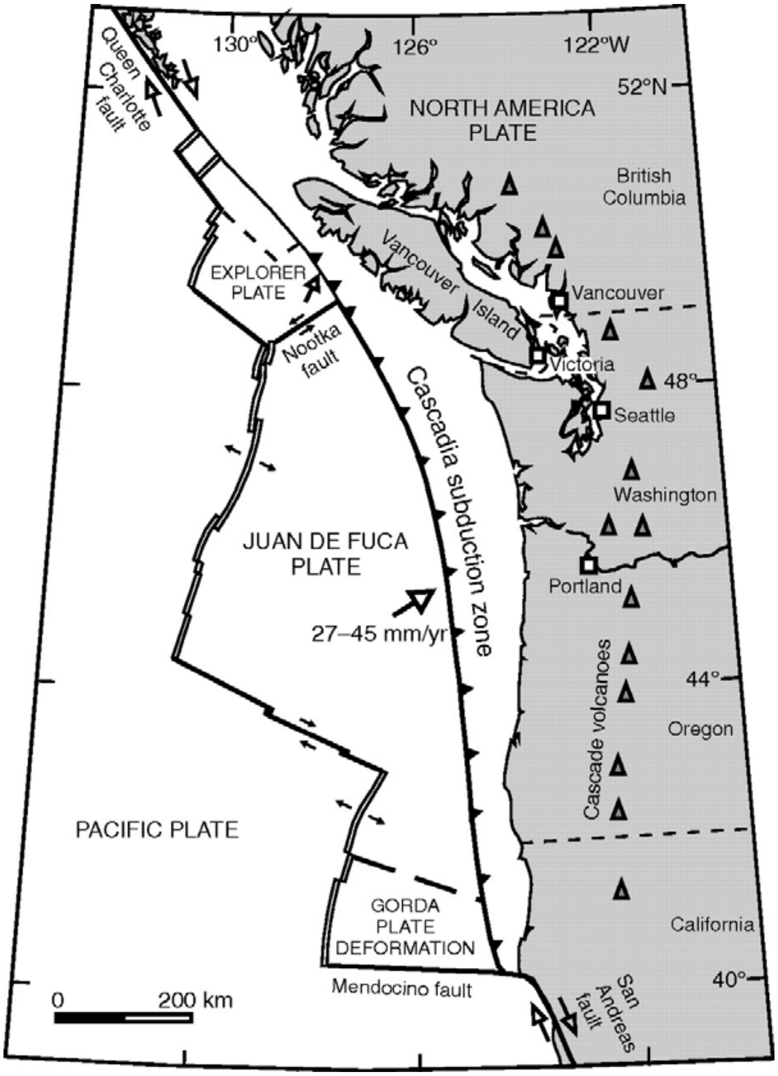
Figure 14: Location of earthquakes with magnitude ≥2.5 in Canada, 1660-2008.



Source: Cassidy, Rogers, Lamontagne, Halchuk and Adams, 2010

Canada's coal corridor is located in what is perhaps the country's most active seismic zone. A closer look at the geography of tectonic plates reveals how the south-western part of British-Columbia is located at the crossroads of several tectonic plates. As seen in figure 15, the oceanic plates Juan de Fuca and Explorer are subducting beneath the North American plate, some 200-250 kilometres away from the city of Vancouver.

Figure 15: Tectonic plates dynamic on North America's West coast.



"This subduction process produces three types of earthquakes: those within the subducting plate, those within the North-American plate and giant subduction earthquakes along the interface between the latter two plates. The last of the three types are sometimes also referred to as megathrust or giant earthquakes" (Cassidy, Rogers, Lamontagne, Halchuk and Adams, 2010, 2).

Source: Google images, 2011

The Cascadia subduction zone has been the source of some of the strongest earthquakes on the planet some of which have been classified as megathrust earthquakes. Most of the 57 earthquakes of magnitude between 6.5 and 7.9 recorded in Canada since 1660 happened near the Cascadia subduction zone. Furthermore, out of the three recorded earthquakes to exceed a magnitude of 8 on the west coast of North-America, one happened in Alaska while the other two occurred on the coasts of British-Columbia (Cassidy, Rogers, Lamontagne, Halchuk and Adams, 2010, 10). The strongest of those three occurred in 1700 inside the subduction zone making it a megathrust earthquake and is believed to have reached a magnitude of 9.0 on Richter's scale. At that time, European settlement had not yet begun, which makes it difficult to evaluate potential damages. However, the 1700 Cascadian megathrust earthquake was "likely similar to the 2004 Sumatra M 9.2 subduction earthquake" (Cassidy, Rogers, Lamontagne, Halchuk and Adams, 2010, 10). It is likely that significant damages and losses of life would have occurred if settlements had existed in British-Columbia at that time. Fortunately, Cascadia megathrust earthquakes are believed to have an average return period of 500 to 600 years (Seemann, Onur and Cassidy, 2008, 3). Seemann and Onur estimate that "the probability of a Cascadia megathrust earthquake occurring within the next 10, 50, 100 years to be 7.5%, 11% and 17% respectively" (Seemann, Onur and Cassidy, 2008, 3). Hence, strong earthquakes of a magnitude superior to 6 are a constant and significant threat to the entire Pacific coast and Western Alberta region. On the other hand, megathrust events are not likely to happen in the near future.

In the case of West shore Terminals, seismic hazards present another danger that is as important if not more important than ground shaking. As an artificial island, the land on which the terminal has been built is not as stable as port infrastructures built directly on the continent. Due to their unconsolidated structure, these artificial islands (mostly made of rocks, soil and sand) are usually unable to withstand the extreme variations of pressure and movement inherent to seismic hazards. When earthquakes happen, the ground can sink and fracture itself, a phenomenon which is known as "liquefaction" or "soil liquefaction". In simple terms, liquefaction "is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading"[26]. The best example of the damages caused by liquefaction to port infrastructures located on artificial islands is the January 1995 Hyogo-ken Nanbu earthquake also known as the Great Hanshin earthquake or Kobe earthquake.

> Widespread ground failure was observed throughout the strongly shaken region along the margin of Osaka Bay. On the islands of Rokko and Portopia, which are reclaimed lands in Osaka Bay near Kobe, liquefaction caused subsidence in the range of 50-300 cm, and large volumes of silty soil were ejected. Local lateral spreading of soils occured along the quay walls in many parts of the extensive port facilities in Kobe, rendering many of them inoperative and causing the disruption and collapse of cranes (Somerville, 1995, 1207).

[26] Johansson, Jorgen. "What is Soil Liquefaction?," Department of Civil Engineering University of Washington, http://www.ce.washington.edu/~liquefaction/html/what/what1.html (accessed May 17, 2012).

Figure 16 gives a better idea of the damages of liquefaction caused to port infrastructures located on artificial islands. At the port of Kobe, liquefaction caused by the earthquake caused extensive damage which took over two years to repair (Chang, 2000, 2).

Figure 16: Damages resulting from liquefaction to port infrastructures at the port of Kobe following the January 17 1995 earthquake.

Source: Johansson, 2012

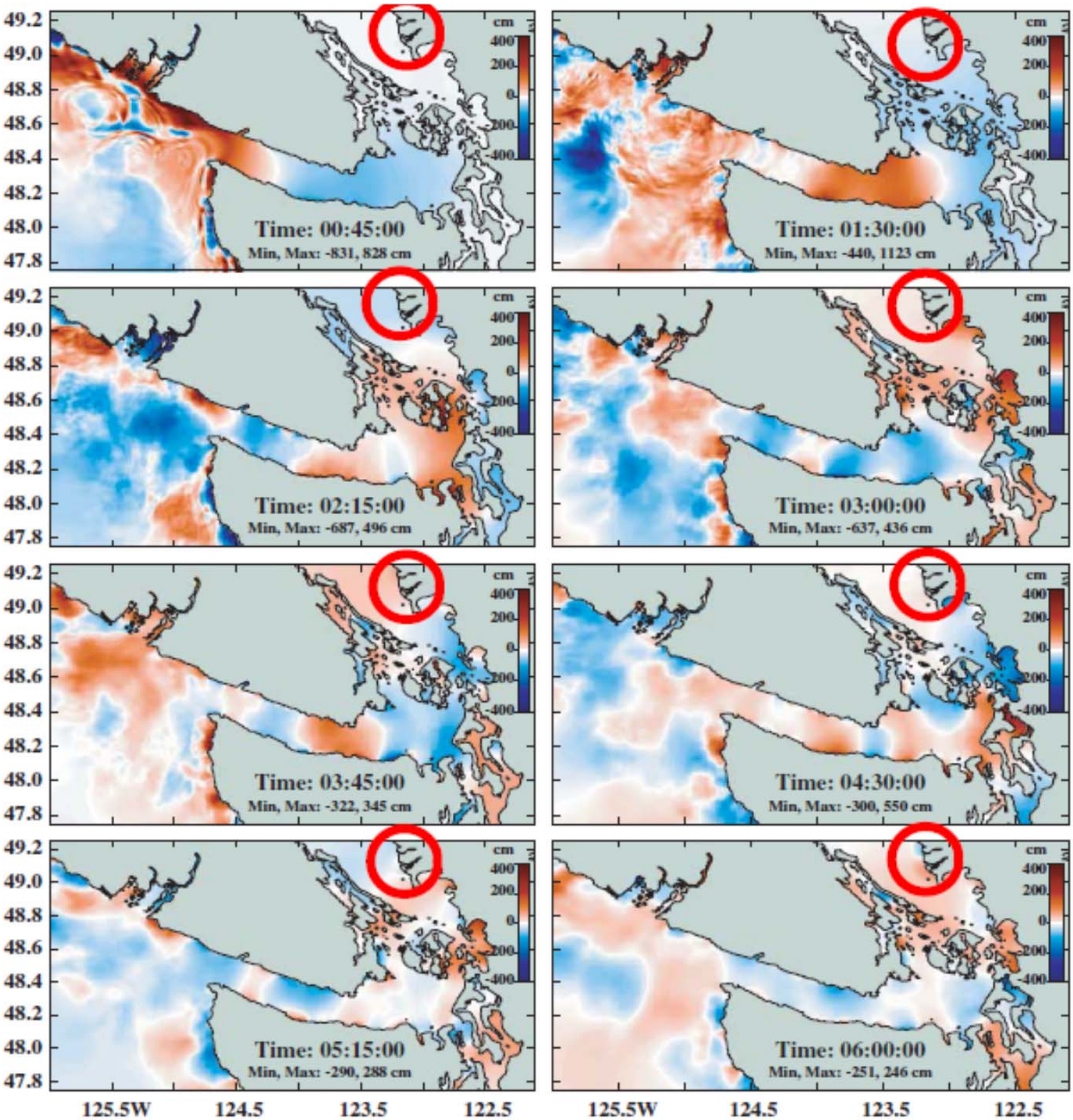
The damage sustained by port infrastructures on reclaimed islands at the port of Kobe are but one of the examples of the destructive power of liquefaction. For West shore Terminals, the risk of liquefaction is high because just like the islands of Rokko and Portopia, port infrastructures are built on artificial islands and are located in an area of intense seismic activity. In other words, West shore Terminals is at risk of being severely damaged by liquefaction which could hinder coal exports for a long period.

Following on the theme of large and mega thrust earthquakes, it is vital to understand that equally dangerous to ground shaking or liquefaction are the large and powerful tsunamis that usually follow seismic hazards. The relationship between tsunamis and earthquakes has already been established in the previous two case studies. Consequently, it is easy to understand why the coast of British Columbia has high tsunami hazard. On the Pacific coast, tsunamis can be triggered by many natural events. “The greatest tsunami hazard comes from local mega thrust earthquake-generated similar to the devastating 2004 Indian Ocean tsunami, but also significant are tsunamis from local crustal earthquakes and far-field subduction earthquakes, as well as local landslide-generated tsunamis" (Leonard, Hyndman and Rogers, 2010, 2). When it comes to the vulnerability of industry to tsunamis, the Canadian coal corridor possesses one advantage that the previous two case studies did not have. Port Metro Vancouver, coal railways and coal mines are protected from direct tsunami waves coming from the Pacific by Vancouver Island. If a tsunami were to happen on the Pacific coast, waves created by the underwater earthquake would be stopped or at least made smaller by Vancouver Island and by the islands of the Strait of Georgia. In such a case, Vancouver Island, acting as a shield for the continent behind it, could receive waves of 5-8 meters that could reach 16 meters in some areas. On the other hand, "wave amplitudes in the Strait of Georgia are expected to be only 20% of the outer coast values" (Leonard, Hyndman and Rogers, 2010, 3). Most of British Columbia's coast located between Johnstone Strait to the north and the Strait of Georgia to the south is expected to be relatively sheltered from damages in times of tsunami. However, according to tsunami simulations of a Cascadian mega thrust earthquake, this statement is not entirely correct. Indeed, waves could reach 3 meters (Cherniawsky, Titov, Wang and Li, 2007, 480) near Vancouver and cause minor damages around Port metro Vancouver. Figure 17 shows that port infrastructures located inside the red circles could be affected by higher waves than usual 3:00, 3:45 and 6:00 hours after a Cascadia subduction zone earthquake.

In the south-western part of British-Columbia, tsunamis could also be triggered by events not related to seismic activity, but by submarine landslide in unstable regions. In fact, the delta of the Fraser River has been identified as a high-risk area for this type of tsunami. Waves reaching 18 meters (Leonard, Hyndman and Rogers, 2010, 4) could wreak destruction inside the entire Strait of Georgia. However, those conclusions are based on simulations alone. Since 1660, landslide tsunamis have not created significant damage in the area around the Strait of Georgia.

In brief, Canada's coal corridor is located in an area of high seismicity. For this reason, earthquakes are both frequent and potentially destructive. Destructive earthquakes of high magnitude have already occurred during the 20th century and are likely to happen again in the future. On the bright side, the likelihood of a mega thrust earthquake is very slim. The region's intense seismic activity explains why tsunamis are also likely to happen in the region. While Vancouver Island protects the industry from tsunamis coming from the Pacific, landslide tsunamis are a theoretical threat to Port Metro Vancouver and coal railroads located close to the coast. However, since this threat has not materialized itself in the past and because potential consequences have not yet been properly assessed (due to a lack of historic examples), this type of tsunami will not be considered as likely to damage the infrastructures or interrupt the activities of the coal industry. Therefore, this case study has a score of 0 for the first criterion, 0 for the second, 0 for the third and 1 for the fourth criterion for a total RI score of 1.

Figure 17: Tsunami waves following a simulated Cascadia subduction zone earthquake.



Source: Leonard, Hyndman and Rodgers, 2010

4.2 RI#2: The vulnerability of the logistics chain to hydrologic hazards.

While section 4.1 evaluated the threat presented by natural hazards created by the movement of the Earth, section 4.2 evaluates the threat presented by natural hazards triggered by water. Hydrologic hazards can come from various sources depending on the location, geography and climate of a region.

Floods are the most common types of hydrologic hazards. For this reason, RI#2 will mostly focus on the assessment of the threat they pose to coal logistics chain. They can be triggered by extreme rain falls or snow falls, cyclones, tsunamis, breakings of dams and other catastrophes involving water. Events of this nature can create two types of floods: flash floods and riverine floods. "Flash floods can occur almost anywhere, and result from a relatively short, intense burst of rainfall" while riverine floods "occur following heavy rainfall when watercourses do not have the capacity to convey the excess water. They occur in relatively low-lying areas adjacent to stream and rivers" (Middelmann, 2007, 62). RI#2 evaluates how likely coal logistics chains are to stop functioning or suffer damages from hydrologic hazards according to the criterion presented in table XVII.

Table XVII: Marking system for RI#2.

Criteria	Value
The corridor is situated in an area where hydrologic hazards are likely to happen.	Yes=0
	No=2
The corridor is situated in an area where hydrologic hazards are likely to cause major damages to the infrastructures and interrupt activities for a long period.	Yes=0
	No=2

Hunter Valley coal corridor

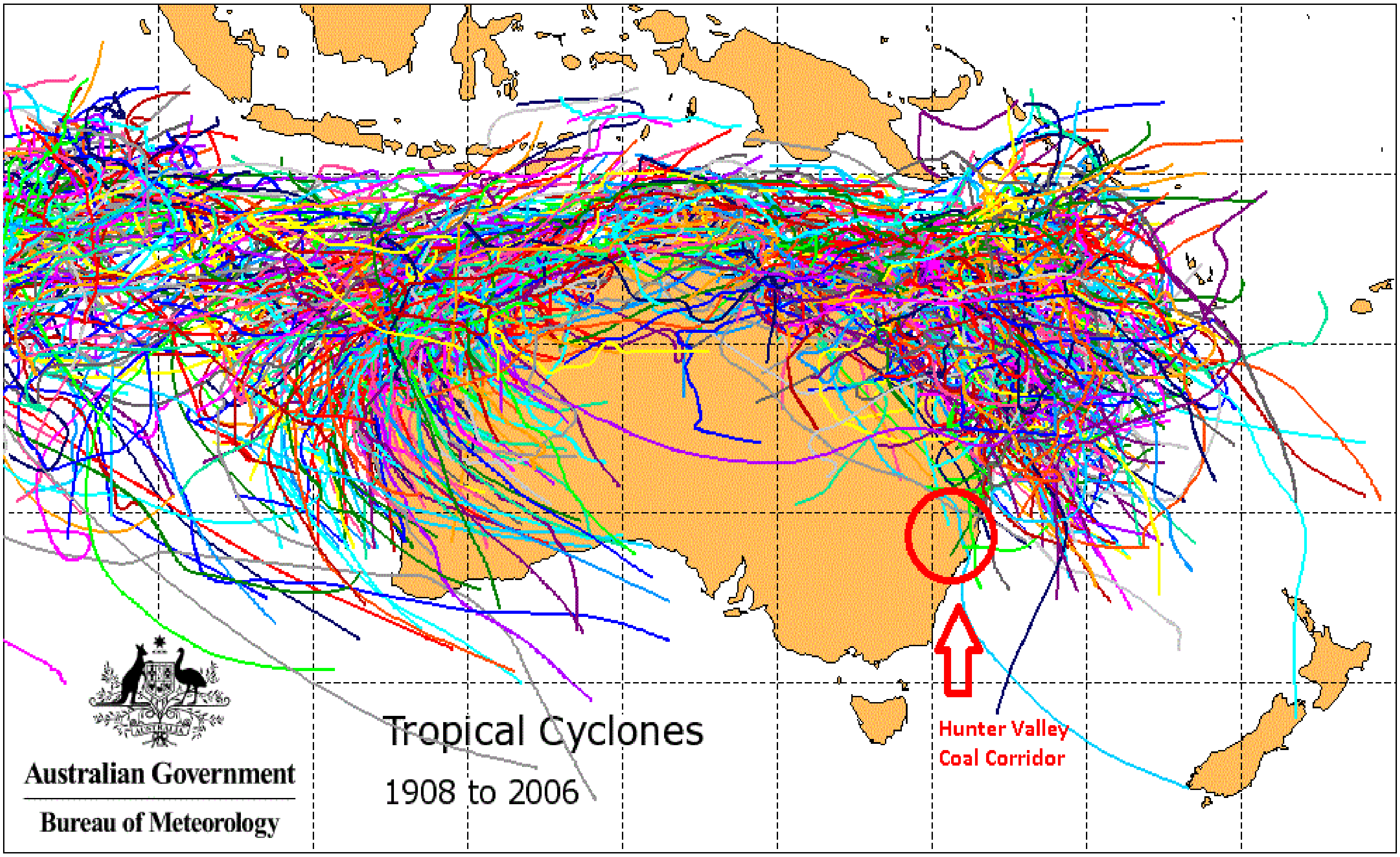
Floods are one of the most frequent and "costly natural disasters in Australia" (Middelmann, 2007, 60). Damages during the 1967 to 1999 period have been estimated at 10.4 billion$ AU. Moreover, numerous flooding have devastated large regions on several occasions since 1999; raising the total cost for this type of catastrophe even higher. The eastern states of Australia, where most of the coal is located, have a long history of floods. From 1958 to 2011, the Australian Government's Bureau of Meteorology has catalogued 66 notable floods in the state of Queensland alone including the December 2010 to January 2011 floods that have paralyzed most of the state's coal industry for several weeks[27]. In New South Wales, notable floods have been fewer, but nonetheless damaging. Among the state's recorded floods, some of the most important events occurred in 1930, 1949, 1955, 1971 and 2007[28].

Australia's long list of floods suggests that the country could simply be a very rainy corner of the Earth. Yet, according to the Australian Bureau of Statistics, "Australia is the world's second-driest continent [...] with average annual rainfall below 600 millimetres per year over 80% of the continent, and below 300mm over 50%" (Trewin, 2006, 39). Australian floods are not the consequence of normal levels of rainfall, but of extreme episodes of rainfall lasting a few days and affecting "the densely-populated coastal river valleys of New South Wales and Queensland (e.g. the Burdekin, Brisbane, Tweed, Richmond, Clarence, Macleay, Hunter and Nepean-Hawkesbury valleys)" (Trewin, 2006, 45).

Two distinct natural phenomena explain the occurrence of random heavy rains in Australia. The first cause consists of the low pressure systems commonly known as tropical cyclones. "Tropical cyclones are the cause of most of Australia's highest-recorded daily rainfalls [...] occasionally bringing heavy rains deep into the inland and causing widespread flooding" (Trewin, 2006, 40). However, figure 18 shows that cyclones usually affect the northern section of the country and have only reached Hunter Valley on a few occasions.

[27] Australian Government Bureau of Meteorology, "Detailed reports on notable Queensland floods," Australian Government, http://www.bom.gov.au/hydro/flood/qld/fld_reports/reports.shtml (accessed February 8, 2012).
[28] Evans, Glenn, Andrew Gissing and Greg Bernard, "The Maitland flood of 2007 operation of the Hunter Valley flood mitigation scheme and the Maitland city local flood plan," Hunter-Central Rivers Catchment Management Authority, http://www.ses.nsw.gov.au/content/documents/pdf/research-papers/42898/The_Maitland_Flood_2007_abstract_paper.pdf (accessed February 9, 2012).

Figure 18: Australian tropical cyclones from 1908 to 2006.



Source: Australian Government Bureau of Meteorology, 2012

The second natural phenomenon is the La Niña, an anomalous cooling of the central and eastern tropical Pacific Ocean generally associated with wetter-than-normal conditions that have contributed to many of Australia's most notable floods (Trewin, 2006, 41). La Niña usually brings higher levels of rain throughout the year peaking during the winter to spring season for south-east Australia. The last events occurred in 1949-51, 1954-57, 1964-65, 1970-72, 1973-76, 1988-89, 1998-01, 2007-08 and 2008-09[29].

The coal industry located in the Hunter Valley region was hit particularly hard by the 2007 floods. Damage in the region reached 1 billion $AU in insurance claims making this catastrophe one of the region's most expensive disasters[30]. One of the most striking images of this

[29] Australian Government Bureau of Meteorology, "La Niña - Detailed Australian Analysis," Australian Government, http://www.bom.gov.au/climate/enso/lnlist/ (accessed February 9, 2012).
[30] ABC News, "Hunter Valley flood bill could reach $1b mark: ICA," ABC News, http://www.abc.net.au/news/2007-07-24/hunter-valley-flood-bill-could-reach-1b-mark-ica/2511202 (accessed February 9, 2012).

catastrophe was the Pasha Bulker coal carrier, pushed aground when it ignored Port of Newcastle's call to return to sea for the duration of the catastrophe (see figure 19).

Figure 19: Pasha Bulker coal carrier pushed aground on the coast of Newcastle.

Source: Steve's marine disaster pages, 2012

In conclusion, the Hunter Valley coal corridor is located where floods happen on a regular basis. Floods in the Hunter Valley region in 2007 and in the states of Queensland in 2010-2011 have shown how vulnerable the logistics chain is to this type of catastrophe. The Hunter Valley coal corridor is located in an area where floods are likely to happen and likely to interrupt activities for a long period. For this reason, this case study has a score of 0 on the first and second criterion for a total RI score of 0.

Mpumalanga coal corridor

South Africa's climatic situation resembles that of Australia. The country is affected by tropical cyclones and, just like Australia, El Niño and La Niña events disrupt normal climate and meteorology patterns. What's more, yearly rainfall levels are relatively low and similar to those of Australia. To be more accurate, "South Africa in general has been approximately 2% hotter and at least 6% drier over the ten years between 1997 and 2006 compared to the 1970s" (Blignaut, Ueckermann and Aronson, 2009, 61). The Mpumalanga and KwaZulu-Natal are the rainiest regions with current yearly average rainfall levels slightly superior to 700mm. While this is true, it is the variance and not the amount of rainfall that is becoming problematic. In every regions of the country besides The Northern Cape and North West provinces, rainfall variance has been increasing resulting in a more unpredictable and extreme meteorology (Blignaut, Ueckermann and Aronson, 2009, 62). The changing variability of rainfalls in South Africa is due, to some extent, to El Niño events that have had a greater effect on South Africa's climate since the last 40 years (Crétat, Richard, Pohl, Rouault, Reason and Fauchereau, 2012, 261).

Two major floods occurred in Mpumalanga's coal corridor in the past years. The first started in South Africa in February 2000, but spread to Botswana and Mozambique in one of Africa's most important natural disasters. "Triggered by exceptionally heavy rain in South Africa,"[31] which lasted for five weeks, the catastrophe was worsened by cyclone Eline which brought even more rain to the region. Structural damage in the provinces of Mpumalanga and Gauteng reached 1 billion $[32]ZAR[33]. The second flood-related catastrophe happened in December 2010 to January 2011 when the state of Queensland in Australia was also hit by major floods. Summer heavy rainfall brought by La Niña caused flooding throughout the entire country[34]. Figure 20 shows

[31] BBC GCSE Bitesize, "LEDC case study: causes and effects of flooding in Mozambique (2000)," BBC, http://www.bbc.co.uk/schools/gcsebitesize/geography/water_rivers/river_flooding_management_rev4.shtml (accessed February 9, 2012).

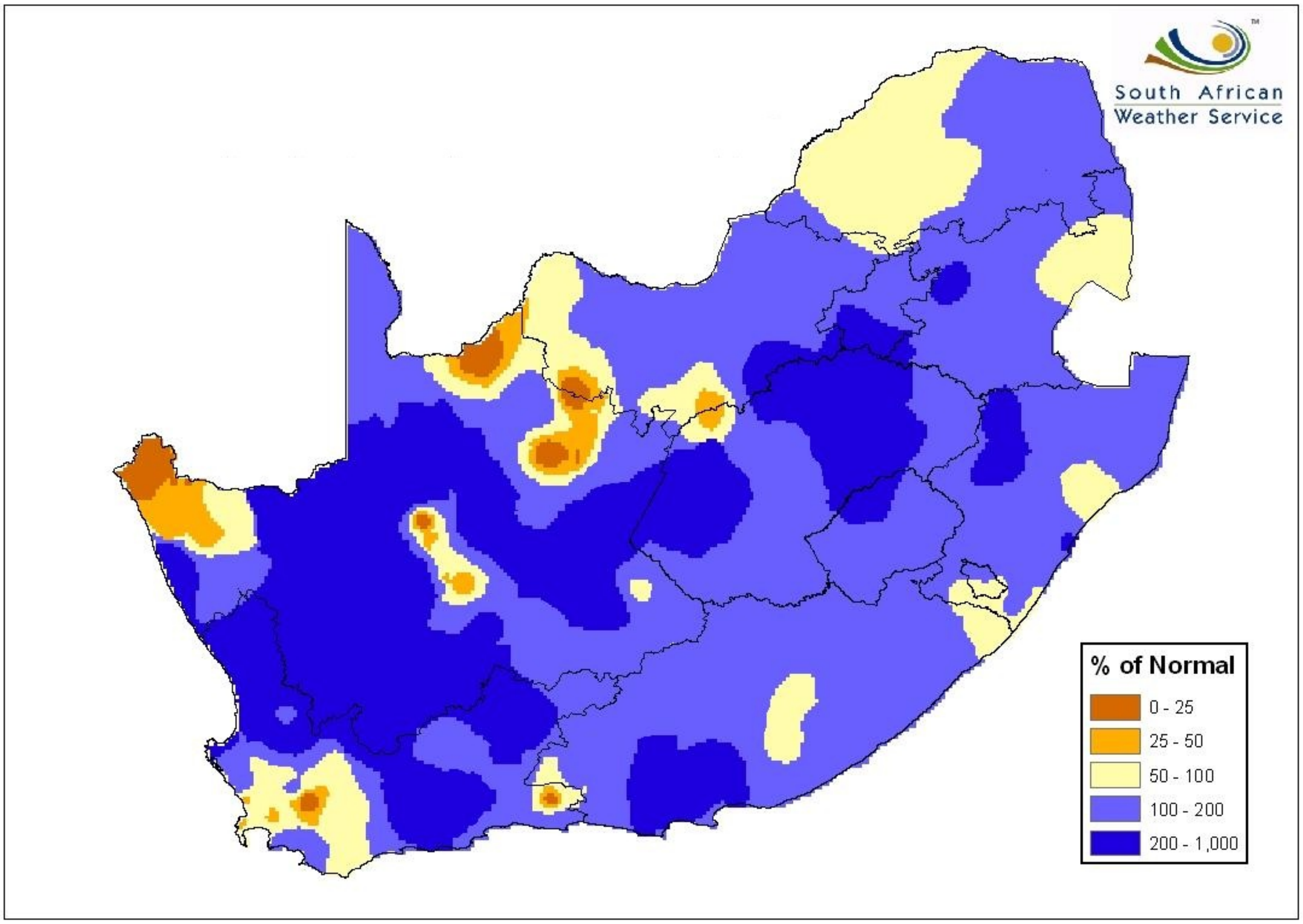
[32] Laing, Mike and Kevin Rae, "Heavy Rain and Floods Over North-Eastern South Africa: 4 to 14 February 2000," South African Weather Service, http://old.weathersa.co.za/Pressroom/2000/2000Feb4to14HeavyRain&Floods.jsp (accessed February 9, 2012).

[33] 131,086,991.10 CAD$

[34] Samuhel, Dave, "La Niña Influenced Flooding in South Africa," AccuWeather.com, http://www.accuweather.com/en/weather-news/la-nina-influenced-flooding-in/44853 (accessed February 9, 2012).

that sections of the Mpumalanga coal corridor received two to ten times the normal amount of precipitations for the month of December.

Figure 20: Percentage of normal rainfall for December 2012.



Source: South African Weather Service, 2012

For the coal logistics chain, flooding meant that "deliveries to Richards Bay Coal Terminal were delayed because the rain halted trains"[35]. Furthermore, large sections of railroads and open-cut coal mines were flooded. According to BHP, coal producers were able to reduce effect of flooding on operations thanks to "preparations before the rainy season"[36]. In brief, the Mpumalanga coal corridor stretches across an area where floods are likely to happen on a

[35] Wild, Franz, "South African Floods That killed 32 May Continue," Bloomberg, http://www.bloomberg.com/news/2011-01-14/south-africa-army-ready-as-floods-that-killed-32-may-continue-over-weekend.html (accessed February 9, 2012).

[36] Worldal.com, "BHP, Xstrata, Anglo Coal Operations Disrupted Amid Rain in South Africa," Worldal.com, http://www.worldal.com/news/australia/2011-01-07/129436650032670.shtml (accessed February 9, 2012).

regular basis. Furthermore, heavy rainfall, tropical cyclones and La Niña are the reasons why floods are usually destructive and likely to interrupt activities for a long time. Thus, South Africa has a score of 0 on the first criterion and 0 on the second for a total RI score of 0.

Canadian coal corridor

Canada's hydrologic hazards are somewhat different than those that affect Australia and South Africa. In the previous two case studies, tropical cyclones and La Niña atmospheric oscillation were the most frequent triggers of heavy rainfall episodes which, in turn, created flooding. In Canada, tropical cyclones usually affect the eastern part of the country. Cyclones and hurricanes on the Pacific coast occur closer to the Equator and do not reach as far north as Canada. El Niño and La Niña events in Canada also have smaller impacts than in Australia and South Africa. According to Environment Canada, parts of Alberta have only 40% chances of precipitation extremes during El Niño winters while small regions in southern British Columbia only have 40% chances of precipitation extremes during El Niño springs[37]. On the other hand, La Niña only creates a 40% likelihood of precipitation extremes over most of Canada's coal corridor during the winter months[38].

In other words, neither tropical cyclones nor El Niño or La Niña events represent frequent causes of floods in Canada. Most floods in Canada are actually triggered by the sudden melting of snow. In the same way, heavy rainfall caused by thunderstorms is another important source of floods. Flood risks in the Fraser Valley, including Port Metro Vancouver and important stretches of the corridor's railways are particularly high. In this region both heavy rainfall and snow melt are likely to trigger floods. Natural Resources Canada explains that “floods along the Fraser River occur during early summer when warm rainy weather rapidly melts mountain snowpack. Floods along smaller streams can occur at any time of the year, but are particularly common during torrential autumn rains. Coastal areas can be flooded by the sea when severe

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[37] Environment Canada, “El Niño Extreme Climate Conditions,” Environment Canada, http://www.ec.gc.ca/adsc-cmda/default.asp?lang=En&n=5AA1FAB4-1#precip1 (accessed February 9, 2012).

[38] Environment Canada, “La Niña Extreme Climate Conditions,” Environment Canada, http://www.ec.gc.ca/adsc-cmda/default.asp?lang=En&n=5AA1FAB4-1#precip1 (accessed February 9, 2012).

storms coincide with high winter tides"[39]. Although the Fraser River has flooded more than 25 times over the past century, no serious events occurred since 1948. Potential damages to infrastructures are therefore difficult to assess. However, since 1948 "governments have spent $160 million building and improving dykes along the Fraser River, allowing more than $13 billion worth of new development on the floodplain behind the dykes"[40]. Those investments have helped protect coal infrastructures from flood-related damages.

The most dangerous hydrologic hazard to affect the Canadian coal corridor occur during the winter months when precipitations can change from rain to snow and form layers of ice on railways following temperature variations. Such hazards usually occur in high altitudes where CPR's coal railroad crosses the Rocky Mountains. As mentioned previously, railroads are vulnerable to snow melts that create floods, but heavy snow falls and ice formations on railroads are more frequent and equally dangerous. The issues associated with snow and ice are numerous and range from reduced visibility for train operators to track deformations caused by ice and, in the most extreme cases, train derailments. For example, on March 8th 2011, 27 of a 115 cars coal train operated by CPR derailed near Fernie in British Columbia. According to the Transportation Safety Board of Canada's investigation report "temperature variations involving freeze/thaw cycles, rain, snow and snow showers, along with melt water" (Transportation Safety Board of Canada, 2011, 8) produced ice formations and accumulation at the base of the rail over the previous four weeks. Track deformation caused by previous trains at the derailment site which had already been recorded by CPR maintenance inspections were deemed acceptable by maintenance standards. However, the temperature variations and ice build-up of the previous weeks aggravated track canting to unacceptable levels which caused the derailment of CPR's coal train. Following this incident, CPR replaced damaged track sections and reduces maximum train speeds in the area. The Transportation Safety Board of Canada also modified a rule concerning track safety to force train operators to conduct track inspections at least twice a year (Transportation Safety Board of Canada, 2011, 11). Through their ability to quickly deteriorate

[39] Natural Resources Canada, "When the Fraser Floods," Natural Resources Canada, http://www.nrcan.gc.ca/earth-sciences/products-services/mapping-product/geoscape/vancouver/6036 (accessed February 9, 2012).

[40] Natural Resources Canada, "When the Fraser Floods," Natural Resources Canada, http://www.nrcan.gc.ca/earth-sciences/products-services/mapping-product/geoscape/vancouver/6036 (accessed February 9, 2012).

the operating conditions of the railway transportation sector, winter time hydrologic hazards such as snow and ice are constant threat to the logistics chain.

In conclusion, only a small section of Canada's coal corridor is likely to be affected by floods. The Fraser Valley region can be considered as a potentially risky area even if floods have not recently caused damages to coal infrastructures. Furthermore, large scale destructive floods like those mentioned in the previous case studies have not recently happened in British Columbia and Alberta. However, the railway transportation sector is vulnerable to disruptive events related to winter conditions such as snow falls, snow melts and ice build-ups. Track damage and derailments on CPR's coal line are a constant reminder that for the Canadian coal corridor, the risk presented by such hazards is serious. Therefore, Canada has a score of 0 on the first criterion and 0 on the second for a total RI score of 0.

4.3 RI#3: The vulnerability of the logistics chain to atmospheric hazards.

In its attempt to assess the vulnerability of the logistics chain to hydrologic hazards, section 4.2 of this research has already analyzed atmospheric hazards related to rain and flooding. For this reason, atmospheric events such as El Niño and La Niña will not be mentioned again in section 4.3. RI#3 analyzes events that are atmospheric both in nature and in effect. Undoubtedly, the most important manifestation of atmospheric events is the action of the wind. As a result, the focus is put on two wind-related atmospheric hazards: severe storms and hurricanes.

Severe storms are natural catastrophes that encompass several smaller natural hazards. They can be divided in two smaller categories: large-scale storms and thunderstorms. Severe storms can be defined as "atmospheric disturbances usually characterized by strong and hazardous winds, frequently combined with heavy rain, snow, sleet, hail, ice and/or lightning and thunder" (Middelmann, 2007, 83). Tornadoes and waterspouts are also common sightings during severe storms.

On the other hand, a hurricane is a low pressure system with average winds of at least 118 kilometres per hour[41]. In some cases, hurricanes can cover regions several hundred kilometres wide with gusts exceeding 280 kilometres per hour. Such hurricanes can cause property damage by turning "airborne debris into potentially lethal missiles" (Middelmann, 2007, 44) and can be dangerous for vessels at sea or moored in harbours. To avoid confusion, it is important to note that such catastrophes have different names depending on the region where they appear. "They are called hurricanes when they occur in the Atlantic, Caribbean, Gulf of Mexico and Eastern Pacific and typhoons when they occur in Northwest Pacific, while when these storms occur in the Indian Ocean they are referred to as tropical cyclones"[42]. According to the criterion presented in table XVIII, RI#3 evaluates how likely coal logistics chains are to stop functioning or suffer damages as a result of both severe storm and hurricanes.

[41] Storm Chasing South Africa, "How Hurricanes Form," Storm Chasing South Africa, http://www.stormchasing.co.za/articles-and-news/storm-chasing-information/education-articles/64-understanding-storms/172-how-do-hurricanes-form (accessed March 19, 2012).

[42] Storm Chasing South Africa, "How Hurricanes Form," Storm Chasing South Africa, http://www.stormchasing.co.za/articles-and-news/storm-chasing-information/education-articles/64-understanding-storms/172-how-do-hurricanes-form (accessed February 10, 2012).

Table XVIII: Marking system for RI#3.

Criteria	Value
The corridor is situated in an area where severe storms are likely to cause minor damages to the infrastructures and interrupt activities for a short period.	Yes=0 No=1
The corridor is situated in an area where severe storms are likely to cause major damages to the infrastructures and interrupt activities for a long period.	Yes=0 No=1
The corridor is situated in an area where hurricanes are likely to happen.	Yes=0 No=1
The corridor is situated in an area where hurricanes are likely to damage the infrastructures and interrupt activities.	Yes=0 No=1

Hunter Valley coal corridor

The state of New South Wales is subject to severe storms during most of the year. During such events, sustained winds and gusts of wind range from 63 kilometres per hour to 150 kilometres per hour on average (Middelmann, 2007, 83). Likewise, thunderstorms affect the east coast of New South Wales on a regular basis. The Hunter Valley region usually has 30 to 50 thunder-days of various intensity during a year (Trewin, 2006, 48). On such days, thunderstorms are likely to be followed by heavy wind of 90 kilometres per hour to 160 and even 196 kilometres per hour in the most extreme cases. Tornadoes are also a common sight on thunderstorm days. 360 tornadoes have been recorded in New South Wales from 1795 to 2003, “but the incidence is certainly far greater given that many tornadoes occur in uninhabited areas and go unreported” (Middelmann, 2007, 86). All wind-related hazards are dangerous because of their ability to lift objects in the air and move them at high speed effectively turning anything into potential missiles. In such conditions, any building is at risk and coal infrastructures can easily be damaged by even the less severe storms or any other wind-related hazard. Furthermore, ships at sea are also at risk since heavy winds can push vessels ashore or even capsize them. Until now, the coal industry has been relatively spared from wind-related large scale destruction. However, "the most damaging thunderstorms, in terms of hail and wind gusts, occur in the eastern halves of New South Wales and southern Queensland" (Trewin, 2006, 48). In fact, Australia's most costly natural disaster was the April 14th 1999 Sydney thunderstorm which occurred only 118 kilometres away from Newcastle. Heavy winds transformed hailstones of 9 centimetres in diameter into flying projectiles and causing losses evaluated at 1.7 billion$ AU (Trewin, 2006, 48).

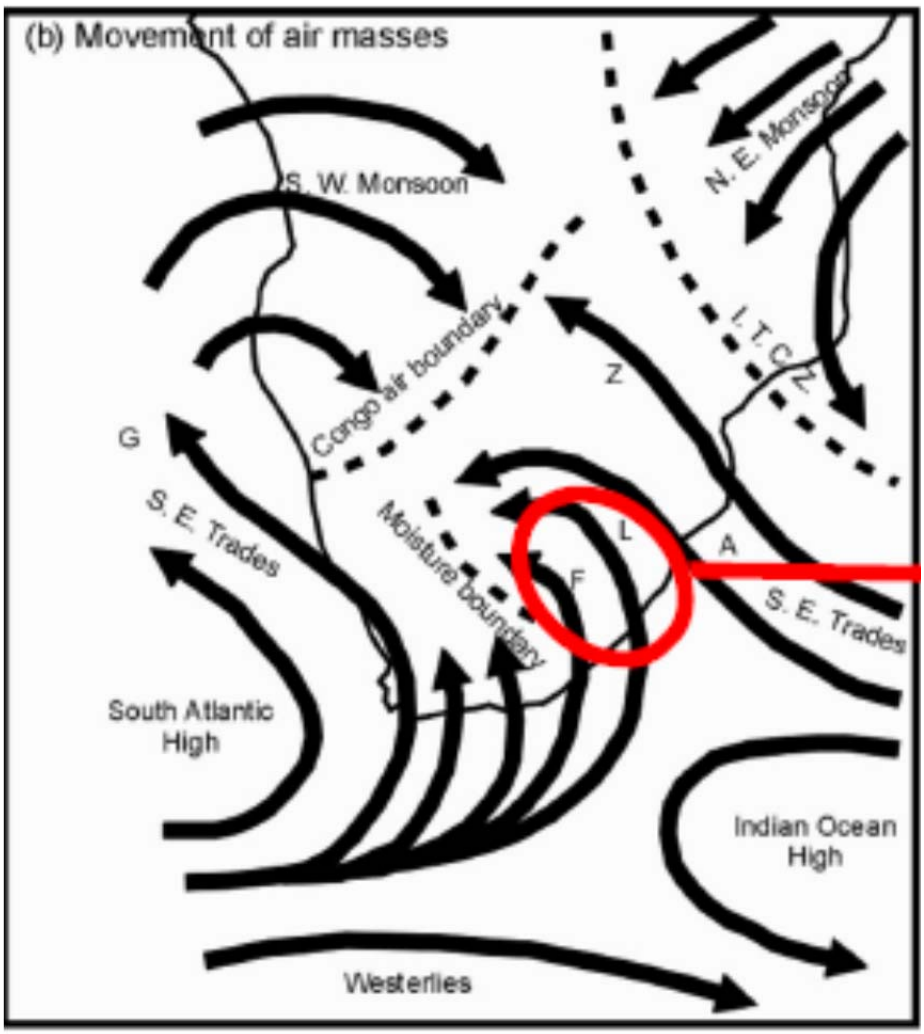
In Australia, hurricanes are known as severe tropical cyclones. (category 4 or 5). On average, three tropical cyclones form on the coasts of Queensland while three more form off the coasts of northern Australia (Trewin, 2006, 41) during tropical cyclone season which starts in November 1st and ends on the 30th of April (Middelmann, 2007, 43). Very few tropical cyclones make it as far south as the Hunter Valley region. Figure 18 shows that the Hunter Valley Coal Corridor has only been affected by tropical cyclones on very few occasions; not enough to assert that tropical cyclones are likely to happen in the region. Furthermore, tropical cyclone lines over New South Wales are either blue or green which represent the two weakest intensities on a scale of 6.

In conclusion, wind-related natural hazards are frequent in the Hunter Valley region. Severe storms are usually dangerous and likely to cause both minor and major damage to coal infrastructures. On the other hand, tropical cyclones are both uncommon and usually not very destructive in the Hunter Valley region. For this reason, Australia has a score of 0 on the first criterion, 0 on the second, 1 on the third and 1 on the fourth for a final RI score of 2.

Mpumalanga coal corridor

Strong winds and gusts of wind are common throughout the country especially on the eastern coast of South-Africa. While the country is crossed by various air masses which bring winds of different speeds, the Mpumalanga Coal Corridor is mostly affected by the South Eastern Trades as shown in figure 21. As we can see, winds come from all directions and bring with them dry or moist air masses depending on their origin. However, wind-related damages are usually not caused by normal wind and air movement. In South Africa, most wind-related damage has been triggered by thunderstorms (Kruger, Retief, Goliger, 2011, 5).

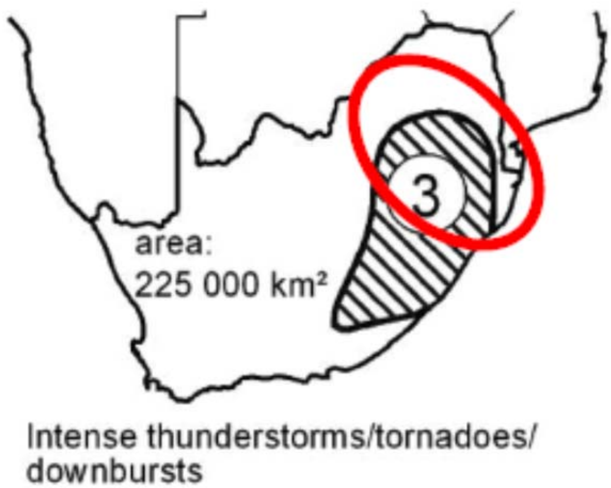
Figure 21: Basic movement of air masses over South Africa.



Source: Kruger, Retief and Goliger, 2011

Thunderstorms are sometimes created when different air masses meet. For example, when air coming from the Indian Ocean meets air coming from the Atlantic Ocean, thunderstorms are more frequent (Kruger, Goliger, Retief, Sekele, 2010, 4). As a result, most of the corridor is located in an area where winds are considered to be the most damaging in the country. In other words, Richards Bay, large sections of coal railways and almost the entire coal mining network (which are located inside the red oval in figure 22) are in an area of intense thunderstorms.

Figure 22: South Africa's high winds and dangerous thunderstorms area.



Source: Kruger, Retief and Goliger, , 2011

Such thunderstorms happen throughout the year, but they become more frequent during the summer season. In addition, tornadoes usually accompany thunderstorms in this region of the country. From 1905 to 1997, most tornadoes have been recorded in Gauteng, the Free State and KwaZula-Natal while Mpumalanga has only been hit by 4 tornadoes during that period. Luckily, South African tornadoes usually create light damage[43]. Records of wind-related damages to coal infrastructures in South Africa are hard to find. However, since heavy winds and thunderstorms are a common sight in the area, coal infrastructures in the Mpumalanga Coal Corridor have most likely already been damaged by such hazards in the past.

In South Africa, tropical cyclones are not as frequent as in northern Australia. As a matter of fact, seven "cyclones affected the eastern parts of South Africa in a 43-year period, from 1962 to 2005[44]". They tend to form between November and April and affect only the northern and eastern regions of the country[45]. During such events, destructive winds sweep through Mpumalanga and KwaZulu-Natal. As an illustration, tropical cyclones Domoina in January 1984,

[43] South African Weather Service, "South African Tornadoes," South African Weather Service, http://old.weathersa.co.za/References/SATornadoes.jsp (accessed February 12, 2012).

Eline in February 2000, but especially Imboa in February 1984 caused "extensive damage to coastal infrastructures as far south as Durban[46].

In conclusion, the Mpumalanga Coal Corridor is located in an area where thunderstorms and strong winds are likely to cause both minor and major damage to infrastructures and interrupt activities for a long time. Moreover, the corridor is also located in an area where strong tropical cyclones are likely to happen and likely to damage the infrastructures. For this reason, this corridor has a score of 0 and all 4 criterion for a final RI score of 0.

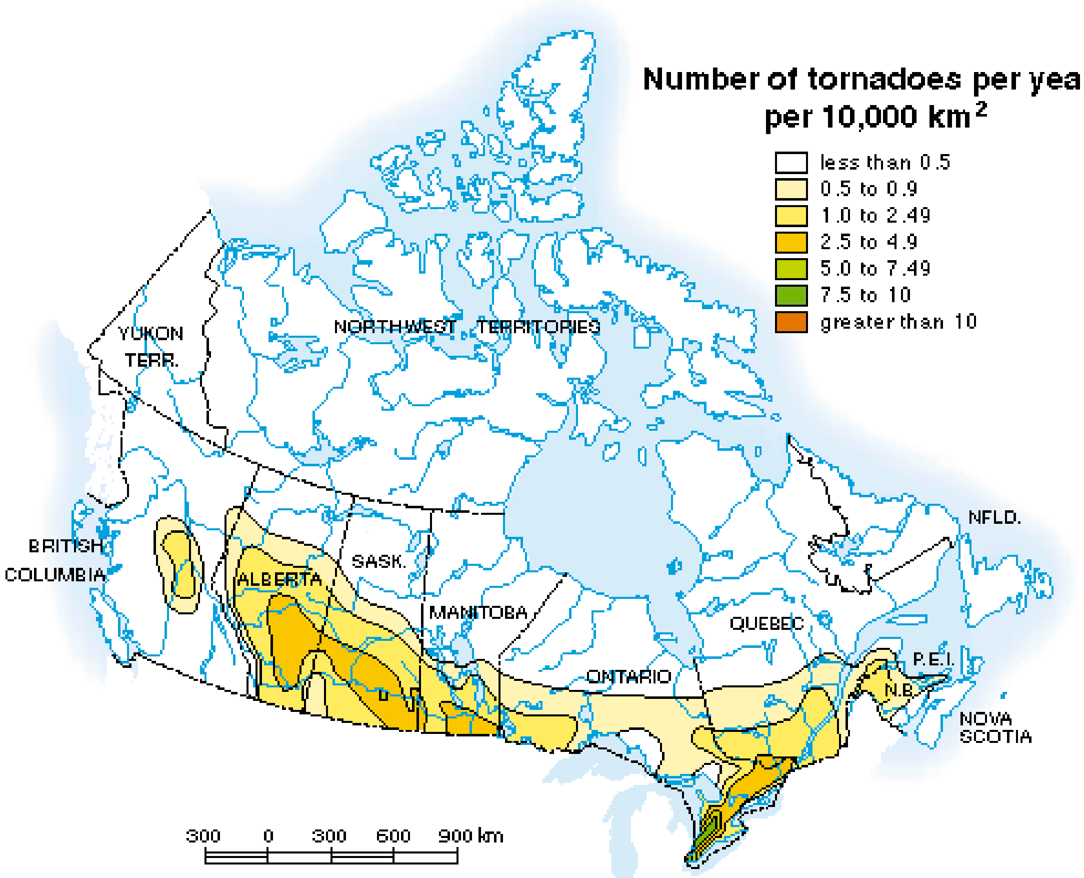
Canadian coal corridor

During thunderstorms, Alberta and small regions in British Columbia can be hit by small to medium-size hailstones three days in a year on average. Tornadoes also affect some sections of the Canadian coal corridor, but are generally rare events that pose no real concern for the coal industry. Figure 23 gives a better idea of tornado activity over the region. Furthermore, British Columbia and Alberta are not provinces of particular strong winds. According to Environment Canada, winds have an average speed of 3-5 meters per second over the majority of the region[47]. If those two provinces do not seem to be crossed by very strong winds, El Niño has a very strong influence on December to March winds. During December and January, winds are stronger with a mean peak wind gust change of 20 to 100% normal wind force in January[48]. In other words, winds that are normally harmless become much more dangerous during El Niño periods. The best example of the threat posed by strong winds is given in the West shore Terminals Investment Corporation annual information form of March 30th 2011. The organization explains how "the terminal is exposed to windstorms. West shore manages this risk by suspending loading operations during periods of high winds, but it is not always possible to anticipate sudden increases in wind speed or wind gusts, as demonstrated by a windstorm in

[44] South African Weather Service, "What is a tropical cyclone?," South African Weather Service, http://old.weathersa.co.za/References/Cyclones.jsp (accessed February 12, 2012).
[45] South African Weather Service, "What is a tropical cyclone?," South African Weather Service, http://old.weathersa.co.za/References/Cyclones.jsp (accessed February 12, 2012).
[46] South African Weather Service, "Tropical cyclone Dera," South African Weather Service, http://old.weathersa.co.za/Pressroom/2001/2001MarchTCDera.jsp (accessed February 12, 2012).
[47] Canadian Wind Energy Atlas, "Overall map," Environment Canada, http://www.windatlas.ca/en/maps.php?field=EU&height=50&season=ANU (accessed February 12, 2012).
[48] Environment Canada, "El Niño- Extreme Climate Conditions," Environment Canada http://www.ec.gc.ca/adsc-cmda/default.asp?lang=En&n=5AA1FAB4-1 (accessed February 12, 2012).

2003 that caused significant damage to the loading facilities at Berth 2" (Westshore Terminals Investment Corporation, 2011, 12). Despite all this, such events remain isolated incidents for the coal industry because even if thunderstorms are relatively frequent, wind-related hazards have not been a real threat in the past and cases of large scale destruction have yet to occur.

Figure 23: Canada Tornado hazard map.



Source: Natural Resources Canada, 2012

Hurricanes triggered in the Gulf of Mexico and in the Caribbean have little to no effect in British Columbia and Alberta. Hurricanes require warm waters to form which explains why hurricanes cannot happen in the colder waters of the Pacific coast. At the very least, natural hazards that happen on the western side of the Pacific, near the coasts of Asia, can sometimes travel to this side of the ocean and bring minor disturbances in British Columbia.

To conclude, the Canadian coal industry is located in an area where, on rare occasions, wind-related hazards only cause minor damage to the infrastructures. Similarly, the corridor is located in a favorable environment where hurricanes do not happen and consequently do not cause any damage to the infrastructures. This case study has a score of 0 on the first criterion and 1 on the remaining criteria for a total RI score of 3.

4.4 Cumulative scores of chapter 4.

In this chapter, the resilience of the logistics chain to environmental hazards has been analyzed with the help of three risk indicators. The first risk indicator evaluated the resilience of the logistics chain to seismic hazards. For this RI, the Hunter Valley and Mpumalanga coal corridors received an equal score since seismic activity in those two countries is average. Their location, far from tectonic plate edges explains this reality. On the other hand, British Columbia and Alberta are extremely close to plate edges and to the Cascadia subduction zone making it a much more dangerous zone. The second RI of this chapter analyzed the resilience of the logistics chain to hydrologic hazards which were centered on what we call floods. In this section, all three case corridors proved to be at risk of hydrologic hazards and received the worst possible scores. Finally, the third RI of this chapter evaluated the resilience of the logistics chain to wind-related hazards. In this section, the Canadian coal corridor ranked first followed by the Hunter Valley and finally, the Mpumalanga coal corridors. Cumulative RI scores for chapter 4 are presented in table XIX.

Table XIX: Cumulative scores for chapter 4.

Case studies	RI#1	RI#2	RI#3	Cumulative Score
Hunter Valley coal corridor	2	0	2	4
Mpumalanga coal corridor	2	0	0	2
Canadian coal corridor	1	0	3	4

In conclusion, the risk indicators of chapter 4 were chosen to demonstrate how environmental hazards can have huge potential impacts on the logistics chain of the industry. The most important conclusion to come out of this chapter is that geography is extremely important when it comes to assessing the likelihood of certain disasters. Some countries are located in areas where some natural hazards are frequent while other countries are located in areas where the same natural hazards do not happen as often. The most striking conclusion to come out of this chapter is the vulnerability of all corridors to hydrologic hazards. While such hazards might not be as destructive as earthquakes, tsunamis or tropical cyclones, the frequency at which issues associated with rain falls or snow falls happen makes them as dangerous as any other natural disaster. Furthermore, the low cumulative scores of all coal corridors show how vulnerable coal logistics chains are to natural hazards. If risk levels could be expressed as percentage where 100% would mean that natural hazards pose no risks whatsoever to the logistics chain while 0% would mean that the risk and dangers of natural hazards are alarming, the Hunter Valley corridor would be at 33%, the Mpumalanga at 17% and the Canadian corridor at 33%.

In Canada, environmental hazards are a serious issue especially when it comes to seismic and hydrologic hazards. In this context, resilience can be improved by human actions and decisions such as the construction of infrastructures with improved levels of resistance to ground shaking. Similarly, the Hunter Valley corridor is very vulnerable to hydrologic hazards, but more sheltered from the negative impacts of seismic hazards. For South Africa, the natural environment in which the coal logistics chain is located is much more a risk than either the Canadian or Hunter Valley corridors. Environmental hazards are both numerous and dangerous.

In this context, decision makers must consider those risks in every decision they make. Improving the industry's resilience to environmental hazards has to be a permanent quest. For all three case studies, the following three basic rules are the most important guidelines to improving the industry's resilience to environmental hazards.

1. Be aware of the natural environment in which your industry is located. Knowing that certain environmental hazards are likely to happen in your area is half the battle.
2. Take the necessary measures to ensure that the activities won't suffer in case of catastrophes. This can be done by investing in construction and engineering to develop more resistant infrastructures or by developing standard operating procedures adapted to the risks of natural disasters.
3. Be aware of the possible consequences natural hazards can have. Disasters have happened in the past and their consequences can be devastating. In some cases, the industry could be seriously damaged and unable to resume operations for several months.

In conclusion, it is important to remember that climate change will probably worsen the current situation by making natural hazards more dangerous and more difficult to anticipate. Natural disasters are expected to be more frequent and more devastating as a result of climate change in the coming years. For this reason, when it comes to improving the resilience of the coal industry to environmental hazards, it is even more important to make the proper decisions now.

In this chapter, each risk indicator has been treated equally even if the occurrence or the level of destruction can vary greatly from one indicator to another. In terms of occurrence, atmospheric and hydrologic hazards usually occur more frequently than seismic hazards. Floods, snow melts, hurricanes and tornadoes are seasonal events that can occur frequently within a year and affect logistics chains on a repetitive basis. On the other hand, earthquakes and tsunamis are rare events that disrupt logistics chains only once every 10 or 50 years, if not more. In terms of destruction, hydrologic and atmospheric hazards are usually less damaging than seismic hazards which can cause large scale destruction and shut down logistics chains for extended periods of time. The equal weight given to each indicator reflects this balance between occurrence and destruction.

Chapter 5: Analyzing the relationship between stakeholders and the resilience of the logistics chain.

Chapter 4 demonstrated how logistics chains are vulnerable to events that are difficult to control or forecast. Environmental hazards such as tropical cyclones can be forecasted a few hours or days in advance, but earthquakes and tsunamis are almost impossible to predict. In addition, most environmental disasters have the potential to disrupt operations for an extended period of time. Preparing for natural disasters and trying to reduce the damage they incur on coal logistics chains is both difficult and expensive.

Chapter 5 explains how stakeholders influence the resilience and overall effectiveness of logistics chain through governance. Unlike environmental hazards which cannot be controlled, governance can be improved and its effects on logistics chains can be controlled and modified. In other words, the resilience of the logistics chain can be improved if stakeholders maintain efficient governance practices. Using five governance indicators, this chapter will show how stakeholders can improve resilience in the coal industry.

First, resilience can be improved when important stakeholders of the chain adopt efficient planning and development strategies. In such cases, the entire logistics chain can avoid the effects of disruptive events altogether. Appropriate planning and the ability to forecast changes and threats greatly influence a system's resilience according to Therrien's definition of resilience (section 1.2). The efficiency of planning and development strategies is evaluated for each case study in GI#1.

GIs# 2, 3 and 4 will analyze corporate concentration in the extraction, railway transportation and port activities sectors. The objective of those three indicators will be to determine whether high corporate concentration or low corporate concentration lead to higher levels of resilience. In the first case, the industry is made of bigger, but fewer actors. The concentration of actors reduces the number of participants included in the decision making process which makes cooperation and communication easier to maintain. When communication between actors is promoted and decisions are made to favour collective benefits over individual needs, efficiency and resilience levels throughout the logistics chain can be raised significantly. Therefore, the actors' ability to cooperate and communicate on a regular basis is an essential asset of an efficient logistics chain. Failure to develop this ability can have negative consequences on the logistics chain as mentioned in a report by the Australian Government.

> The efficient operation of coal supply chains requires logistics management that coordinates daily operations between all parties in the coal chain. However, each service provider typically designs its operations around its own requirements rather than the needs of the coal chain as a whole. The lack of coordination in scheduling coal movements between mines and loading on ships can constrain the coal chain and contribute to costly bottlenecks. These inefficiencies can impact significantly on coal chains that are running at or near full capacity (Australian Government, 2005, 21).

However, high concentration also has disadvantages such as low competition and fewer incentives in innovation and efficiency. In the case of low concentration, more stakeholders are involved in the activities of the chain. Competition is also more present which can yield several benefits in terms of productivity, efficiency and service quality. However, communication and consensus are usually more difficult to achieve.

The industry's corporate concentration is evaluated for each case study in GI#2 for the extraction phase, GI #3 for the railway transportation phase and GI #4 for the port activities phase. Finally, GI #5 evaluates market segmentation among each case study's national clients. The evaluation process of GIs #2, 3 and 4 will be based on the hypothesis that high concentration yields more benefits in terms of resilience than low concentration. For this reason, the marking systems of those three indicators will award higher scores for case studies where the industry's corporate concentration is higher.

5.1 GI#1: The efficiency of planning and development strategies.

To assess the efficiency of planning and development strategies, section 5.1 will list the most important problems inherent to each case study. Afterwards, it will determine whether or not those problems are a consequence of poor planning[49] and development strategies. Table XX explains in more details the logic behind GI#1's marking system.

Table XX: Marking system for GI#1.

Criteria	Value
Planning and development strategies have been efficient and have contributed to a more resilient logistics chain.	3
Poor planning and development strategies have caused problems, but have not significantly affected the resilience of the logistics chain.	2
Poor planning and development strategies have created major problems that negatively affect the resilience of the logistics chain.	1

Hunter Valley coal corridor

Poor planning and development strategies are not usually identified as the main sources of problems in the Hunter Valley logistics chain. In fact, efficient planning and development strategies among most actors of the chain have managed to establish the Hunter Valley network as one of the most important producers in the world. The main problems of the Hunter Valley chain have to do with the large number of actors and their inability to align operations (which will be discussed in more details in section 5.2). According to the Australian-based international law firm Freehills, the main problem is that port and rail infrastructures are not being managed on a "system-wide basis"[50] which reduces efficiency. The Hunter Valley Coal Chain Coordinator (HVCCC) reaches similar conclusions when stating that most problems inherent to the system

[49] Poor planning constitutes any decision or strategy that has led to a degradation of the efficiency and quality of operations.
[50] Strauss, Adam, "Hunter Valley rail access undertaking finally commences," Freehills, http://www.freehills.com/7369.aspx (accessed March 02, 2012).

are a result of corporate planning on an individual level[51]. Moreover, many private consultation firms which have analyzed capacity constraints in the Hunter Valley coal chain have reached conclusions that support HVCCC's point of view. For example, in a review of coal supply chains, the economic consulting firm *Synergies* explains how “a lack of alignment between participants in relation to optimising supply chain performance; and information gaps, which impede planning and operations” have been the major causes of problems (Synergies Economic Consulting Pty Ltd., 2009, 5).

Nonetheless, in light of this situation, the creation of the Hunter Valley Coal Chain Planning Group (HVCCPG) in June 2003, which became the Hunter Valley Coal Chain Logistics Team (HVCCLT) in 2004 and its transition to the HVCCC in August 2009, are excellent examples of good planning and development strategies. Indeed, coal transporters and producers came together to align operations and development to reduce capacity constraints in the network. Through this single controlling entity, the entire logistics chain was able to achieve positive performance and capacity gains by solving problems inherent to the system in place (for more details on logistics teams, see the annex). In conclusion, planning and development strategies have not been major sources of problems for the Hunter Valley coal chain. Furthermore, the creation of the HVCCC demonstrated how the Australian coal industry actually implanted efficient planning and development strategies that allowed some of the industry's most important problems to be solved. Therefore, this case study has a score of 3 for GI#1.

Mpumalanga coal corridor

The South African coal industry missed most business opportunities that arose on the export market following the commodity boom of the last few years. Furthermore, chapter 3 indicated that the industry has been affected by capacity constraints and costly derailments. Unlike its Australian counterpart, poor planning and development strategies are at the heart of most of the logistics chain's problems and failures. To be even more accurate, *Transnet*, the state-owned rail transporter which has a monopoly on the entire rail transportation sector has failed to establish efficient planning and development strategies. The company's poor governance is

[51] Hunter Valley Coal Chain Coordinator Limited, “History,” Hunter Valley Coal Chain Coordinator Limited, http://www.hvccc.com.au/AboutUs/Pages/History.aspx (accessed March 02, 2012).

actually twofold since on one side, “there is an apparent lack of planning and investment coordination between Transnet, coal producers and ports” (Eberhard, 2011, 21) which has prevented rail capacity to reach 91Mt to match Richards Bay's expansion. On the other hand, Transnet's bad decisions can also be explained by its status as an integrated rail-ports-pipeline state-owned monopoly. The transporter's inefficient development strategies are a result of the company's focus on other areas of its business, namely oil pipelines and port management which have been much more lucrative in the past years. For instance, “in 2009 rail contributed R241M to its profit, pipelines R590M and ports R5262M” (Eberhard, 2011, 21) which explains why Transnet has decided not to invest in coal infrastructure upgrades. In other words, its monopoly-status has led Transnet to adopt poor governance and inefficient strategies that have reduced efficiency, value proposition to clients, resilience and infrastructure reliability while increasing “the logistics cost burden” (Thompson, 2009, 11). In its 2008 annual report, Transnet recognizes some of its wrongs, stating that “the company was not sufficiently oriented towards its customers - in fact, Transnet's inefficiencies were rubbing off on some of its major customers in the form of real losses of international opportunities and low efficiencies resulted in congestion at the ports and unstable service delivery in freight transport” (Thompson, 2009, 12). Summing up, it is clear that poor planning and development strategies on Transnet's part have led to several of the Mpumalanga coal logistics chain's problems. As a result, this case study has a score of 1 for GI#1.

Canadian coal corridor

As chapter 3 demonstrated, the Canadian coal industry benefits from efficient transport infrastructures. Until recently, the major constraint to the rapid development of the coal industry in Canada has been geographic in nature. Long distances between coal mining areas and Port Metro Vancouver have maintained transport costs at high levels, putting the entire industry at a comparative disadvantage. However, if coal prices remain high on world markets, the Canadian coal industry could grow rapidly with increases in production and throughput. In such a context, planning and development strategies in all spheres of the industry could really be put to the test in the upcoming years as the level of activity increases and potential bottlenecks become more likely. This being said, it is logical to assume that the current state of the coal logistics chain in Canada is a good indication of the success of recent planning and development strategies. In fact, the following features of the Canadian coal logistics chain are good examples of the efficiency of recent planning and development strategies:

- Continuous increase in exports over the last few years combined with several mining development projects[52];
- High capacity trains and railroads; and
- Sufficient port capacity at Port Metro Vancouver completed with capacities at the Port of Prince Rupert.

Despite the efficient operational environment of the Canadian coal corridor, it is important that actors remain proactive and aware of potential risks that usually arise when production and throughput increase rapidly. In this regard, Synergies states that “coordination problems in the supply chains have really only emerged when capacity has become constrained. However, it is also evident that participants should not wait for capacity to become constrained before putting a framework in place to be able to optimize supply chain performance” (Synergies Economic Consulting Pty Ltd., 2009, 36).

Planning and development have so far been efficient and have contributed to a more resilient logistics chain. Nevertheless, when trying to increase resilience levels, planning and development strategies, coordination and communication must all be fostered and maintained at all times. Such determination is especially important in the case of the Canadian coal corridor since it has not yet “experienced capacity constraints, but has the potential to do so in the future” (Synergies Economic Consulting Pty Ltd., 2009, 6). In conclusion, this case study has a score of 3 for GI#1.

[52] For a list of mining development projects, see: Stone, Kevin. *2009 Coal report*. Ottawa: Natural Resources Canada, 2010 and; Ministry of Energy and Mines. *Opportunities to Explore: British Columbia Mining and Minerals 2011*. Vancouver: Ministry of Energy and Mines, 2011.

5.2 GI#2: The industry's corporate concentration in the extraction sector.

Section 5.2 evaluates the level of corporate concentration of the extraction sector using the marking system presented in table XXI. This section will analyze the number of stakeholders and their respective shares of total exportations.

Table XXI: Marking system for GI#2.

Criteria	Value
Is corporate concentration in the extraction sector increasing the resilience of the logistics chain?	Yes= 2 No= 0

Hunter Valley coal corridor

The Australian coal industry is mainly located in the states of Queensland and New South Wales where close to 110 coal mines were operating in 2005 (Australian Government, 2005, 12). In the Hunter Valley region, 31 coal mines were owned by 10 small producers and seven larger ones in 2008. Among those large companies, *Xstrata* and *Coal* & *Allied* represented 70% of the region's production (Zacarias, Fisher and Gapp, 2008, 3). On a nation-wide level, the importance of the largest companies is even more pronounced. "The four major global coal suppliers, *BHP-Billiton*, *Rio Tinto* (*Coal & Allied* and *Pacific Coal*), *Xstrata Coal*, and *Anglo Coal* have a significant presence in Australia, accounting for around 90 per cent of the Australian coal production" (Australian Government, 2005, 12).

14 companies of the Hunter Valley region exported coal through the port of Newcastle during the 2008-2009 fiscal years. These companies and the mines they operate are presented in table XXII. The four major global coal suppliers mentioned earlier: *BHP-Billiton*, *Rio Tinto* (*Coal & Allied*), *Xstrata Coal*, and *Anglo Coal* had a combined production of 77.021Mt or 82.9% of total Hunter Valley coal exports. On a related note, the establishment of the HVCCC has aligned most of operations in a single direction. While mining operations are still being undertaken independently by each company, overall production can be seen as being controlled by a single entity, the HVCCC. For this reason, while 14 different companies export coal in the Hunter Valley, actual export concentration is the highest in Australia since it is almost entirely

controlled by the HVCCC. In conclusion, mining activities, clearly controlled by a small number of actors in the Hunter valley coal corridor, are worth a score of 2 for GI#2.

Table XXII: Major operating mines of the Hunter Valley region that exported through the Port of Newcastle in 2008-2009.

Company	Mine	Production (Mt)
Anglo Coal	Drayton	4.273
BHP Billiton	Mt. Arthur Operations	11.774
Bloomfield Collieries	Bloomfield Rix's Creek	0.492 1.133
Centenial Coal	Newstan	1.265
Coal & Allied	Hunter Valley Operations Mt Thorley Warkworth Bengalla	10.462 8.260 5.413
Donaldson Coal	Donaldson Able	0.903 0.119
Gloucester Coal	Stratford	0.639
Idemitsu	Muswellbrook Boggabri	1.150 1.440
Peabody Energy	Wambo North Wambo Wilpinjong	2.228 2.044 6.952
Vale (Integra Coal)	Camberwell Glennies Creek	2.176 1.362
Whitehaven Coal	Whitehaven Werris Creek Tarrawonga	0.176 1.107 1.577
Xstrata	Cumnock South Beltana #1 Bulga United Liddell Mt Owen/ Ravensworth East Ravensworth Narama Ravensworth Newpac Ulan West Wallsend	0.379 3.526 5.079 2.040 3.047 8.288 3.999 1.932 6.527 2.022
Yanzhou Felix Resources **Austar Coal**	Ashton Austar	3.209 1.317
Total coal exports	**92.920 Mt**	

Source: Boyle, 2010

Mpumalanga coal corridor

The corporate structure of the South African coal mining sector resembles that of Australia. Indeed, all South African mining companies are privately owned and operated (Eberhard, 2011, 9). Furthermore, five very large companies account for approximately 80% of the country's coal production: *Anglo-American, Exxaro, Sasol, BHP Billiton* and *Xstrata* (Eberhard, 2011, 3). However, unlike coal producers in the Hunter Valley, Mpumalanga coal producers sell a large amount of their production on the local market. For example, *Exxaro* only sold 2.5Mt of coal on world markets out of a 42.7Mt production capacity in 2009 (Moses Maleka, Mashimbye and Goyns, 2010, 25). It is therefore more difficult to determine the amount of coal exported by some of the country's producers. Moreover, South African coal mining companies do not always specify the mines where coal exports come from in their operational reports. Consequently, it is not always clear if coal exports come from mines inside or outside of the Mpumalanga province. What is known however is that, among the eleven members of the Chamber of Mines of South Africa involved in the coal industry (Chamber of Mines of South Africa, 2010, 18), eight have operations in the Mpumalanga province and export coal through Richards Bay Coal Terminal (*Optimum* which is not a member of the Chamber also exports coal from mines in the province) (Eberhard, 2011, 23). Thus, a relatively small number of companies export coal from the Mpumalanga province. Another indication of the industry's high level of concentration is that three of Richards Bay Coal Terminal's shareholders: *Anglo-American, BHP Billiton* and *Xstrata* represented 75% of the allocated capacity of the terminal's infrastructures (Eberhard, 2011, 23). For this reason, mining activities are mainly controlled by a small number of actors which increases the resilience of the corridor's extraction sector. Thus, this case study gets a score of 2 on GI#2.

Canadian coal corridor

The Australian and South African case studies have shown how the mining sector is usually dominated by a few large, multinational companies like BHP Billiton, Xstrata or Rio Tinto. In Canada however, the reality is different. Mining operations in British Columbia and Alberta[53] are

[53] The list of mines and companies in table 23 only includes operations that export coal through the port of Vancouver.

mostly controlled by smaller companies. Having a look at table 23 reveals that besides Peace River Coal, which belongs to Anglo Americans, the large international coal mining conglomerates have no operations in the Canadian coal industry. Furthermore, only six companies with operations inside the corridor were active on the world market. Accordingly, there currently are fewer actors exporting on the international coal market in Canada than in Australia and South Africa. However, similar to the Australian and South African situations, Canadian export operations are not evenly divided among the actors. Table XXIII reveals that *Teck Resources* was responsible for 70% of total exports and that 86% of total exports came from mines belonging to either Teck Resources or Sherritt International Corporation. According to these numbers, corporate concentration among all three case studies is highest in Canada increasing resilience and giving this case study a GI score of 2.

Table XXIII: Current major operating mines in British Columbia and Alberta that exported through the Port of Vancouver.

Company	Mine	Origins	Production Capacity (Mt)	Percentage of capacity total (%)
Walter Energy Inc.	Brule	Foreign	2	6.06
Sherritt International Corporation	Coal Valley Obed Mountain	Founded in Canada	4 1.2	15.76
Teck Resources Limited	Coal Mountain Elkview Fording River Greenhills Line Creek	Founded in Canada	2.7 5.6 8.3 4.5 2.2	70.61
Grande Cache Coal	Grande Cache	Founded in Canada	2	6.06
Vitol Group	Quinsam Mine	Foreign	0.5	1.51
Peace River Coal (Anglo American)	Trend Mine	Subsidiary of a foreign company	2	6.06
Total coal exports	**33Mt**			**100**

Source: Stone,2009

In the extraction sector, the ability to maintain communication and cooperation between stakeholders is the most effective way of improving the chain's resilience. When the number of stakeholders involved in daily operations becomes too great, various problems can arise, causing resilience to drop. A highly concentrated system is therefore more efficient at maintaining high resilience than a low concentration system where competition is high and communication and cooperation are harder to maintain. The highly concentrated systems of the Canadian and Mpumalanga corridors and the centralized management system of the HVCCC have shown how high concentrations are a key to high resilience.

5.3 GI#3: The industry's corporate concentration in the railway transportation sector.

Section 5.3 evaluates the level of corporate concentration in the railway transportation sector. To do so, GI#3 will first determine the number of companies involved in the operations of railway transportation. Then, it will assess whether or not the number of companies influences the resilience of the chain. The marking system for this GI is explained in table XXIV.

Table XXIV: Marking system for GI#3.

Criteria	Value
Is corporate concentration in the railway transportation sector likely to lower the logistics chain's resilience?	Yes=0 No=2

Hunter Valley coal corridor

In the Hunter Valley coal corridor, railway transportation is structured by a *below- rail /above-rail* system. The below-rail part of the sector is made of the actual owners of the region's railroads. The fist member of this group is the New South Wales government who owns all of Hunter Valley's rail infrastructures. Under a 60 years lease signed in 2004, the government transferred the management of rail infrastructures in the Hunter Valley region to the Australian Rail Track Corporation (ARTC). Under this agreement, the ARTC is allowed to sell "rail access to train operators" (Zacarias, Fisher and Gapp, 2008, 3) and is required to invest in the development of rail infrastructures. The ARTC is therefore the second member of the bellow-rail group. The above-rail group is made of two rail providers, Pacific National and Queensland Rail who are responsible for all of the region's coal transportation. Both companies are allowed to operate on the network "under the terms of track access purchased from ARTC" (Zacarias, Fisher and Gapp, 2008, 3).

As mentioned in chapter 3, the Hunter Valley coal corridor suffers from recurrent traffic problems on its railway network. However, the inability of the industry to keep up with a rapidly growing demand is not the only explanation for the various problems in railway transportation. One of the most frequently cited reasons of congestion is the passenger priority that the ARTC has to respect as part of its lease with the state's government. The priority given to passenger trains creates traffic on the network and takes rail capacity away from the coal industry especially on single lines where coal trains have to stop and cede passage to higher priority trains (Australian Government, 2005, 52).

None of the publications on railway congestion in Australia or on the Hunter Valley's railway network have identified corporate concentration or the below-rail/ above-rail system as likely explanations of the problems in this sphere of the logistics chain. According to the findings of this research and the general consensus in the literature, corporate concentration cannot be identified as likely to lower the resilience of the logistics chain. Furthermore, under the new operating structure of the HVCCC, the operations and strategies of Pacific National, Queensland Rail and the ARTC have been aligned to tackle the system's traffic problems. Thus the Hunter Valley coal corridor has a score of 2 for GI#3.

Mpumalanga coal corridor

The various problems of the Mpumalanga coal corridor have already been discussed in chapter 3. Furthermore, this corridor's bad performance in the rail sector has been explained in section 5.1. It is clear that the monopoly status held by Transnet has contributed “significantly to high levels of inefficiency” (Thompson, 2009, 12). The lack of competition has prevented the industry from being proactive and determined in its will to solve the problems of the rail sector. Thus, the presence of a monopoly, the ultimate form of corporate concentration, has been a major source of problems and can be seen as a direct cause of the logistics chain low levels of resilience in railway transportation. Angry coal miners have presented “alternative business models [...] including possible private ownership and operation of rolling stock” (Eberhard, 2011, 22), but to this day, changes remain to be seen. Thus, extreme corporate concentration in the railway transportation sector is the main reason for the logistics chain's low resilience level. Therefore, the Mpumalanga coal corridor has a score of 0 on this KPI.

Canadian coal corridor

The level of corporate concentration in the Canadian railway transportation sector is somewhere between Transnet's monopoly and the multi-layered jurisdiction system of the Hunter Valley network. The situation in the railway sector for bulk transportation can be described as a duopoly between CPR and CN. "The railways of Canada can easily, probably too easily, be said to constitute a duopoly. It is certainly not a duopoly in which one is striving to eliminate the other. The two big Canadian railways, as a matter of fact, co-operate with each other on many matters" (Hewetson, 1951, 542). In coal transportation, this cooperation has translated in the carriers' regional specialization. On one hand, CPR handles most of the coal shipments bound for Port Metro Vancouver while, on the other hand, CN handles most shipments to the Port of Prince Rupert. The absence of other actors in the transportation business has also allowed both carriers to perform many functions at once. CPR and CN are not only in charge of transportation, but also of railway construction and maintenance. In other words, both companies benefit from a high level of freedom and independence in their operations, development and strategic planning. In conclusion, corporate concentration in the railway sector has allowed CN and CPR to maintain high levels of operational efficiency that have been beneficial for the logistics chain's resilience. Thus, the corridor has a score of 2 for GI#3.

As the main coal transporter to Port Metro Vancouver and owner as well as operator of coal railways, CPR is close to holding a monopoly on railway transportation in the Canadian coal corridor. However, fierce competition in railway transportation in North America has forced CPR to adopt operating procedures and innovations, such as higher axle load capacities on coal railways and the introduction of new aluminium high capacity ore cars (see section 3.1), used by other transporters in Canada and the United States. In other words, while the company has a *close to monopoly* on coal transportation in the Canadian coal corridor, it is still competing with several other transporters for container and other bulk transportation. This reality explains why CPR and Transnet, both holding monopolies in coal transportation, influence the resilience of the logistics chain in very different ways.

Section 5.3 has shown that, when it comes to railway transportation, competition is essential in maintaining high levels of resilience and overall efficiency. In the Hunter Valley, railway transportation has experienced congestion problems, but the priority given to passenger transportation more than concentration issues explains this situation. In the Mpumalanga corridor, the absence of competition and the extreme concentration of the industry are the main cause of the sector's poor resilience. Finally, in the Canadian corridor the duopoly between CPR and CN and the competition found within the North American railway transportation explain why coal transportation has been resilient and highly efficient. For all three case studies, concentration remains high since no more than two transporters are usually present, with other stakeholders involved in the case of the Hunter Valley corridor. Nevertheless, more than industry concentration itself, the most important warrant of the sector's resilience is competition between stakeholders.

5.4 GI#4: The industry's corporate concentration in the port activities sector.

In the previous two sections, this paper has analyzed the number of companies operating in the extraction and railway transportation sectors to determine if corporate concentration is an important factor in the logistics chain's resilience. For the port activities sector, the same process cannot be applied since each case study includes only one port of exportation. When trying to assess the resilience of port activities, one of the most important factors is ownership. Coal exporting terminals require a complex system of infrastructures that is expensive both to build and to manage. For this reason, many companies usually cooperate to finance the construction of port terminals, effectively becoming co-owners of the infrastructures. In most cases, a company's export quota and right of access are determined by their percentage of shares in the terminal. In section 5.4, GI#4 will evaluate the number of companies involved in the ownership of port infrastructures for each case study and will determine how the structure of ownership is influencing the resilience of the port activities sector. The marking system for GI#4 is presented in table XXV.

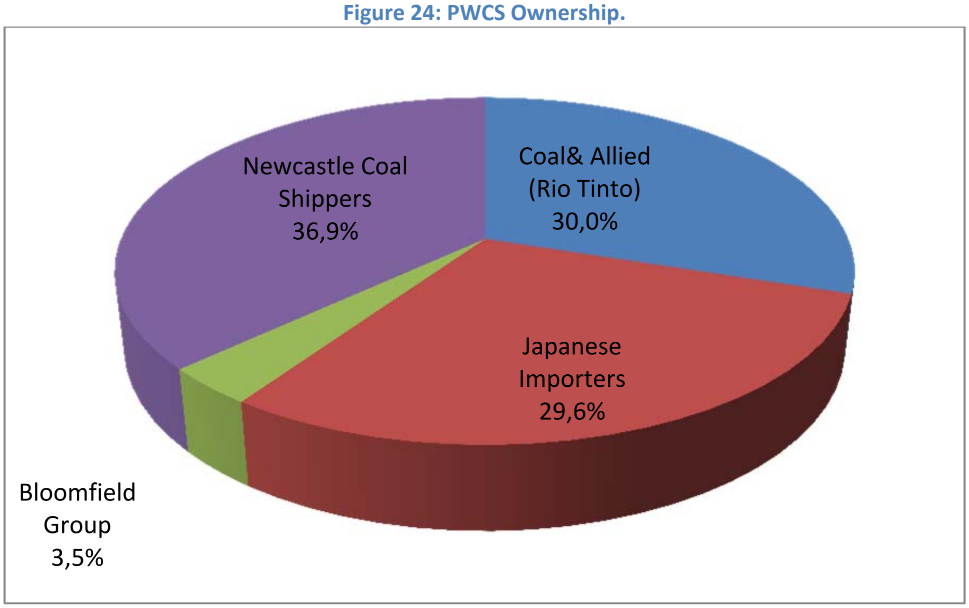
Table XXV: Marking system for KPI#8.

Criteria	Value
Is corporate concentration in the port activities sector likely to lower the logistics chain's resilience?	Yes=0 No=2

Hunter valley coal corridor

Ownership of lands and infrastructures on which coal terminals have been built at the Port of Newcastle is multi-layered. As in most of New South Wales' ports, the port of Newcastle is “state owned, but leased to private operators” (Bayer, Rademacher and Rutherford, 2009, 258). To be more accurate, the port is currently “owned and operated by the Newcastle Port Corporation (NPC) which was established as a NSW Statutory State Owned Corporation in July 1995, under the *Ports corporatisation and Waterways Management Act 1995*” (Australian Government, 2005, 68). Furthermore, the land on Kooragang Island belongs to the state which leases it to the industry on long-term contracts. In other words, while NPC itself is state owned, coal terminals and their infrastructures are privately operated by companies who have leased land inside the port. At the moment, two different conglomerates operate coal terminals inside the port of Newcastle; Port Waratah Coal Services (PWCS) and Newcastle Coal Infrastructure Group (NCIG). The first terminal operator, PWCS owns and operates the facilities on Kooragang Island and Carrington. The lion's share of PWCS is owned by local coal mining companies who export through the terminal while the rest is owned by Japanese coal importers of Hunter Valley's coal. Accurate ownership of the group is presented in details in figures 24 and 25. While figure 24 represents the effective ownership structure of PWCS, figure 25 shows both the shares of the various companies within the “Newcastle Coal Shippers” group and their effective ownership share (or shares of PWCS compared to all shareholders) of PWCS in percentage.

Figure 24: PWCS Ownership.

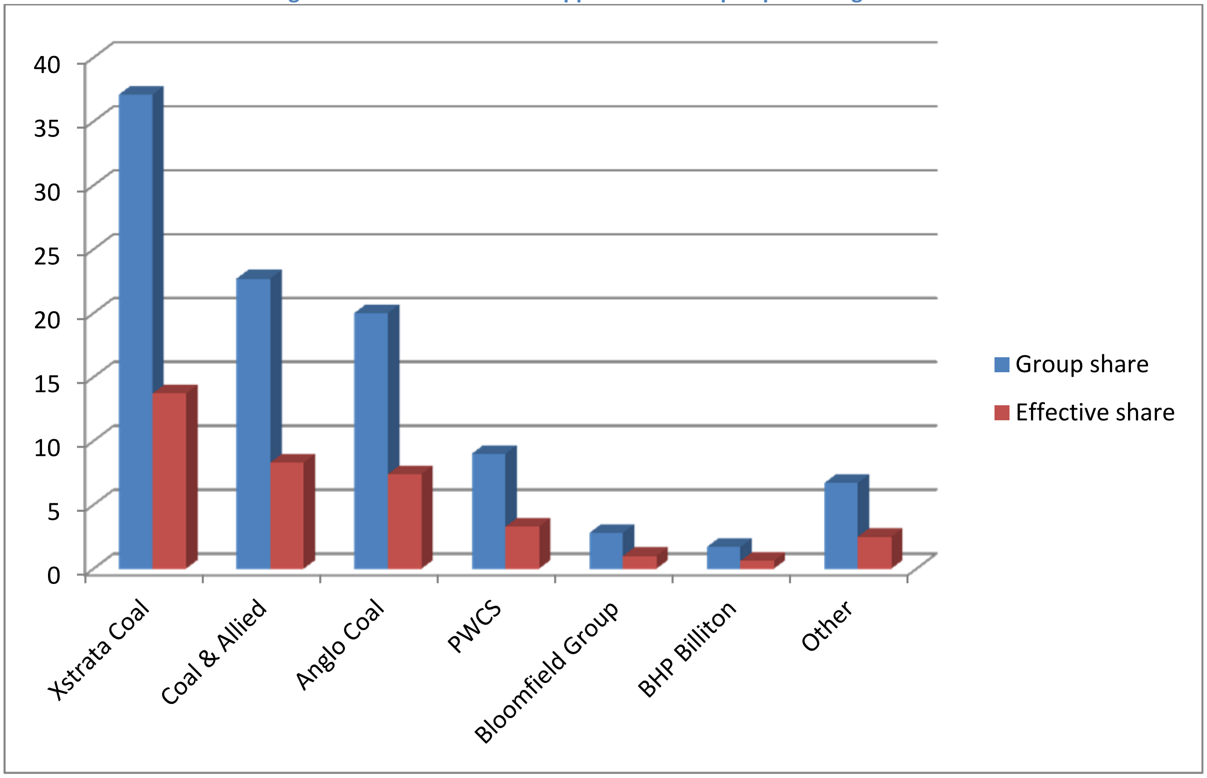


Source: Boyle, 2010

Under the leasing agreement between the NSW government and PWCS, coal terminals are available to any party as “common user facilities”. However, in terms of actual throughput used, Xstrata (29%) and Coal & Allied (20%) are clearly the most frequent users of PWCS's terminals (Boyle, 2010, 9).

This common user facility clause has been the source of conflicts and tension among PWCS's terminals' users of different views on efficient capacity allocation. While the conflict itself has not been particularly harmful for the terminals' resilience, each side has justified its position by claiming that its view on capacity allocation is the most efficient way of solving bottlenecks and traffic problems. At the heart of this debate lies the question of accessibility of port infrastructures and capacity allocation at Kooragang and Carrington terminals.

Figure 25: Newcastle Coal Shippers Ownership in percentage.



Source: Boyle, 2010

In 2004, PWCS proposed the controversial *Capacity Distribution System* (CDS), a "system based on loading allocations which are divided on a pro-rata quarterly basis that is in line with coal producers' demand forecasts and the capacity available at the Port of Newcastle" (Zacarias, Fisher and Gapp, 2008, 4). Behind this idea was PWCS's presumption that such an initiative would decrease ship queues and reduce general traffic problems within the port. Their argument was based on the following two assumptions: first, the *Common User Provision* (CUP), which is the legal foundation of the common user facility clause, prevented a long-term commercial framework to be followed. The CUP allocated capacity on a monthly basis, which prevented large mining companies from establishing long-term contracts with buyers. The second assumption was that the CUP put PWCS at a disadvantage on coal loading markets because of its incapacity to sign long-term contractual agreements. Furthermore, the opening of NCIG's terminal, which was not operating under the CUP, made PWCS's disadvantage even more obvious (Zacarias, Fisher and Gapp, 2008, 6).

On the other side, the region's smaller coal producers, traders and some of PWCS's minor shareholders have voiced their will to maintain the common user facility status of the terminals. The following is a summary of the main arguments against the proposed CDS. First, the CDS would put Xstrata and Rio Tinto (through Coal & Allied) in a conflict of interest since as the most important users and major shareholders of PWCS, they would receive most of the allocated capacity. Second, the CDS would "cover up the real problem and relieve the pressure from PWCS to upgrade port facilities and increase efficiency" (Zacarias, Fisher and Gapp, 2008, 5). Finally, under a CDS, coal traders would not receive any capacity which would put them at a disadvantage. Supporters of the CUP state that it brings fairness and equality to small and new actors of the industry making the industry open to competition and aligned on the market (Zacarias, Fisher and Gapp, 2008, 5).

With the establishment of the HVCCC, this debate has been put to the background. However, it still provides an indication of the different point of views that exist throughout the industry concerning capacity, traffic and bottleneck problems. Furthermore, it shows that the large number of actors involved in the logistics chain have prevented the port activities sector from finding quick and efficient solutions to their problem. As one of the most important coal exporting operations in the world, the Hunter Valley coal network is made of a high number of actors. In the port activities sector, the various coal mining companies exporting through the Port of Newcastle, coal traders and PWCS's shareholders (both local and foreign) have made consensus more difficult to achieve. For this reason, while corporate concentration in the port activities sector has not lowered the logistics chain's resilience *per se*, it has certainly prevented traffic and capacity allocation problems from being solved efficiently which, in turn, prevented resilience levels to be improved. To this day, congestion at the Port of Newcastle remains an important problem. In the beginning of January 2012, "Newcastle's ship queue hit 60 for the first time in several years"[54]. According to Newcastle Port Corporation's weekly operating report of March 19 2012, there were 8 vessels waiting to be loaded with an average waiting time of 11.76 days[55]. In conclusion, the Hunter valley coal corridor has a score of 0 for GI#4.

[54] Energy Bangla, "Coal ship queue hits 60 at Newcastle Port in Australia," Energy Bangla, http://www.energybangla.com/2012/01/02/232.html#.T3Ca8zEgfwY (accessed March 26, 2012).

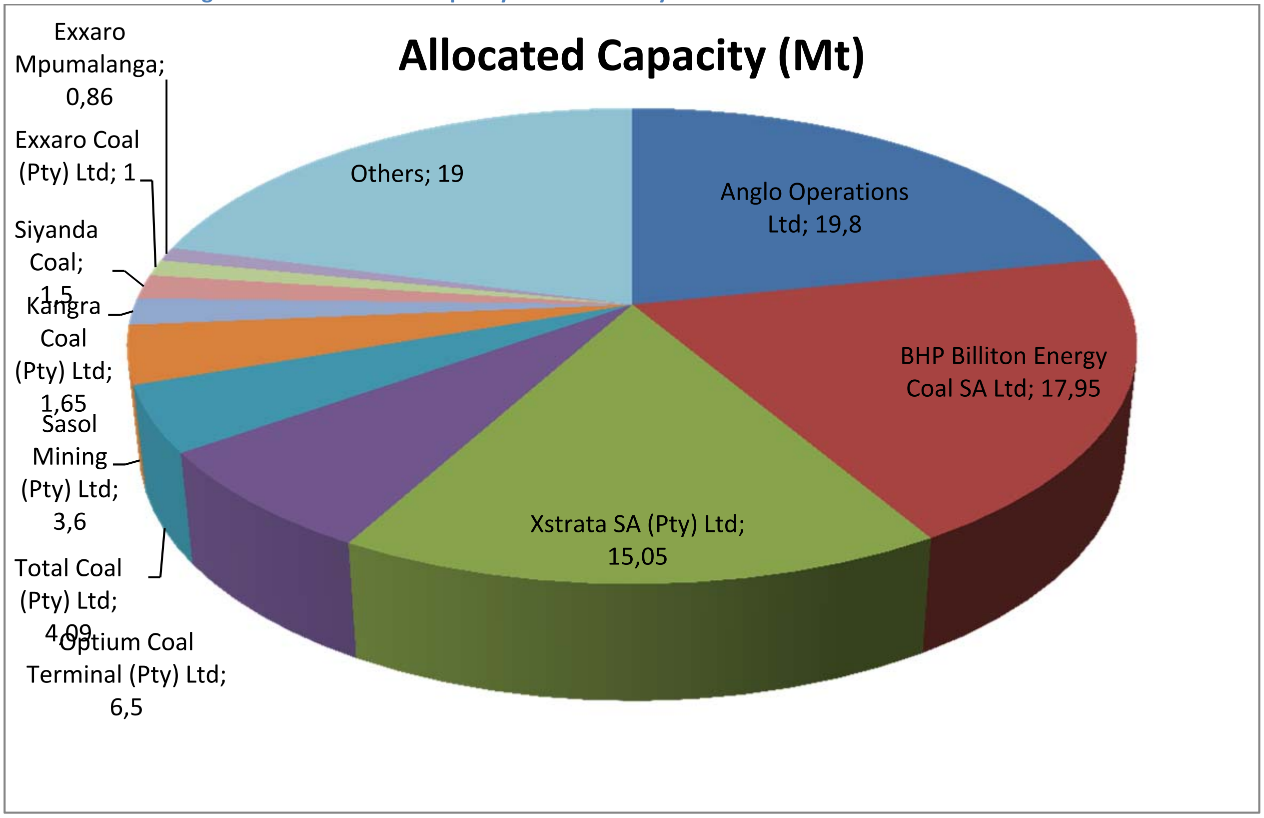
[55] Newcastle Port Corporation, "Weekly Operations Report," Newcastle Port Corporation, http://www.newportcorp.com.au/client_images/1060451.pdf (accessed March 26, 2012).

Mpumalanga coal corridor

Section 5.3 showed how difficult the situation is in the railway sector of the Mpumalanga coal corridor. In contrast, the port activities sector centered on the activities at Richards Bay Coal Terminal has managed to operate efficiently despite the problems of its railway counterpart. The operating structure resembles that of Newcastle Port Corporation since the port itself is owned and operated by the state-owned entity, Transnet, while the coal terminal is privately owned and operated. "The general picture of the Transnet ports is one of efficiency for the bulk ports at Richards Bay and Saldhana Bay as compared with relative inefficiency at the remainder" (Thompson, 2009, 10). However, since the coal terminal is actually made of privately owned infrastructures, Transnet has not been directly involved in the operations and development strategies. Figure 26 shows the current shareholders of Richards Bay Coal Terminal and their respective allocated capacity[56]. As a privately owned operation, the terminals' success can be explained by its ability to follow market trends and fluctuations, a necessity that Transnet Rail has not managed to achieve as a state-owned monopoly. In fact, despite an aggressive expansion strategy, the coal terminal's exports have decreased not because of corporate concentration or other port-related issues, but "mainly because of the rail constraints" (Eberhard, 2011, 22) mentioned throughout this research. In other words, despite the numerous shareholders and other companies who use the infrastructures, corporate concentration has not lowered the resilience of the terminal. The most likely explanations to this conclusion are that the operations of the terminal are market-driven and privately owned and that the sheer size of the terminal allows for many companies to operate without problems. Therefore, the Mpumalanga coal corridor has a score of 2 for GI#4.

[56] The "Others" group consists of capacity allocated to smaller mining companies and to companies that are not shareholders of the coal terminal.

Figure 26: The allocated capacity of Richards Bay Coal Terminal's shareholders.



Source: Chriwa, 2010

Canadian coal corridor

Port Metro Vancouver's coal terminals are both privately owned and operated. The smaller of the two, Neptune Bulk Terminals has three loading berths of which only Berth#1 is used for coal exports while the other two are used to handle potash and fertilizers. Of the three owners of the terminal, Teck Resources Limited is the only coal exporter giving it exclusive access to the infrastructures[57]. In other words, as far as coal exportations are concerned, Teck Resources Limited holds a monopoly on the terminal. However, such a high level of corporate concentration has not been an issue because, as the only owner and user of the terminal, Teck operates in a closed system that does not affect the operations of other actors.

Table 23 shows that, excluding American coal miners, six Canadian mining companies export through Westshore Terminals. As a private entity, "Westshore Terminals Investment

[57] Neptune Terminals, "Terminal Operations," Neptune Terminals, http://www.neptuneterminals.com/terminal-operations/ (accessed March 26, 2012).

Corporation, through its wholly-owned subsidiary Westshore Terminals Holdings Ltd., owns all of the limited partnership units of Westshore Terminals Limited”[58] and all of the terminal's infrastructures. Unlike PWCS, NCIG and Richards Bay's terminals, Westshore's shareholders consist of various funds and institutions not related to the maritime or coal industry[59]. The port activities sector of the Canadian coal corridor is therefore highly concentrated since each of the two coal terminals are owned and operated by a single stakeholder. However, coal exports out of Port Metro Vancouver have been increasing since 2006 (see section 3.3) without major problems or drop in operational efficiency. As a result, it can be said that high corporate concentration in the sector has not lowered the logistics chain's resilience. Thus, the Canadian coal corridor has a score of 2 for GI#4.

This section has shown that in the port activities sector, the link between concentration levels and resilience levels is not as easy to establish as in the extraction or railway transportation sectors. In the Hunter Valley, lower concentration has prevented stakeholders from solving congestion problems. On the other hand, high concentration levels in the port activities sector of the Canadian coal corridor have resulted in efficiency and higher resilience. In the case of the Mpumalanga coal corridor, low concentration has not hindered nor fostered resilience. The ability of RBCT to expand and maintain high standards of operation are more direct causes of the sector's high resilience than corporate concentration levels. Thus, corporate concentration does not seem to be a key factor or the logistics chain's resilience in the port activities sector.

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[58] Westshore Terminals, “Investors,” Westshore Terminals, http://www.westshore.com/investors.html (accessed March 26, 2012).

[59] Morningstar, “Westshore terminals Investment Corp,” Morningstar, http://quote.morningstar.ca/Quicktakes/owners/OwnersOverview.aspx?t=WTE.UN&region=CAN&culture=en-CA (accessed march 26, 2012).

5.5 GI#5: The diversity of the industry's portfolio of clients on world markets.

The world economic crisis of 2008 hit the economy of most developed countries with a magnitude unseen since the Great Depression of 1929. While the crisis started in the U.S. housing market and quickly spread to the international banking system, most sectors of the economy were ultimately affected. The economies of the West, namely those of the United States and of the European Union, were arguably the most affected while most East Asian countries managed to ride out the storm. Driven by increasing development and domestic consumption levels, countries like China and India continued to seek raw materials on world markets which helped the mining industry in several countries. More important was the coal industry's performance during the economic crisis. Exporting countries with a diversified portfolio of clients or with clients located in the rapidly developing Asian countries managed to maintain high exportation levels throughout the crisis.

On a more theoretical level, economic crisis are some of the most catastrophic disruptive events likely to affect the operations of logistics chains in general. In the case of coal logistics chains whose operations depend on the good health of the world economy, economic crisis are important threats to resilience. Indeed, while natural hazards or infrastructure problems usually affect one or two links of the chain, economic crisis affect the entire chain by severely reducing the level of activity and, in the most serious cases, the survival of the many companies operating inside the chain. Reducing the negative effects of economic crisis should therefore be considered as an important goal for any industry focused on maintaining high levels of resilience. As mentioned above, having a diversified portfolio of clients is an effective way to achieve this goal. With the marking system presented in table XXVI, GI#5 will determine which case studies are the most resilient to economic crisis.

Table XXVI: Marking system for GI#5.

Criteria	Value
Are the corridor's clients mostly located in countries likely to maintain their coal imports despite difficult economic periods?	Yes=2 No=0
Are the corridor's exportations sufficiently divided among different clients to avoid significant negative impacts on the logistics chain if an economic crisis was to affect one or several clients?	Yes=2 No=0

Hunter Valley coal corridor

According to the New South Wales Minerals Council, "85% of Hunter export coal goes to Japan, Korea and Taiwan"[60]. The market share of each client for Hunter Valley coal has been relatively stable for the past 10 years despite the various economic fluctuations. However, as seen in table XXVII, China has been an increasingly important buyer of Hunter Valley coal especially since 2009-10.

Table XXVII: Percentage of market shares of the top 10 buyers of NSW coal[61].

Country	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
Japan	53.4	54	59.9	55	54.3	55.1	61	54.5	52.8	50.3
Republic of Korea	12.1	8.7	7.6	10.7	12.8	10.3	13.8	16.5	16.5	17.5
Taiwan	15	14.3	11.9	15.9	14.4	14.2	13.6	12	11.5	13.5
China	2.2	2.8	1.5	1.5	2.8	2.6	1.1	4.7	10.1	9.3
India	2.2	3.3	3.1	3.2	2.5	3.1	2.8	3.2	3.4	3.5
Thailand	0	0	0	0	0.6	1.7	1.5	1.9	0.9	1.6
Mexico	2.5	4.1	2.7	4.7	6.3	6.1	1	2	2.8	1.4
Malaysia	1	2.2	2	3.2	2.3	2.5	1.2	1.8	0.4	1.3
New Caledonia	0.2	0.3	0.3	0.3	0.2	0.3	0.3	0.2	0.4	0.4
Italy	0.6	0.8	0.9	0.6	0.4	0.5	0.5	0.3	0.2	0.2

Source: NSW Minerals Council, 2011

It is clear that the bulk of Hunter Valley's coal goes directly to the East Asian markets and that other markets are but a fragment of the region's exportations. However, what table XXVII does not show is that the number of Hunter Valley's clients has been dropping over the years. Between 2001-02 and 2006-07 the region's coal exportations went to 42 different countries. That number dropped to 25 in 2007-08, to 23 in 2008-09, to 21 in 2009-10 and to 18 in 2010-11.

[60] NSW Minerals Council, "Coal specific Statistics," NSW Minerals Council, http://www.nswmin.com.au/Mining-in-NSW/Facts-and-Figures/Economic-Contribution/Coal-Specific-Statistics/Coal-Specific-Statistics/default.aspx (accessed March 28, 2012).

[61] Table 26 represents all of NSW's coal exports which either exit the country through the Port of Newcastle or Port Kembla. Since Port Kembla only represents 10-15% of the state's exportations, these numbers still offer and accurate picture of Hunter valley's clients on world markets.

In other words, the corridor's coal exportations are becoming more concentrated in a small group of countries. Geographically, coal exportations are also increasingly concentrated in Asia while the European countries have almost disappeared from the list of Hunter Valley's clients. For this reason, this corridor has a score of 2 on the first criteria and 0 on the second for a final score of 2 for GI#5.

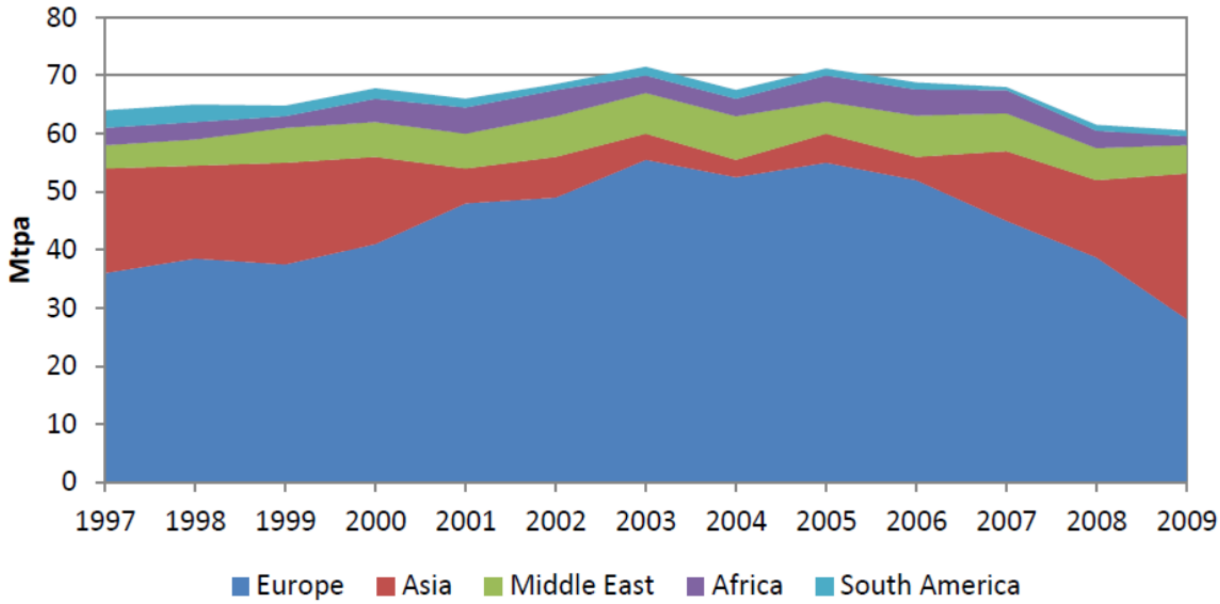
Mpumalanga coal corridor

Historically, most of South Africa's coal exportations went to the European market. At its peak, this market represented approximately 60% of the country's coal exportations (Maleka, Mashimbye, Goyns, 2010, 41). To be more accurate, the country's thermal coal went to Belgium, Denmark, France, Germany, Italy, Netherlands, Portugal, Spain, Switzerland and the United Kingdom. South Africa's clients were also located in the following four regions of the world:

1. The East: Mainly India, but also China, South Korea, Malaysia, Pakistan and Taiwan.
2. The Middle East: Israel, Turkey, United Arab Emirates.
3. Africa: Morocco, Kenya, Mauritius, Reunion and Senegal.
4. Latin America: Argentina, Brazil Chile and Mexico represent the less important market (Eberhard, 2011, 25).

The interesting fact about South Africa's export markets is that the geographic balance of clients is quickly shifting to the east. From 2005 to 2009, the European market fell from 75% to approximately 50% of the country's exports as shown in figure 27. On the other hand, growing demand in India, China and other countries of the Pacific has allowed the corridor's client portfolio to be more diversified and less dependent on any one market (Eberhard, 2011, 25). Thus, the geographic location of the Mpumalanga corridor, close to both the European and Asian markets represents an advantage in this context. In conclusion, since the Asian market (which is likely to maintain its imports of South African coal despite difficult economic periods) is expected to keep on occupying a growing share of South African coal exports and is already important enough to be considered as a major market, the Mpumalanga coal corridor has a score of 2 on the first criteria. On the second criteria, the diversity of markets on which the corridor's coal is being exported also gives it a score of 2 for a final score of 4.

Figure 27: Major markets for South Africa's coal exports (1997-2009).



Source: Eberhard, 2011

Canadian coal corridor

Similar to the Hunter Valley coal corridor, Canada's coal corridor's most important market has always been Eastern Asia. In fact, both corridors' main clients include Japan, South Korea and China. Table XXVIII offers detailed information about Canada's clients on the coal market.

Table XXVIII: Destinations of coal exports through Port Metro Vancouver from 2008 to 2010.

Metric tonnes	2008	2009	2010
Metallurgical coal total	21 670 364	18 473 001	22 304 915
Japan	7 695 394	5 411 340	6 841 417
Korea (South)	4 536 791	4 093 397	4 382 453
China	301 784	3 856 414	4 066 402
Brazil	1 182 679	525 407	1 211 817
Germany	1 689 710	949 853	1 206 621
Other/ Unspecified coal total	4 235 135	5 714 379	8 020 830
Korea (south)	1 069 825	2 945 114	4 072 275

Japan	1 889 946	1 884 809	1 615 416
China	338 785	279 230	1 387 822
Chile	137 433	71 902	691 701
Thailand	0	255 368	134 103

Source: Port Metro Vancouver, 2011

As a smaller coal producer and exporter, Canada does not have as many clients as Australia or even South Africa. Furthermore, with the exception of Germany, British Columbia and Alberta coal is not exported on the European market probably because transport costs are too high. However, China's desire to diversify its supply sources of coal has been beneficial to the Canadian coal industry. Indeed, exports to China between 2008 and 2010 have increased by 1347% for metallurgical coal and 409% for the "unspecified coal" category. As mentioned previously, Canada has the advantage of being present on the Asian coal market which requires large quantities of coal imports even during difficult economic periods. For this reason, the Canadian coal corridor has a score of 2 on the first criteria. For the second criteria, the industry's inferior scale of production and exportation has not allowed it to develop a diversified network of clients resulting in a score of 0. The final score for the Canadian coal corridor in GI#5 is 2.

5.6: Cumulative scores of chapter 5.

In this chapter, the relationship between stakeholders and resilience in the three case studies has been analyzed using five governance indicators. In the first section of this fifth chapter, GI#1 analyzed the efficiency of planning and development strategies. This process revealed how the actors involved in the activities of the Hunter Valley and Canadian coal corridors have been successful in adopting planning and development strategies that solved capacity problems and allowed the industry to maintain high levels of operational efficiency. On the other hand, poor planning on the part of Transnet has seriously hampered the development of the Mpumalanga coal corridor. For GI#2, analyzing the corporate concentration in the extraction sector has shown that all three case studies have a similar situation since their respective extraction sectors are clearly controlled by a small number of companies. The third section of this chapter analyzed the effects of corporate concentration in the railway transportation sector. GI#3 revealed how the Canadian duopoly and the multi-layered railway sector of the Hunter Valley have helped increase logistics chain's levels. In contrast, Transnet's monopoly on railway transportation has proven to be a major source of problem for the Mpumalanga coal corridor. In the port activities sector, the Canadian coal corridor and the Mpumalanga coal corridor have received the best score in GI#4 while congestion problems at the Port of Newcastle put the Hunter Valley corridor in last position. Finally, GI#5 evaluated the diversity of the industry's portfolio of each corridor's clients on world markets. For this section, the Mpumalanga coal corridor had the best score, followed by the Hunter Valley and Canadian corridors with equal scores. Cumulative GI scores for chapter 5 are presented in table XXIX.

Table XXIX: Cumulative scores for chapter 5.

Case studies	GI#1	GI#2	GI#3	GI#4	GI#5	Cumulative Score
Hunter Valley coal corridor	3	2	2	0	2	11
Mpumalanga coal corridor	1	2	0	2	4	7
Canadian coal corridor	3	2	2	2	2	11

Chapter 5 contained GIs designed to show that stakeholders' governance can have important impacts on the resilience of coal logistics chains. Just like modern, high-quality infrastructures increase resilience by fostering efficiency and sometimes solving problems like traffic, governance also provides multiple benefits if it is based on resilience. As seen in table XXIX, cumulative scores have been relatively high. In other words, this research has shown that the governance is a strong point of the coal industry especially in the cases of the Canadian and Hunter Valley corridors who both scored 11 out of 13 (85%). The following guidelines, based on the finding of chapter 5 are particularly important when trying to maintain high levels of resilience.

1. The ever changing operational environment of the coal industry affects every sphere of its logistics chain, changes due to external factors such as economic crisis, global warming, our society's opinion of the coal industry, the depletion of coal reserves, so on and so forth,
2. For those reasons, governance has to be carefully understood, assessed and taken into consideration by all actors of the chain in every sector of operation. Thinking ahead and anticipating possible changes in the operational environment are the best way to ensure that the logistics chain's resilience levels will remain high.

Lists of the best examples of resilience in the coal industry's logistics chain.

Chapters 3, 4 and 5 of this research were designed as a comparative analysis of the coal logistics chains of the Hunter Valley, Mpumalanga and Canadian coal corridors. The four infrastructure indicators, three risk indicators and five governance indicators have given different scores to each case study based on their relative resilience levels. Each corridor's scores for all IIs, RIs and GIs are cumulated in table XXX to determine the most and least resilient case studies.

Table XXX: Cumulative scores IIs, RIs and GIs from chapter 3, 4 and 5.

	The Hunter Valley coal corridor	**The Mpumalanga coal corridor**	**The Canadian coal corridor**
II #1	2	3	3
II #2	2	3	2
II #3	2	2	1
II #4	3	3	2
RI #1	2	2	1
RI #2	0	0	0
RI #3	2	0	3
GI#1	3	1	3
GI #2	2	2	2
GI #3	2	0	2
GI #4	0	2	2
GI #5	2	4	2
Total	**22**	**22**	**23**

The total scores of table 30 show that all three corridors have similar resilience scores. Furthermore, none of the case studies really sets itself apart for better or worse. The Canadian coal corridor is nevertheless the most resilient of all three case studies followed by the Hunter Valley corridor and the Mpumalanga coal corridor with an equal score. Each corridor's result as a percentage is easy to find since chapters 3 and 4 had a maximum value of 12, while chapter 5 had a maximum value of 13 for a total and of 37. The Canadian coal corridor has obtained a percentage score of 62.2% while the Hunter Valley and Mpumalanga corridors obtained a score of 59.5%.

While these results offer some insight as to which logistics chain is the most resilient, the main objective of this study is not to determine which corridor has the best overall resilience level and which corridor has the worse. The objective is to determine which corridor has the best resilience in each of the 12 indicators chosen.

Table XXXI: Best example of resilience in the coal industry's logistics chain based on the examples to follow for each indicator.

IIs/RIs/GIs	Case studie(s) showing the best results	IIs/RIs/GIs	Case studie(s) showing the best results
II #1	The Canadian corridor & The Mpumalanga corridor	RI #3	The Canadian corridor
II #2	The Mpumalanga corridor	GI #1	The Canadian corridor & The Hunter Valley corridor
II #3	The Hunter Valley corridor & The Mpumalanga corridor	GI #2	All three corridors
II #4	The Hunter Valley corridor & The Mpumalanga corridor	GI #3	The Canadian corridor & The Hunter Valley corridor
RI #1	The Hunter Valley corridor & The Mpumalanga corridor	GI #4	The Canadian corridor & The Mpumalanga corridor
RI #2	None	GI #5	The Mpumalanga corridor

Thus, table XXXI serves as a reference to guide decision makers in their attempt to improve the resilience within their sphere of activity. The table allows decision makers to identify the examples to follow for each of the 12 indicators. For example, to understand how loading equipment operating rates (II#4) impact infrastructure resilience and to have an example of resilient infrastructures, one should look at the Hunter Valley or Mpumalanga corridors. In the same manner, to understand how planning and development strategies affect the entire logistics chain's resilience (GI#1) and to have examples of corridors that have performed well in that area, one should look at both the Canadian and the Hunter Valley corridors. Decision makers interested in specific sectors of the logistics chains can look at the following which is a breakdown of examples to follow by sectors of activity.

1) Extraction sector:
   a) RI #1: The Hunter Valley corridor and the Mpumalanga corridor;
   b) RI #2: None;
   c) RI #3: The Canadian corridor;
   d) GI #1: The Canadian corridor and the Hunter Valley corridor;
   e) GI #2: All three corridors; and
   f) GI #5: The Mpumalanga corridor.
2) Railway transportation sector:
   a) RI #1: The Hunter Valley corridor and the Mpumalanga corridor;
   b) RI #2: None;
   c) RI #3: The Canadian corridor;
   d) II #1: The Canadian corridor and the Mpumalanga corridor;
   e) GI #1: The Canadian corridor and the Hunter Valley corridor;
   f) GI #3: The Canadian corridor and the Hunter Valley corridor; and
   g) GI #5: The Mpumalanga corridor.
3) Port activities sector:
   a) RI #1: The Hunter Valley corridor and the Mpumalanga corridor;
   b) RI #2: None;
   c) RI #3: The Canadian corridor;
   d) II #2: The Mpumalanga corridor;
   e) II #3: The Hunter Valley corridor and the Mpumalanga corridor;
   f) II #4: The Hunter Valley corridor and the Mpumalanga corridor;
   g) GI #1: The Canadian corridor and the Hunter Valley corridor;
   h) GI #4: The Canadian corridor and the Mpumalanga corridor; and
   i) GI #5: The Mpumalanga corridor.

The previous breakdown also gives some insight on the most resilient sectors of the chain of each corridor. For instance, in the extraction sector, all three corridors proved to be the most resilient on an equal number of occasions meaning that none of them can pretend to be benchmarks. In the railway transportation sector, the Canadian coal corridor was the most resilient on four occasions which is more than its Australian and South African counterparts. In terms of coal transportation, the Canadian coal corridor can boast of setting the example in terms of resilience. Finally, in the port activities sector, the Mpumalanga corridor showed that RBCT is not only the biggest coal exporting terminal in the world, but also one of the most resilient having received the best scores in six different indicators.

Conclusion

The results and conclusions presented in the previous section support what the literature generally states concerning the success and viability of operations of each of the three case studies. In other words, the previous section is a realistic representation of what the coal industry does best. For these reasons, the methodology employed in this paper has successfully accomplished its task of providing a way to analyze and compare the resilience of coal logistics chains in the Hunter Valley, Mpumalanga and Canadian coal corridors. First of all, the decision of selecting only three coal exporters proved to be useful. By limiting the selection to three case studies, this paper managed to stay focused while avoiding unnecessary amounts of information and examples that would have overburdened the reader and diminished the clarity of the text. The decision to study logistics chains in Australia, South Africa and Canada allowed this paper to cover all kinds of logistics chains from the very large and very busy ones to the smaller exporting operations. In the same way, the literature on coal logistics chains in those three countries was both abundant and usually relatively easy to access. For coal logistics chains in countries like Russia or Indonesia, the task of collecting information could have been more difficult, which would have made the comparison process more difficult to accomplish. Choosing to analyze the resilience of the upstream links of the logistics chain, while avoiding the downstream links, was a necessary decision that simplified the task of analyzing data.

The concept of "corridor", a geographic construct designed to include all elements of the extraction, railway transportation and port activities sectors has given clarity to what was and was not part of the study. For instance, the Australian coal industry is a vast network of activities involving more than one logistics chain. Without the concept of corridor, which allowed this paper to focus on a single logistics chain, the Hunter Valley logistics chain, the amount of information to analyze would have been both too confusing and too broad. As geographic frameworks, the corridors have been successful in giving clarity and focus to the analysis process.

The data gathering procedure has also proved to be a successful way of finding the relevant information. It is important to remember that issues related to many different fields of research have been tackled throughout this research. Relevant information came from such varied sources as: atmospheric, hydrologic and climatology studies, mining industry publications, railway and maritime transportation publications, engineering publications so on and so forth. Extracting information from such varied sources of information has given a very global and more complete look at logistics chains than the usual all economic or technical approaches. Relying on literature more than interviews with members of the industry had advantages and disadvantages. The main advantage of this approach was that it allowed this research paper to have a *bird's view* perspective on all variables and all sections of the logistics chain, which was necessary to carry out a comparison analysis on such a large scale. On the other hand, relying on interviews from specialists would have added more details and more recent data. Interviews would also have made it possible to understand the importance (or the weight given to each variable in the decision making process of decision makers) given by stakeholders of the industry to each of the variables chosen in this paper. In this perspective, the methodology lacked from interviews with participants of this industry that could have brought more depth to the comparison process. Such a task could be the objective of a related study on coal logistics chains.

The use of infrastructure indicators, governance indicators and risk indicators has been successful in analyzing specific components of the logistics chain. These indicators proved to be efficient tools of measuring resilience for each of the three core variables. Furthermore, the partition of resilience into three sub-categories: infrastructure resilience, resilience and the risks posed by environmental hazards and finally, governance resilience provided a more complete analysis than one based only on resilience and performance which is often the case in the literature. Having twelve indicators allowed each variable to be analyzed in details. It also allowed this paper to cover the most important themes related to each variable. For example, studying hydrologic, seismic and atmospheric hazards was enough to have a complete understanding of the relationship between environmental hazards and resilience. Adding more indicators would have simply resulted in excessive information while fewer indicators would have left out important issues related to the variable. The marking system used throughout this paper was helpful in identifying which corridor showed the best resilience for each indicator. Having different ranges and different values from one indicator to another gave flexibility to the marking system while remaining easy to understand. The issue of using the proper set of indicators was probably the most important limit of this study. The resilience of a system can be affected by a large number of factors such as human factors, environmental factors and productivity factors. In the end, none of the indicators usually used in the literature or by the industry itself to assess the quality of its operations proved capable of evaluating variables of such different natures. As a result, it became more logical to compare the resilience of all three case studies not with an overall perspective, but on an indicator to indicator level.

Going back on the issues tackled by the research questions identified in section 1.3, the general and open approach of each question proved to be useful. Since the three core variables (infrastructure, environmental hazards and operational environment) were broad in nature, the research questions were also designed to be answered by a broad analysis process. Because they were general in nature, each research question was answered by a given number of detailed indicators providing the necessary amount of details. In other words, the relatively loose approach of the research questions gave way to a very effective and accurate method of answering the questions. Furthermore, the three research questions paved the way to a very complete analysis of logistics chains and of the coal industry. This approach also established a clear link between the context of this research, the need to operate efficient logistics chains and the importance of maintaining high levels of resilience.

Monitoring and maintaining resilience can reap positive long-term and short-term benefits for systems such as coal logistics chains. In a time of increasing competition on coal markets, a resilient logistics chain will have distinct advantages over its rivals. The increase in world production has led exporting countries to increase the level of activity within a short period of time. Furthermore, a rapidly growing demand for coal has brought added pressure on exporting countries to supply world demand. The increase in production and demand has also created a new multi-partner system where both exporting and importing countries are now looking to increase their number of trading partners. This new multi-partner system has also increased competition between sellers and between buyers to secure export markets and new sources of supplying. With such high levels of activity and competition, issues that were already present within coal exporting systems or that appeared as a result of rapidly increasing levels of activity can seriously reduce the competitiveness of logistics chains. In this context, high levels of resilience are vital because they reduce the magnitude and length of disruptive events, add efficiency to the logistics chain, reduce costs and elevate performance levels of the whole industry. In a high competition environment, high levels of resilience will give competitive advantages to coal exporting systems allowing them to remain ahead of competitors.

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Annex: An overview of coal chain logistics team

Following persistent capacity problems and bottlenecks in the system, several companies involved in the activities of the coal industry in the Hunter Valley region decided to create a logistics team. Metaphorically speaking, the logistics team acts as a manager responsible to oversee and manage the activities of its members to achieve collective gains. The actual role of the logistics team is larger since it "is tasked with developing, managing systems and looking at opportunities to maximise coal chain throughput to the Port of Newcastle through the efficient planning of coal movement along the coal chain from load points to vessels, as well as identifying and accelerating expansions in infrastructure capacity" (Australian Government, 2005, 25). On a daily basis, the logistics team has to ensure that all participants cooperate so that all activities can be aligned and coordinated[62].

Commonly known as the Hunter Valley Coal Chain Coordinator (HVCCC), the logistics team currently controls the operations of companies from every link of the upstream part of the logistics team. Indeed, members of the organisation include service providers such as PWCS, Pacific National, QR National, the ARTC, Newcastle Port Corporation and 13 coal producers[63].

The HVCCC has proved that logistics teams are valuable and effective to reduce capacity constraints and increase operational efficiency throughout the logistics chain. Since its creation, it has managed to get rid of bottlenecks and unlock additional infrastructure capacity. Furthermore, the logistics team has "led to over 15% of coal volume improvements" (Bayer, Rademacher and Andrew, 2009, 262).

It is clear that logistics teams are useful in solving capacity problems, aligning companies' operations, fostering coordination and planning future development projects. Through such abilities the HVCCC has managed to increase operational efficiency and, as a result, the entire logistics chain's resilience.

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