THESIS

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Supply chain resource dependency & Risk mitigation strategies for manufacturing companies

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ABSTRACT

Purpose: This paper aims at providing a set of guidelines to help companies mitigate the increasing threat posed by natural resource scarcity in their supply chain. More specifically, we will address resource-efficient supply chain as a means to create better resource management.

Design/Methodology/Approach: This research is supported by previous theoretical and conceptual research on Natural Resource scarcity (NRS), Natural Resource Based View (NRBV) & Resource Dependence theory (RDT). The resource-efficient supply chain (RESC) theory and resource-advantage theory are used conjointly with a case study and semi-guided interviews on Solvay (chemical manufacturer).

Findings: Six main indicators of resource dependency were identified: price and quantity of the resource, availability of alternative suppliers and products as well as cost of switching suppliers and geopolitical risks. Short term risk mitigation (bridging and buffering strategies) as well as long term orientation with the development of a closed-loop supply chain were proposed.

Managerial implications: Managers in manufacturing firms have the right mindset and have begun carefully crafting strategy to alleviate resource dependency but a more proactive approach should be advocated.

Research Limitation: The research should be extended over other market and manufacturing industries to validate the results. The research was also conducted based on a multinational scale and SMEs were not part of the scope.

Originality/value: The research combines theoretical and practical considerations set within a targeted market: Polyamide 6.6. The plastic market is highly dependent on resource which makes it the perfect case study.

Keywords: Resource scarcity, Resource dependency, Supply chain management, Supply chain risk management

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1.1 Overview

This first section introduces the research context, the existing literature and the discrepancies identified. The aim of this paper, objectives, research question and a first look at the methodology design will also be highlighted in this section.

1.2 Research context

Demand in industrial products has been steadily increasing which makes the elaboration of a global supply chain in a seven billion people world a challenging task. Natural resources are not infinite and our planet may not be able to cope with the trend toward a 10 billion population slowly taking place (*UN press release, 21/06, 2017)*.
Supply chain integrity with natural resources such as metal, agricultural crops, water or petroleum lies in our ability to maintain balance between supply and demand. Capability and logistic costs will depend on the availability, location, quantity and quality of said natural resources. Industrials tend to be ingenious in avoiding resource scarcity by overcoming the issue thanks to their technological ability to find alternatives products or new sources of natural resources. Scarcity is defined as “the gap between limited – that is, scarce – resources and theoretically limitless wants” (Investopedia definition). This situation requires people to make decisions about how to allocate resources efficiently, in order to satisfy basic needs and as many additional wants as possible. Any resource that has a non-zero cost to consume is scarce to some degree, but what matters in practice is relative scarcity” (Investopedia).

Market trends in the chemical industry and natural resources also greatly influence scarcity and prices of material resources. Price shifts in the raw material industry have highlighted the implications raw materials can have on supply chain process. Firms and operators on the upstream scope of raw materials (i.e. extracting, refining and processing operations) are closely monitoring material supply and price swings. However, the importance of raw material on supply chain operations should be even more emphasized for all stakeholders. A purely reactive response has limited efficiency. Stakeholders thus need to have a more proactive and informed approach when dealing with their supply chain.

The other type of resource beside material ones to take into account to attend to the scarcity issue is natural resources. Natural resources are used to manufacture every product as part of their manufacturing process or in the service industry. They can either be renewable (e.g. crops, wood, etc.) or nonrenewable (e.g. minerals, metals, organic resources such as petroleum). Resource scarcity can happen locally or globally but it has repercussions on the logistics of a supply chain. One well-known example of local scarcity is water which can force people and companies alike to travel long-distances to obtain it. On a more global scale, lithium which is a mineral crucial to mobile phone battery is a very scarce resource. Prices for scarce resource tend to skyrocket proportionally to their scarcity level which may force manufacturers and consumers to find alternative sources.

1.3. Research problems and discrepancies

Growing interest in sustainability has not helped in identifying the interaction between supply chain and the usage of resources.

In the overall sustainability research agenda, resource usage and consumption throughout the supply chain should definitely be a key subject. Nonetheless, very little has been made to map the optimal supply chain configuration which would integrate the high risk resource dependency represents on a supply chain.

1.4. Research Aim, Objectives and Questions

In light of raising awareness to the importance of mitigating resource supply risks, this paper will examine the question of resources vulnerability, both material and natural from the perspective of a chemical manufacturer. Three sub-questions will address this issue:

- **Outcomes**: What are the key changes occurring in a supply chain as a result of resource scarcity or limited availability?
- **Mechanisms**: What are the factors driving resource scarcity?
- **Strategies**: Which strategies help companies mitigate their dependency towards resources?

1.5. Research design and methodology

The objective of this paper is to explore ***how an optimal supply chain can help companies and managers mitigate their resource dependency***. As a starting point, a review of the resource literature to understand resource dependency will be introduced. Further theoretical and managerial background will be given on the dependency of natural and critical resources in the chemical industry. It will be followed by an exhaustive review summarizing the existing literature on the challenge of material scarcity and natural resource depletion in supply chain management. The literature review allows us to define material and resource scarcity from a supply chain management perspective for manufacturing companies. Then, further conceptual foundations on risk management and the outcomes associated with managing the supply of critical elements will be presented to conclude the first part.

The ensuing case study on the Solvay multi-national company, an international chemical group, will be conducted in parallel with semi-guided interviews from varied and relevant persons in targeted functions.

This paper concludes by offering a best practice framework of risk mitigation on resource dependency and recommends revisions of ongoing supply chain strategies to thrive toward the establishment of a resource-efficient supply chain.

2. Conceptual Foundations

This section develops first and foremost the notion of supply chain focusing on the resource dependency challenge as well as the conceptual foundations and framework of the two main leading theories found in resource-efficient supply chain (RESC): the Natural Based View (NRBV) and Resource Dependence Theory (RDT).

2.1. Understanding supply chain challenges: Focus on resource dependency

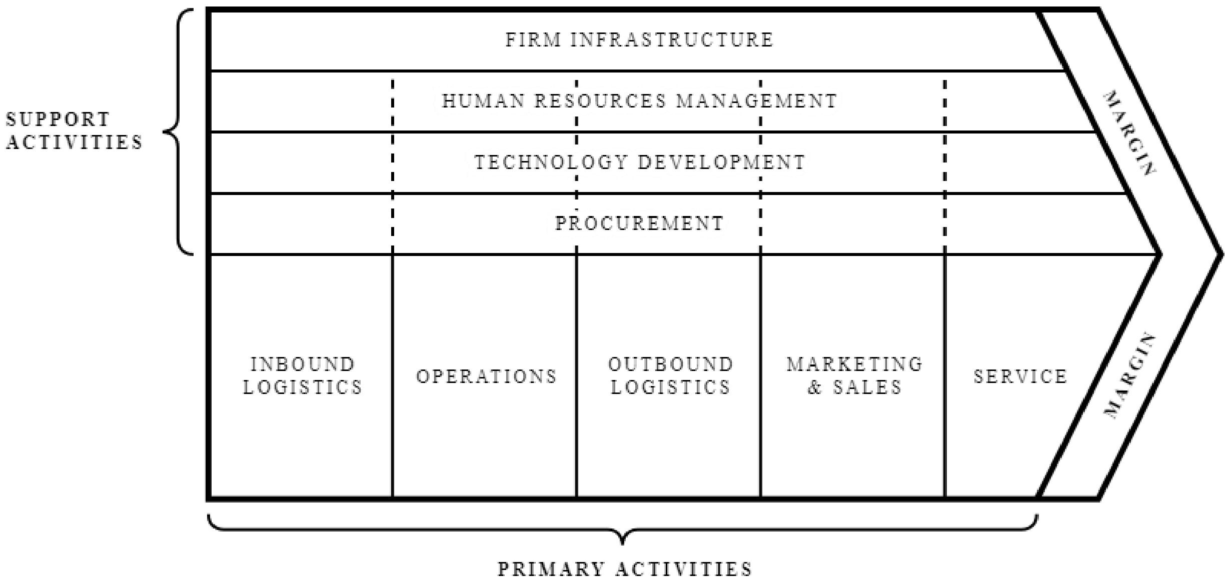
Over the last 30 years, many scholars and forward-thinkers have studied and improved management theories to provide higher value to the customer. One of the most preeminent scholars was Michael Porter, the famous Harvard Business School Professor who developed and perfected strategies framework on competitive advantages that are still used by managers to this day.

The “value chain” concept in particular has brought competitive advantage into the limelight. As shown in Figure 1, there are two categories of value chain activities:

- The **primary activities** (inbounds logistics, operations, outbound logistics, marketing and sales, and service)
- The **support activities** (infrastructure, human resource management, technology development and procurement)

Competitive advantage is obtained when firms deliver value to their customers while performing these integrated activities more efficiently than its competitors or by performing these aforementioned activities in such a unique way that it creates differentiation.

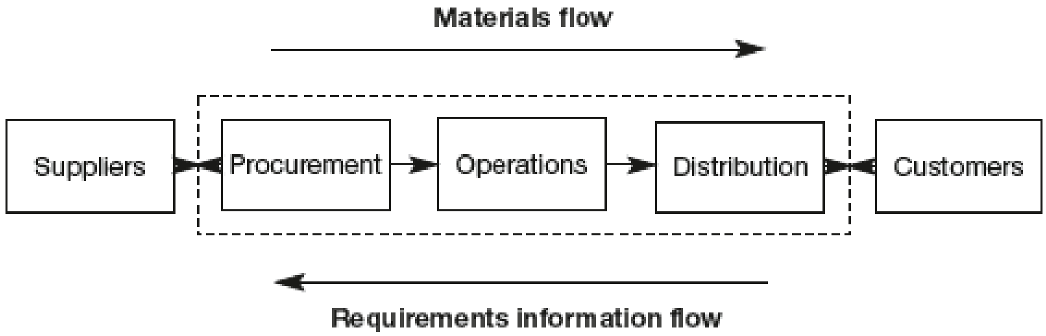
Figure 1: Michael Porter's value chain (Source: Porter, M.E., competitive Advantage, The Free Press, 1985)



Michael Porter value chain model brings strategic thinking in a way that firms need to constantly assess their current activities in their value chain. If one activity does not yield competitive performance, then it might be an indicator to consider outsourcing or improving the activity to reach higher cost or value advantage.

Managing the primary and support activities to achieve the desired levels of quality and service at the lowest possible cost is the mission of logistics management. Logistics is the intermediary between the market place and the supply chain. The scope of logistics management is spread throughout the whole organization from raw materials management to the delivery of the final product (illustrated in Figure 2).

Figure 2: Logistics management process (Source: Christopher M., Logistics and supply chain management, 2016)



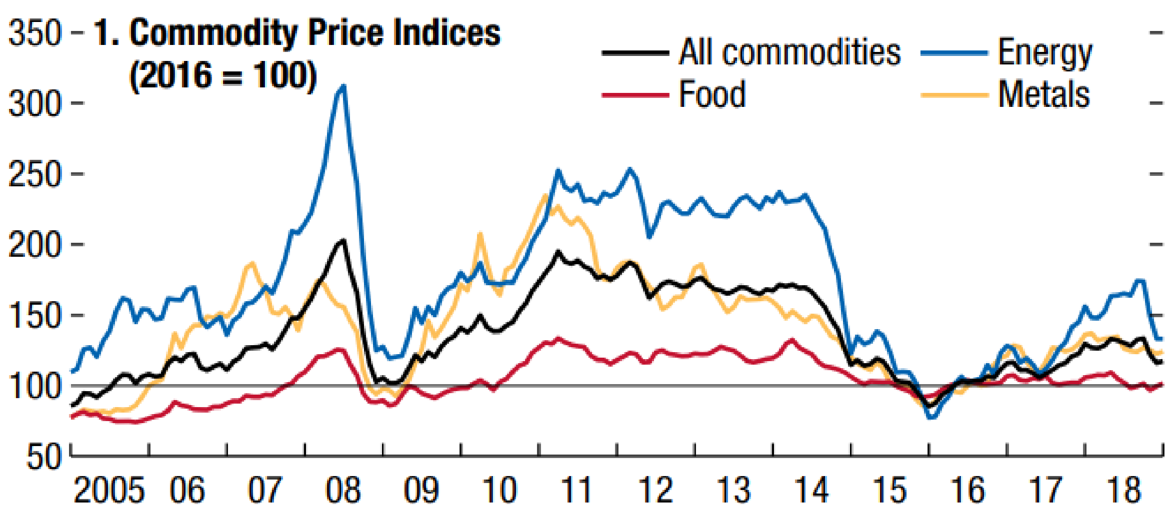
The business landscape is growing more complex and competitive every day which proves to be challenging for logistics and supply chain management. Indeed, the business organization is nowadays met with many strategic issues of whom the most pressing one revolves around logistics and supply chain management. Christopher Martin (*Logistics and supply chain management, 2016*) highlighted several major trends on SCM (supply chain management) including market globalization, outsourcing, decreasing supplier base, shorter product life cycle as well as the volatility of the business environment and supply chain vulnerability which might lead to disruption.

Supply chain vulnerability and especially resource scarcity is putting pressure on supply chain integrity. Resource scarcity can happen for several reasons. For **natural resources**, substitution, discovery, recovery and reclamation help alleviate the resource scarcity level and provide undisrupted availability. On the other hand, the (over)consumption, degradation and increased competition will increase the scarcity level of the resource. Until now, technological advancements have enabled to harness the power of substitution and recovery to create alternatives for a resource or to find new sources of resources (e.g.: oil or natural gas). However, substitute resources cannot sustain the rate at which the population is expanding and the increased competition leading to exponential economic growth.

For **raw materials**, the increasing trend towards more price shifts and volatility identified more than a decade ago (2005-2009) has forced organizations to address their sourcing strategy. After almost a century of tremendous economic growth, abundance and easy access to resources, the landscape of the earth's geological and ecological resources has taken a shift since the beginning of the new millennium. For instance, the price of non-food agricultural resources have increased on average by 6% per year and by almost 120% across a range of seven products since 2000. (*McKinsey Global Institute MGI Resource Index 2013*). This average can be deceiving as the rubber industry was hit by a price increase of 359% since 2000.

For minerals, metals and energy resources, we can draw the same observation. Analysts have argued that this surge in raw material costs is consistent with the commodities cost cycle. The drop in commodity price in 2008/2009 (illustrated in Figure 3), consequence of the financial crisis, is used as evidence that commodity prices will eventually be forced to stabilize.

Figure 3: Commodity market developments (Source: IMF, Primary Commodity Price System)



Others argued that the commodity cost cycle does not include the socio-economic reasons that disrupt the world's current balance. Scientists, climatologist and more specialists have pointed towards a simple reason to this issue: the earth's resources are reaching their breaking point. This debated issue will cause unprecedented problems in the way business operates by directly influencing raw material availability and consequently costs of raw material (*GEO-5 for business, 2013*). Competition to access the material resources has been amplified since historical supplier countries such as China have become consumers themselves of such raw materials.

Demographic trend and economic development of emerging countries have intensified the quantitative demand for raw materials as well as the variety of needed raw materials. Indeed, raw material availability is linked directly to their geological abundance. The European commission has taken action by enabling a study on raw material criticality. The goal is first to assess and establish a list of the critical raw material which are identified by the two following criteria:

- *Economic importance* : how important that material is to the European Union economy
- *Supply risk*: how risky the disruption of material is to the European Union. The supply risk is assessed at the “bottleneck” stage of the material which can be either during extracting or processing because it represents the highest supply risk.

The European Commission also introduced the European innovation Partnership (EIP) on Raw materials which aim is to bring together industry stakeholders, public services, NGOs and governments to address future challenges on raw materials. The EIP is instrumental in creating new research and innovation approach to enable the continued and sustainable supply of raw materials within the European economy (*European Commission*).

2.2. Natural Resource Based View (NRBV) & Resource Dependence theory (RDT): A resource-efficient supply chain view

The resource-based view (RBV) has taken a lot of momentum in the field of supply chain management. The resource-based view theory (*Barney, 1991*) advocates that a sustained competitive advantage is obtained through:

- the valuability, rarity and inimitability of a resource

- the company’s capabilities

However resource-focused the RBV theory is, it fails to present the interaction between an organization and its environment.

Hence the importance to base our resource-efficient supply chain characteristics on both the Natural Resource Based View (NRBV) theory introduced by Hart in 1995 and the Resource dependence theory (RDT) by Pfeffer & Salancik, 1978.

The **natural resource based-view** is complementary to the RBV theory by also including environmental considerations. The NRBV prone the efficient use of natural resources and the minimization of waste and emission throughout the company’s entire value chain.

The first step to building a resource-efficient supply chain is to raise awareness on how resources are used and its impact. Measurement of resource efficiency in supply chain management often uses indicators such as labor, equipment, technology and energy. A more recent trend in green SCM has rendered mainstream the usage of performance indicators such as level of water consumption, waste or emission productions.

However issues arise to quantify resource usage along the supply chain as this must often be done among a diverse group of organizations. Resource awareness is thus interconnected with information exchange between aforementioned organizations and its success lies in their willingness and capability of measuring performance together. Literatures has proven that sharing information greatly enhance best practices in resource management (*Zhou and Benton, 2007*) but asymmetry of information is easily created as many companies still shy away from sharing their resource usage. This is especially the case in global supply chain where supplier or customer can be reluctant or unable to provide information on resource use due to lack of proper measurement tools.

If companies and managers however succeed in establishing information exchange, they are able to identify, trace and quantify flows of energy consumptions and materials. This later enable them to identify critical and scarce resource used across their supply chain and consequently adopt appropriate methods, tools and performance indicators to quantify them.

The second step characterized in the natural resource-based view theory lies in companies' ability to be resource sparing to sustain their competitive advantage. Once awareness is achieved, it is easier to implement operational continuous improvement and reduce resources usage at different operational stages (e.g: product adaptation, production process, closed-loop supply chain creation). Resource sparing is agile enough to be applied in traditional manufacturing process or even for returns management, reverse logistics and reuse.

The resource dependence theory advocates that companies' success and survival are highly dependent on their environment and therefore, have to react to changes on their resources supply. Competitive advantages gained through optimal resource usage management are the combined effort of companies to collaborate in pooling their resources together as previously stated.

Resources changes on the supply chain are made harder to identify by the growing offshoring and outsourcing trend (*Ellram et al., 2013*). Indeed, the depth and range of resource interdependence often grows more complex as the supply chain becomes more global. Supply chain management scholars have since then endeavored to assess and identify supply chain risks and their sources (*Narasimhan and Talluri, 2009*).

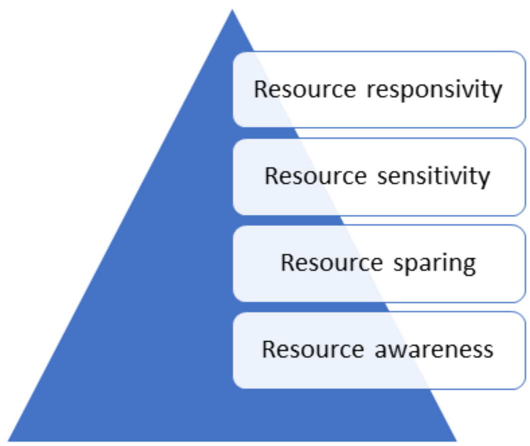
The third step in establishing a resource-efficient supply chain is accurately sensing shifts in natural resource and raw material availability. Any potential blockage to access resource must be spotted with the help of the company's environment (suppliers and customers). A resource sensitive supply chain implies vigilance and monitoring toward price variations or any changes in supply of resource it needs due to degradation, depletion or natural disasters. A larger macro-trend environment such as demand pattern shifts, demo-graphical indicators or geopolitical situation must be taken into account.

The last characteristic of a RESC, resource responsivity is naturally interlinked with resource sensitivity. Organizations and ensuing supply chain are inherently complex and adaptive systems which can react and adapt to the shifts and change identified. *Walker and Jones (2012, p. 16)* even suggest "there is no one right way to approach sustainable

SCM, and that the best course of action is contingent upon the internal and external situation”. As previously stated in the research context, supply chain requires some degree of agility to be able to respond to the uncertainty that comes with product innovation, changes in demand and market trend and more critically to resource availability. The goal being of such a responsive supply chain is to develop and act upon strategies to alleviate their resource dependency.

The framework of the key characteristics of a resource-efficient supply chain is presented in Figure 4 in a bottom down approach.

Figure 4*:* Resource-efficient supply chain framework (Source: Aristides Matopoulos, 2015)

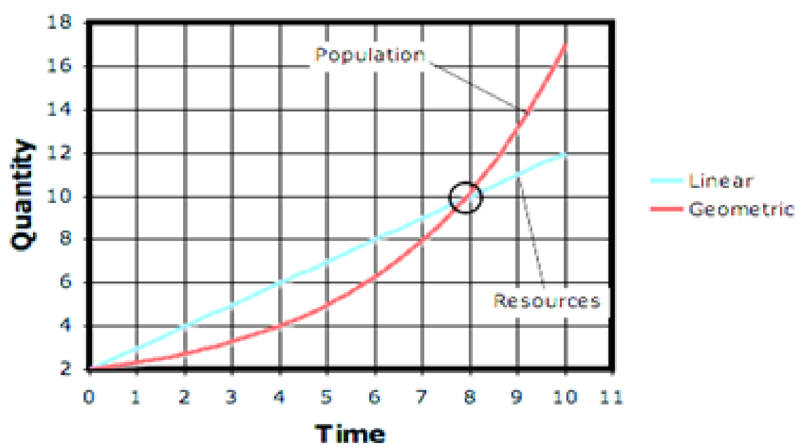


2.3 Natural Resource Scarcity: Resource-Advantage Framework

Extensive studies have been conducted in economics or management to understand Natural resource Scarcity (NRS). Adam Smith equilibrium theory or John Stuart Mill natural monopoly were both linked on the notion of scarcity. These theories emphasized the benefits and positive outcomes of resource scarcity and heavily implied that an organization could gain competitive advantages by using scarce resources.

Later on, economists such as Malthus argued the potential negative impacts of Natural resource scarcity. The Malthusianism was built on the principle that population growth was fundamentally exponential while resource growth is linear (as illustrated in Figure 5).

Figure 5: The Malthusian Growth (Source: Principles of political economy, Malthus)



Optimistic scholars believe that population growth will continue to be manageable through technological use (*Neumayer, 2000*) while less optimistic economists are more doubtful that technological progress will be able to keep up with such population growth (*Brander, 2007*). While natural resource scarcity is catching the press attention, it has become a strategic challenge for both businesses and governments (*Bishop, 2009; Wagner, 2002*).

Some have focused their attention on raw materials and minerals shortages during the product designing stage (*Duclos et al., 2010*), other experts in the field of environmental and agricultural science address the water scarcity issue (*Biswas, 2005*) which is directly linked to much-discussed food scarcity issue. On a political scale, resource scarcity has become a tool to wage competition between neighboring nations. The scarcity of rare earth metals has also become a pressing issue in the development of high-end and military technologies.

The above mentioned literature has made it obvious that resource scarcity has mostly been analyzed on the macro-environment. Resource scarcity poses a threat that needs however to be addressed within the frame of an organization.

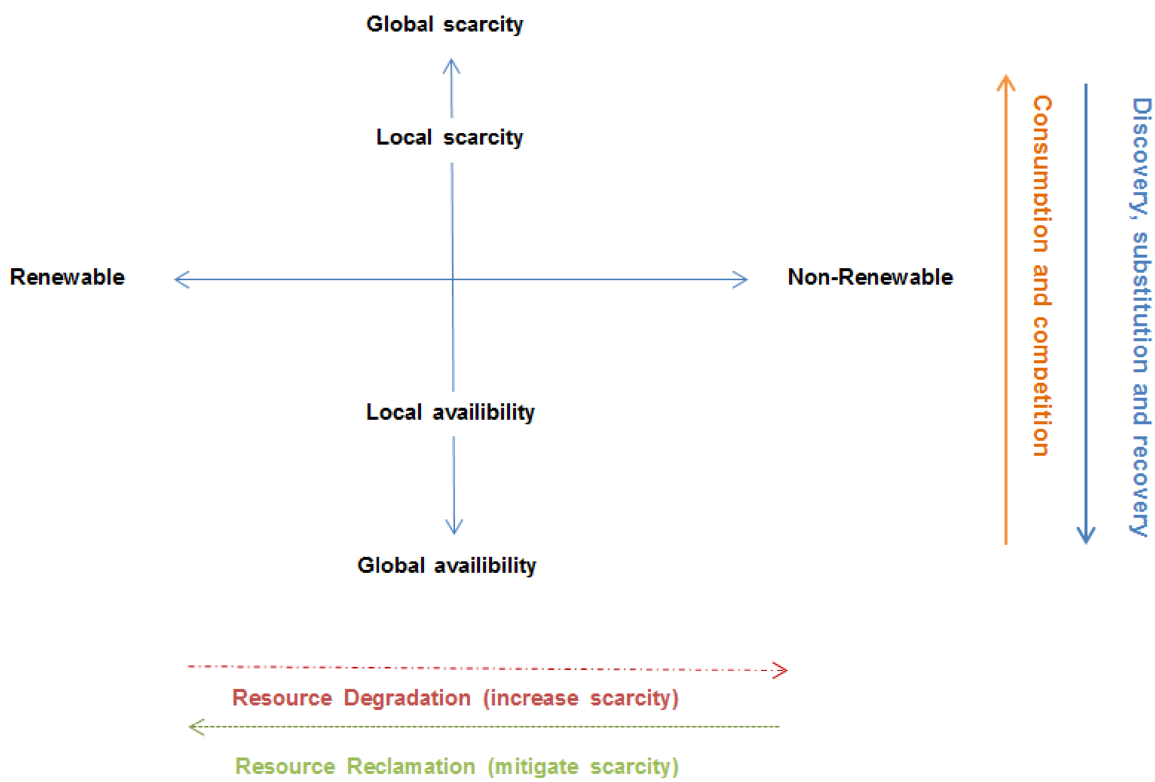
The **Resource-Advantage theory (R-A)** offers the perfect perspective to craft mitigation strategies against resource scarcity (Hunt, 1995, 2000). This theory is a combination of the heterogeneous demand theory found in the marketing field and the Resource-Based-View theory previously mentioned. Hunt and its R-A theory places the firm as a combiner of heterogeneous and mobile resources. The R-A theory provides a great framework to analyze close-loop supply chain (CLSC) as a potential response to NRS. The Closed Loop Supply Chain management is defined as "design, control and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time" (Bell, J.E., Mollenkopf, D.A.,2013, pp.352)

The status of a natural resource can be categorized into several attributes:

- *Renewability* : the ability of a resource to regenerate given a period of time
- *Scarcity* : the degree of scarcity is dependent on the balance of physical supply and demand

The renewability and scarcity components provides a tool to assess the NRS status (illustrated in Figure 6)

Figure 6: Natural Resource Scarcity Status (Source: Adapted from Bell, J.E., Mollenkopf, D.A., 2013)



The resource heterogeneity level (quality and quantity of a resource at a location) is a third attribute to measure the NRS status. For example, coal has been extracted and mined for generations and the most accessible and highest quality source of coal have been already consumed. Some regions or countries are thus left with insufficient quantities and inadequate type of coal for their needs. In other words, firms can have access to a local resource in sufficient quantities and quality for a period of time but it can be lacking to meet the specific and heterogeneous demand needs for the resource. Managers and firms often mistake the scarcity status of a resource due to the high heterogeneity of the demand: high-grade coal is globally scarce and only lower grade are locally available. They make the false assumption that the demand is homogeneous and that one type of resource can provide for heterogeneous needs.

The status of a resource can change rapidly due to its environment and more specifically by seven forces identified by *Bell et al. (2012).* Among these seven forces developed in below Table 1, two will impact the resource status on the renewability axis (horizontal) and the other five will affect status along the scarcity axis (vertical).

Table 1: Seven forces identified impacting NRS (Source: Adapted from Bell et Al. 2012)

Category	Forces	Description and examples
Increase scarcity	Degradation	The resource base is plagued by pollution, misuse, over-harvesting which leads to increasing scarcity of the resource and what was once renewable resource becomes non-renewable. *Examples: Global warming, carbon emissions, water scarcity or food scarcity*
	Consumption	Availability at a specific location is reduced proportionally to the consumption of the resource. Population growths as well as emerging economic power from developing nations are putting pressure on the consumption level on industrial products and natural resources. For the most coveted resources, local scarcity will become global. *Examples: Deforestation, source of fresh water unavailability, loss of biodiversity...*
	Competition	Competition between firms lead to local and global scarcity as they compete to secure scarce resource to gain competitive advantage and prevent rivals to access that resource. Nonrenewable resource such as rare earth elements are the most threatened. *Examples: Platinum, Gallium, Indium (used in solar panels), Zinc...*

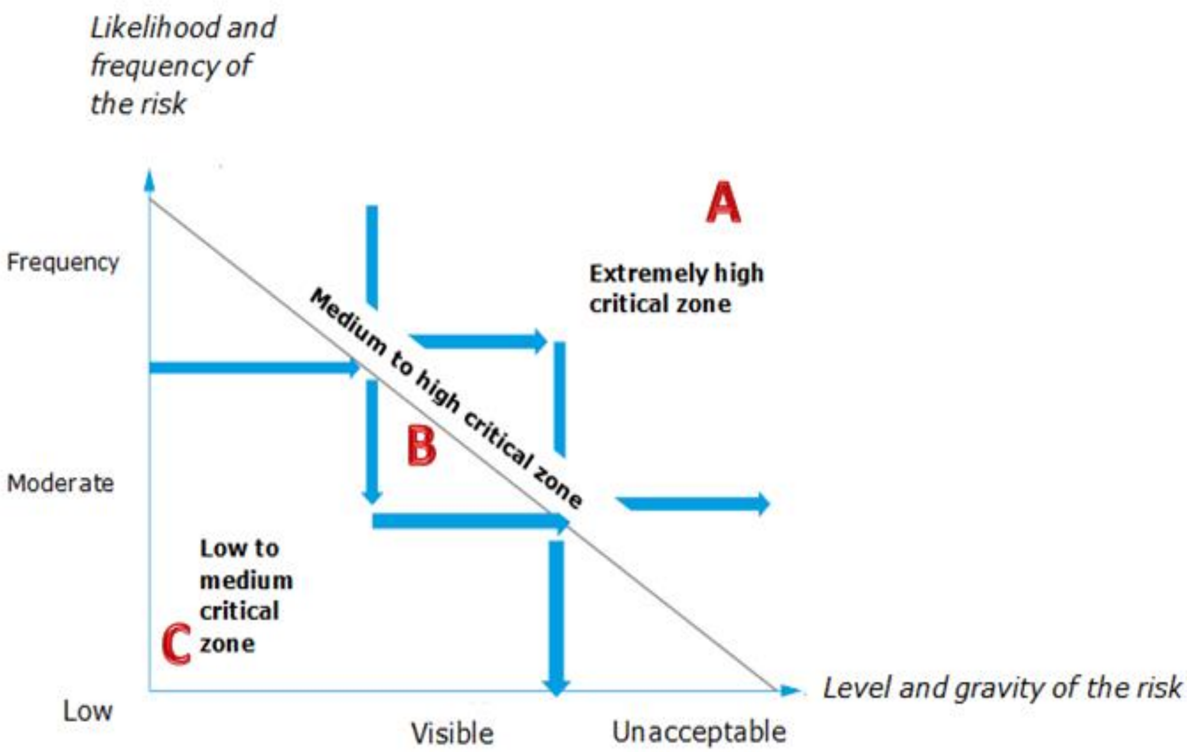
Mitigate Scarcity	Discovery	Discovery is the perfect counter strategy to resource scarcity. Resource price surge gives incentives to companies to explore the Earth and find new resources. Technological advancements and innovations have made feasible and economically sound new process such as hydraulic fracturing to recover gas or oil. Extraction and discovery of new resource is however uncertain and not strong enough to balance NRS by itself.
	Substitution	When a resource becomes scarce and its price rises, the economic force of substitution takes over. Cheaper replacement or available replacement can mitigate resource scarcity Substitution has however its limits as many resources are non-substitutable or alternatives can compromise the product design integrity. *Examples: Timber and wood were replaced by industrials by steel and iron.*
	Recovery	Recovering or also called recycling natural resources can increase their supply and consequently mitigate their scarcity level on local or even global scales. Most often, companies implement recycling strategies as part as their environmental strategy and not as a way of countering scarcity
	Reclamation	To increase renewability of resource, reclamation is a strategy to improve the resource base through combined efforts either by reducing pollution or soil degradation. Companies need however to act with caution as resource reclamation can by itself pollute the environment.

2.4 Sourcing mechanisms: risk management

Suppliers can be the makers or downfall of a company's success. The risks are even higher as a good supplying strategy and network represents a large part of its turnover. Managing suppliers and sourcing involves managing risks whether they are legal, financial or operational.

In risk management, the risk matrix (Figure 7 below) is a management tool used to assess and measure risk to enable managers to take informed decisions. Positioning on the matrix defines the level of risks: limited, medium, high or unacceptable.

Figure 7: Risk Matrix (Source: Adapted from Olivier Wajnsztok, Stratégies Achats)



Managing risks in a company requires following several steps. The first step is the *identification* of the potential risks linked to every company's activities. The second step is the *assessment* of the threat level linked to every identified risk in the previous stage. The third step is the *evaluation* of frequency of each risk. Frequency of the risk happening does not define the risk level. It is used conjointly with the fourth step which is the *prioritization* of risk. Risk should be prioritized according to the criticality. The criticality is the combination of high frequency and high threat level.

The objective of the risk matrix is to help identifying these risks and prioritize them in order to achieve the following results:

- Elimination of highly critical risks (Point A)
- Diminution of highly and moderate critical risks (Point B)
- Monitoring low critical risk (Point B)

Within risk management, some typology of risks (illustrated in Figure 8) is made to further enable better risk identification.

- **Financial risks** encompass risks that have financial impact (delivery delay, quality issue…) which most often generate extra costs.
- **Operational risks** are linked to quality, logistic, production operations within the firm.
- **Legal risks** are most often inherent to the firm activities as they represent the regulations or contracts with suppliers and customers.
- **Brand image risks** are any type of risks which could endanger the brand image or notoriety of the firm.

Figure 8: Typology of risks (Source: Adapted from Olivier Wajnsztok, Stratégies Achats)

This paper will focus most specifically on financial risks and operational risks.

Among financial risks is the risk of raw material price shifts. Purchase price of raw material can greatly influence the retail price of a product. This risk is most often difficult to assess as it is unpredictable. Price of a commodity can stay roughly the same for long period of times and surge unpredictably due to economic conjecture or availability issue. Companies resort to several financial tools including swap which allows the company to receive payment linked to the raw material price at a fixed rate established by both parties in advance.

Operational risks are best represented by the supplier risks. If one defaulting supplier is identified, a strong network of contingency suppliers is needed to cover that risk. Auditing supplier and contractors enables to identify trustworthy and strong supplier.

2.5. Outcomes of resource scarcity

Now that we have established what resource scarcity is and why it can occur, we should focus on the changes resources scarcity can bring in a supply chain.

Besides the usual short-term shortage consequences and immediate effects, resource scarcity has also mid-term and long-term issues to be considered. The entire production chain is disrupted and can be fragilized. Direct and indirect costs for both the manufacturer and its customer will be generated. Customers might also lose faith and confidence in the reliability of supply. Customers will also actively look for alternatives, either in terms of supply or product substitution.

A balanced supply and demand situation can justify the good and sustainable margins that have been observed throughout the polyamide chain for the upstream manufacturers. However, due to resource scarcity issue, this balance is easily disrupted and companies on the downstream can suffer a lot from this as they also experience a lack of information and transparency to understand the reasons behind supply shortage.

Identifying potential source of resource scarcity will force stakeholders to find new or alternative resource deposits. Avoiding the use of scarce resource will become instrumental in a company's success over the coming years as well as an increasing trend towards returns management and recycling.

Strategies and processes will need to be adapted to create supply chain that can re-use or recycle to develop closed-loop supply chains. Managers will be tasked with building strategies based on efficient logistics, avoidance or allocation to mitigate their dependency towards resources.
The full implications of NRS on supply chain are however still missing and further individual case studies needs to be dissected to offer creative scarcity risk mitigation strategies.

3. Methodology and research design

3.1. Research approach

Due to the conceptual and exploratory nature of this paper, a case study methodology was chosen. Case study is the most suitable methodology in order to refine conceptual and theoretical knowledge. Conjointly, semi guided interviews were conducted to further refine the theoretical evidence.

To achieve this paper's objectives presented in Research aim, objectives and questions, we will focus the research on one specific product branch from the chemical industry: Polyamide 6.6. The case study will be elaborated focusing on the Belgium chemical manufacturer Solvay and its market and competitors environment.

What is Polyamide 6.6?

Polyamide 66/PA66/Nylon 66 is one of the most popular engineering thermoplastics with a wide range of applications and most specifically used as alternative to metal in automotive applications. Its processability, heat resistance, hydraulic stability makes this nylon grade a coveted choice for automotive parts, sports equipment, roller skates, clothing items, etc.…

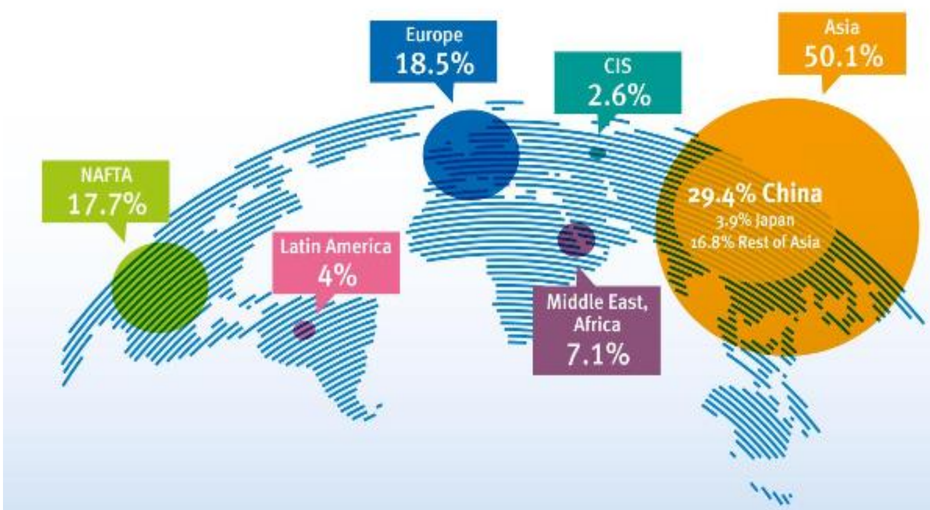
Polyamide 66 was first discovered in 1931 as Wallace Carothers carried out a research project at DuPont on molecules called polymers. Polyamide 66 is synthetized by polycondensation (chemical reaction leading to the formation a compound of a higher molecular weight) of *Hexamethylenediamine* as well as *Adipic acid* (illustrated in Annex 1).

The Plastics Market

Polyamide is but one category of the larger family of thermoplastics. Plastic markets publish every year an extensive market study on the plastic industry. Below are some of the key figures and characteristics of this large industry.

- The plastic industry ranks as seventh largest industry on par with the pharmaceutical industry and close to the chemical industry.
- in 2017, almost 60 000 companies involved in the industry employed 1.5 million people
- The industry had a turnover of 355 billion euros in 2017
- In 2017, 64.4 million tons of plastic were produced in Europe and 348 million tons worldwide.
- Demand for plastics is the highest in Germany (24,6%), followed by Italy (14%), France (9,6%), Spain (7,7%), the United Kingdom (7,3%) and Poland with 6,5%. These six countries make up for almost 70% of the European demand.
- The largest producer of plastics in the world is China with almost 30% of the world total production (illustrated in Illustration 1).

Illustration 1: Distribution of plastics production (Source: Plastics Europe Market research)



While global demand for plastics is still led by China, the trend is different for PA66. In 2005, the northern American market was the biggest consumer of PA66 with approximately 1,250 million tons against a bit less than 900 million tons in 2012. China had the reverse trend with 250 million tons in 2005 and almost 500 million in 2015. Demand in PA66 nearly doubled in the last decade for the Chinese market while the American market lost nearly ¼ of its demand. China demand for PA66 is expected to create further disproportionate growth as the automotive Chinese market is expanding. *(Shen, 2013, Tecnon Orbichem)*

In the automotive industry, polyamides offer a cost and weight-efficient alternative to metals. Polyamides are lighter compared to steel or other types of metal while allowing for more complex design. Inventions using polyamides are still being developed and more applications are made by combining existing processes.

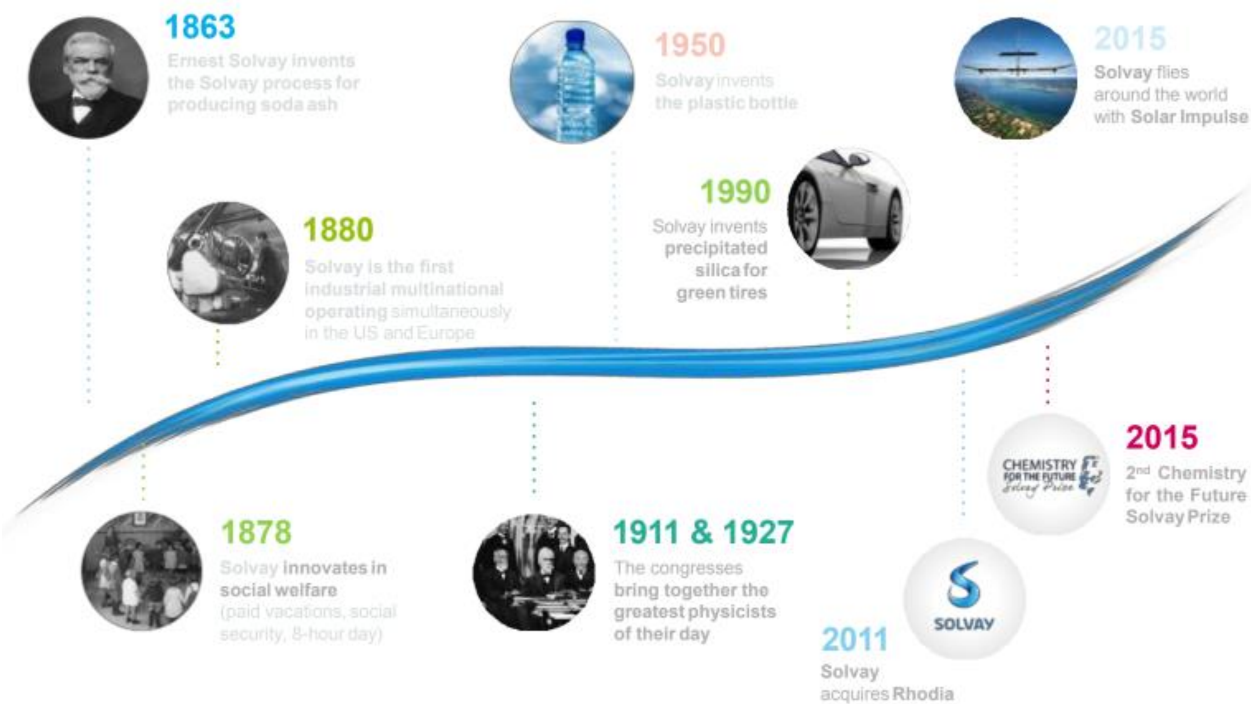
On average, a modern car contains approximately ten thousand individual components which includes roughly between 8 to 18% of polyamides. As they are light and of lower density, this can represent up to 70% of the total volume composition of a car (*Moraitakis, 2017*)

Solvay: an international chemicals and plastics company presentation

Solvay is an advanced materials and specialty chemicals group, engaged in the development of solutions to meet major societal challenges. Solvay innovates in partnership with its customers in various end markets such as aeronautics, automotive, batteries, electronics and consumer goods, as well as in gas and oil mining, thus contributing to combining efficiency and sustainability. The Group, headquartered in Brussels, employs approximately 24,500 people in 61 countries.

Its long history is illustrated in the timeline below from the discovery of the ammonia-ash process that laid the foundations of Solvay to more recent prowess and endeavors. (Illustration 2)

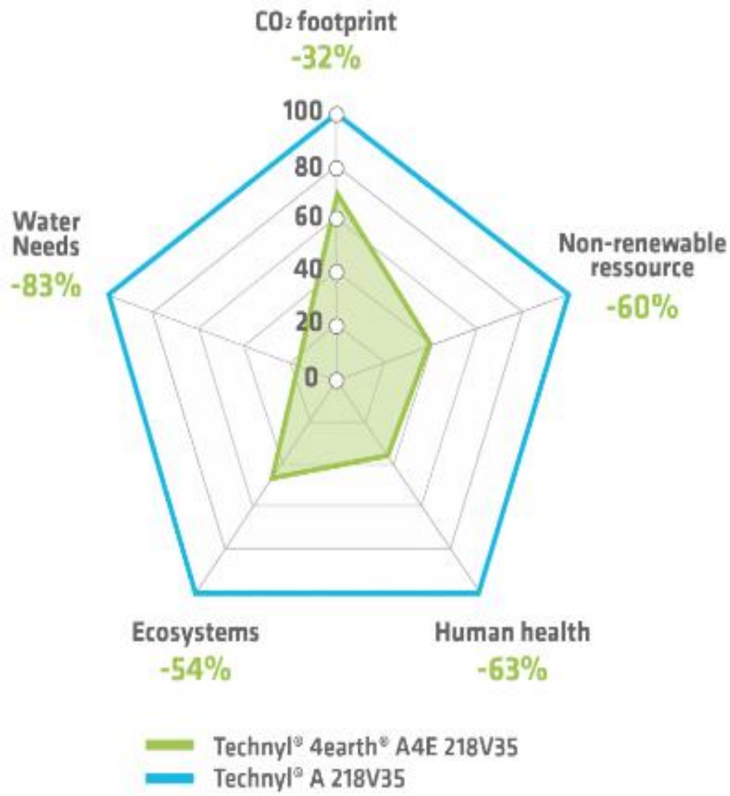
Illustration 2: Solvay's group timeline (Source: Solvay official website)



Innovation

Solvay has recently taken on a new sustainability challenge through the Move 4Earth program. Solvay's Gorzow (Poland) plant patented in 2016 their industrial process to transform stable sources of end-of life technical textiles into high quality engineering plastics. The process uses automotive airbags which are then stripped to be recycled into PA66. Over 70% of European airbags are produced with nylon and silicone textile manufactured from PA66 so the raw material supply should be less easily disrupted by material availability. Compared to the Technyl A 218V35, the TY 4Earth has some unarguable benefits. Figure 9 illustrates that this eco-friendly plastic grade allows for a cut of 60% the use of non-renewable resources and by 83 the consumption of water needed to manufacture it.

Figure 9: Environmental impact comparison between regular PA66 grade (TY A218V35) and recycled grade (TY 4Earth) (Source: Solvay Life Cycle assessment)



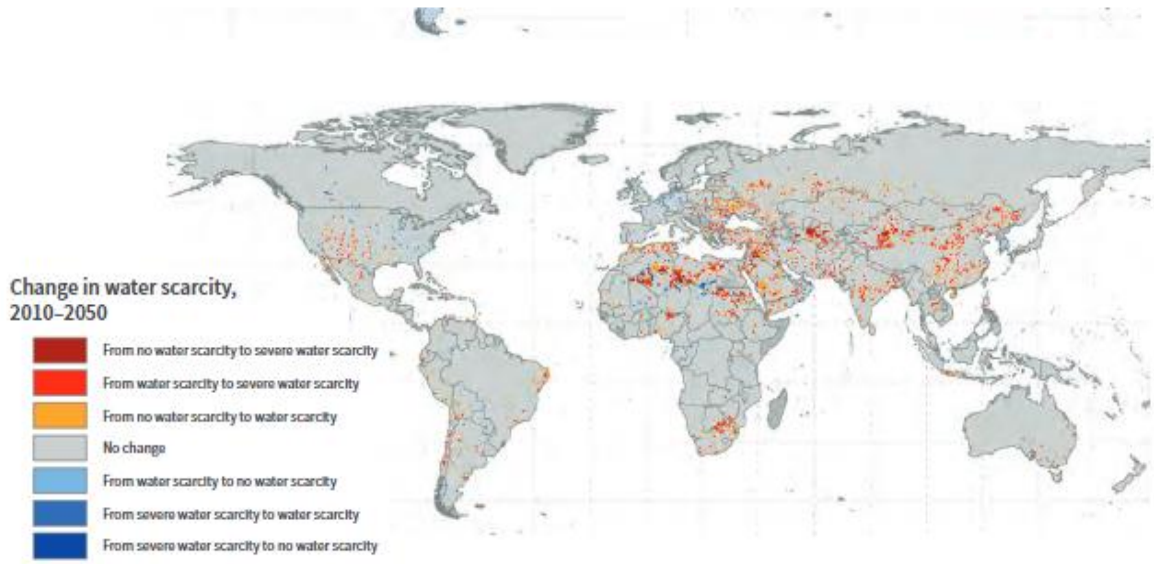
Water management at Solvay

Context

Freshwater is non-renewable and limited. It represents only 2, 5% of water on the planet. Water distribution is also not homogeneous depending on the region or season. Illustration 3 below shows the regions most affected by the water scarcity risk in the upcoming years.

Water management policy at Solvay involves recycling and reusing water resources.

Illustration 3: Change on water scarcity (2010-2050) (Source: Natural based solutions for water, 2018, UNESDOC)



Solvay's water policy goal is to protect the quality of their water resource as well as limit the freshwater withdrawals linked to their industrial activities, especially in regions with a constrained access to freshwater.

Risk Management process

Being involved in such a diverse and broad range of activities, Solvay has implemented the Solvay's "Enterprise Risk management" (ERM) approach which is a dynamic process to assess risks in every activity. The global business units (GBU) at Solvay all conduct every year their own risk assessment as integrated in their annual strategic review.

The risk assessment strategy entails a first analysis phase, followed by strategic decision-making on how to manage critical risks and implementation of risk management actions. Critical risks and how to address them are closely monitored by the Group Risk Committee.

The Group Risk Committee has listed main risks according to four possible impacts: economic impact, impact on people, on the environment and on reputation. Impacts are evaluated from high to moderate and every year these risks are included in a comprehensive report.

Market and growth strategic risks assess the development actions used by Solvay to gain exposure in their markets and competitive environment. Some of their mitigation actions are a systematic analysis of markets trends and marketing possibilities and development of customized solutions with their customers. In 2017, Solvay chose to *initiate the cession of their Polyamide business judged too unsustainable as part of their market and growth strategic assessment.*

Supply chain and manufacturing reliability risks entails risks related to raw material availability and usage, supplier's network, production, storage facilities as well as inbound and outbound transportation mechanisms. This includes risk of resource shortage as well as strikes and natural disasters. Mitigation strategies are created for each key risk with corresponding customized policy and risk control programs such as supplier qualification and assessment process, integrated resource planning, supply chain optimization or crisis management. To address supply chain risk, Solvay integrates environmental, social, supply security and innovation criteria to identify mitigation actions.

Some suppliers can be categorized as critical due to their strategic importance or simply because they are identified as business, country or product liability. Those strategic suppliers must take part in a Corporate Social Responsibility (CSR) assessment and continuous improvement process. They must also sign and adhere to Solvay's Supplier Code of conduct.

An industrial activity such as the polyamide industry relies heavily on energy consumption. Solvay is particularly focused on energy reduction so they are adamant in securing reliable energy suppliers. To achieve that goal, they leverage their technological prowess in industrial operations to reduce their energy consumption. They also engage in maintenance and reviewing their industrial’s sites performance. Solvay has as well strong supply strategy coverage with secure and reliable partnerships and medium to long-term contracts with price hedging mechanisms for protection. The group also relies on forecasting reports to monitor energy and raw material prices trends to anticipate and determine their sales strategy.

3.2. Case study data collection

3.2.1 Market trends: Focus on the automobile sector

Through the mist of automotive slowdown trend in the last few months, Solvay has been cautiously monitoring the after-effects of this decrease on its PA66 market. Below is an analysis of the automobile market from Solvay.

Global car sales have been decreasing for three consecutive quarters and the weakness in the second half of 2018 has extended further with another drop of more than -6.5% in the first quarter of 2019, down to only 22.5 million vehicles sold worldwide. The slowdown varies in intensity from region to region and results from multiple factors, but one cause is most commonly observed, especially in advanced economies: consumer confidence is down, resulting in lower consumer spending. Trade disputes and a very volatile global geopolitical environment are urging consumers to wait and see before committing to purchasing expensive goods such as cars.

In the US:

This general trend was exacerbated by local policies and events. In the United States, the Trump administration's insisted to further boost consumer demand in an economy that was already performing well has eventually lead to the saturation of the automotive market. At the same time inventory levels have been running very high in the US manufacturing industry.

In Europe:

In Western Europe, another Global car manufacturing giant, Germany, has hit several issues, regulatory and environmental, and has struggled to manage these challenges. The so-called Dieselgate (*Volkswagen emission fraud in 2015*) has prompted lawmakers to reassess car emissions according to a new measurement method. The worldwide harmonized light vehicles test procedure (WLTP) looks at more realistic conditions of use. Its implementation from the second half of 2018 has resulted in acknowledging increased emission levels for most vehicles - and in particular for the powerful ones made in Germany, which are being more heavily taxed or were simply driven out of the market. As a result, production of Light Vehicles collapsed in Germany from 1st September 2018, after a large inventory build-up in the first half of the year.

Also, the German industry faced a real logistical nightmare in 2018, which has impacted many supply chains and not only the automotive sector. The Rhine reached its lowest historic level in October 2018 which prevented navigation and impacted many sectors during the last six months of 2018. This unprecedented low level forced major stakeholders to declare “Force majeure” which we will explain in further details in below section. The Rhine is crucial for German industry because it provides not only an avenue for the supply of raw materials and building blocks but also a means of transporting finished industrial goods to Europe's largest port, Rotterdam.

In Asia:

In Asia, the Chinese car market, which today represents more than 1/4 of the world market, is also on a roller-coaster ride, with spikes and slumps that are being amplified by government policies. In 2018, China experienced its first decline of its automotive market, with car sales dropping by more than 3%, following a cut in government support and growing environmental constraints. Beijing has recently decided to slash government subsidies for the purchase of new electric vehicles by half - concentrating instead on infrastructure and supporting car models with higher autonomy. However, even though the ride downward is steep and in spite of a very disappointing first quarter 2019, analysts remain reasonably optimistic, as they deem it likely that the Chinese government will step in to support its automotive market. Further measures were already introduced to stimulate demand in rural areas, while Beijing decided to decrease VAT on all manufactured goods from April 1, 2019.

Many players in the chemical industry are keeping a very close watch on automotive: on average, chemical products account for about one-third of the value of a car. Solvay has a diversified product portfolio and serves a variety of end markets but its sales to the automotive industry accounted for roughly 14% of its turnover in 2018.

Also due to the current high level of inventories, caution as supplier to the automotive sector is the best advice for the future. Inventories are expected to be consolidated in the last quarter of 2019 to face future potential supply threats and in hope of resurgence in activity in 2020.

3.2.2 Supply situation: uncertainty and shortage

Among end-market weaker demand for PA66, potential polyamide 66 shortage talks and escalating prices have gained momentum.

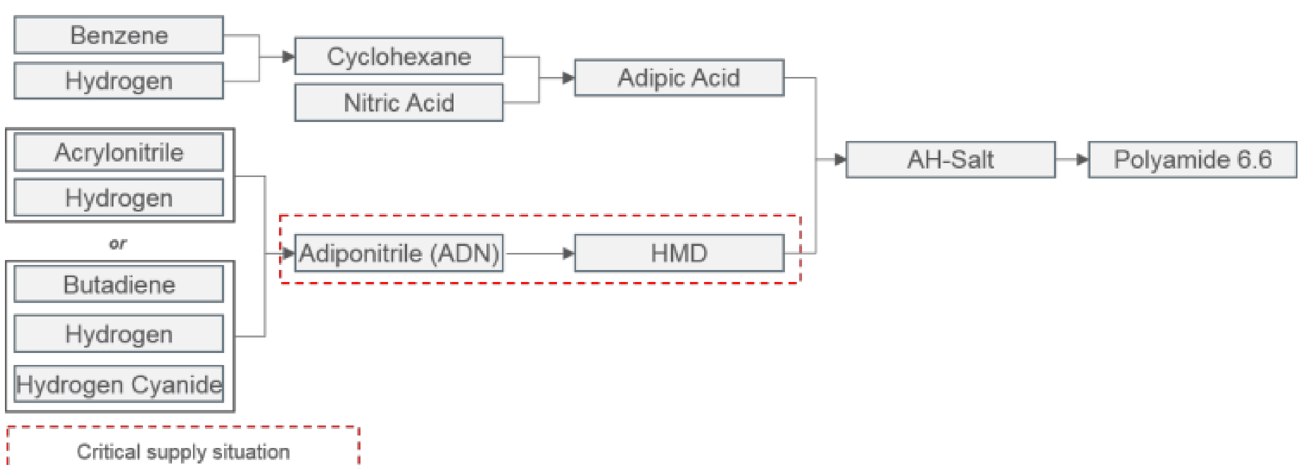
Ascend Performance Materials is the world's largest fully-integrated manufacturer of nylon 66. Ascend has announced its plan toward *Adiponitrile* (ADN) capacity expansion which is one of the upstream key component to produce Hexamethylenediamine (HMD). Since 2017, Ascend completed successfully its first expansion and steadily moves towards its new 2022 extension goal for a total of 270 kilotons (kt) of ADN extension. Ascend president and CEO Phil McDivitt commented "These additional investments will enhance the reliability of our supply and meet the increased demand we see for HMD and PA66 in a wide variety of applications on a global basis." (*Ascend press release, 15/05/2019*)

To further understand the issue faced by the PA66 market and its major actors, we need to look back on some historical facts. The PA66 supply chain was drastically changed when DuPont, thermoplastics pioneer, renamed its nylon intermediates business INVISTA and then subsequently sold it in 2003 to Koch Industries. DuPont's invention of the PA66 could not have happened without its intellectual property on the ADN process. Even the Ascend production process in Florida, USA was built by DuPont. Nowadays, all the ADN capacity in the U.S is a the result of the DuPont process and since DuPont sold its property of the nylon supply chain, the PA66 market lost its visionary in terms of building plant according to demand and forecasts.

The world supply of PA66 is under pressure but the European market is in a more drastic situation. The European market is plagued by a very tight supply situation. Increasing demand and incidents along the supply chain of Polyamide 6.6 have created a surge in price. Some reports mention that this shortage has seen the index price of the market increased by over 40% from August 2017 to June 2018.

As explained in the research approach, the polyamide 6.6 manufacturing process relies heavily on two primary products. The Adiponitrile (ADN) and its successor product HMD (Hexamethylenediamine) are critical to produce Polyamide 66 (as illustrated in the Figure 10 below)

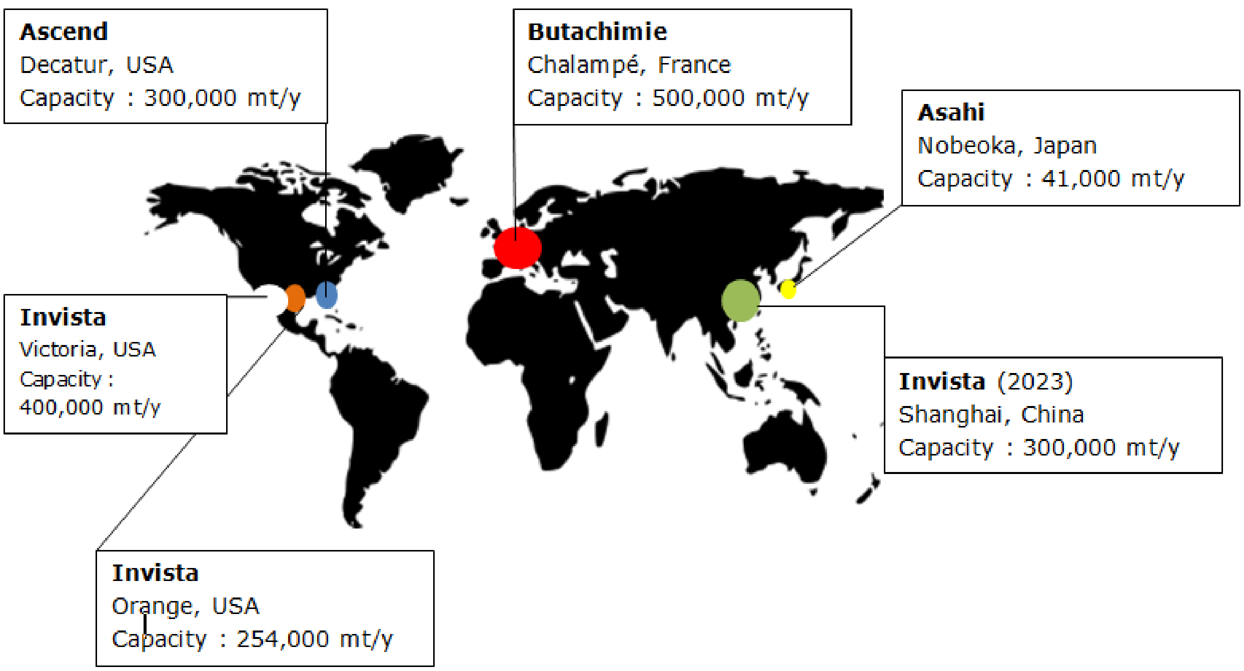
Figure 10: Detailed Polyamide 6.6 process chain and illustration of the critical supply situation (Source: Solvay)



The fragility of the polyamide 6.6 chain is visible and its dependency on adiponitrile and HMD is made obvious. In addition, HMD is fundamentally dependent on the supply of adiponitrile. There are only 4 producers worldwide of ADN with only one location in Europe.

Adiponitrile production is concentrated mainly in the US and in Europe (as illustrated in Illustration 4 below). HMD production plants in China are strongly dependent on imports from the US and Europe but it means equally long transport lead time. China being a key market for Polyamide 66, struggles due to their dependence on Adiponitrile from US and Europe. Invista will change the power balance when the completion of their world-scale ADN plant in China will be completed.

Illustration 4: ADN supplier world plants (Source: Adapted from Nikos Moraitakis, 2017)



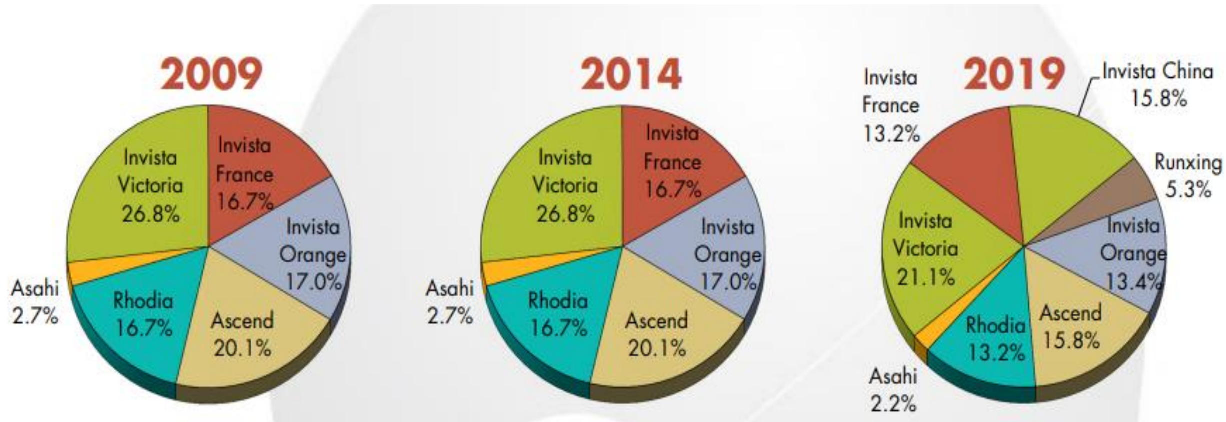
Butachimie is the result of a joint venture between Solvay and its American partner Invista. Currently standing as the largest producer of ADN in the world, Butachimie can produce up to 500 000 tons per year (*Butachimie official website*).

The other key players of the global adiponitrile market are Invista (USA), Ascend (USA), Asahi Kaisei (Japan) and Solvay (Belgium).

China made an attempt at building their own ADN plant though the Runxing chemical company with a capacity of 300,000 mt /year but the plant burned down in 2015 in a tragic explosion. (Nikos Moraitakis, 2017)

The global annual capacity of adiponitrile was compiled in 2015 in a *Tecnon Orbichem* report (Illustration 5 below) with forecasted capabilities in 2019. Runxing however was decommissioned and the Invista Chinese-based plant is still under construction.

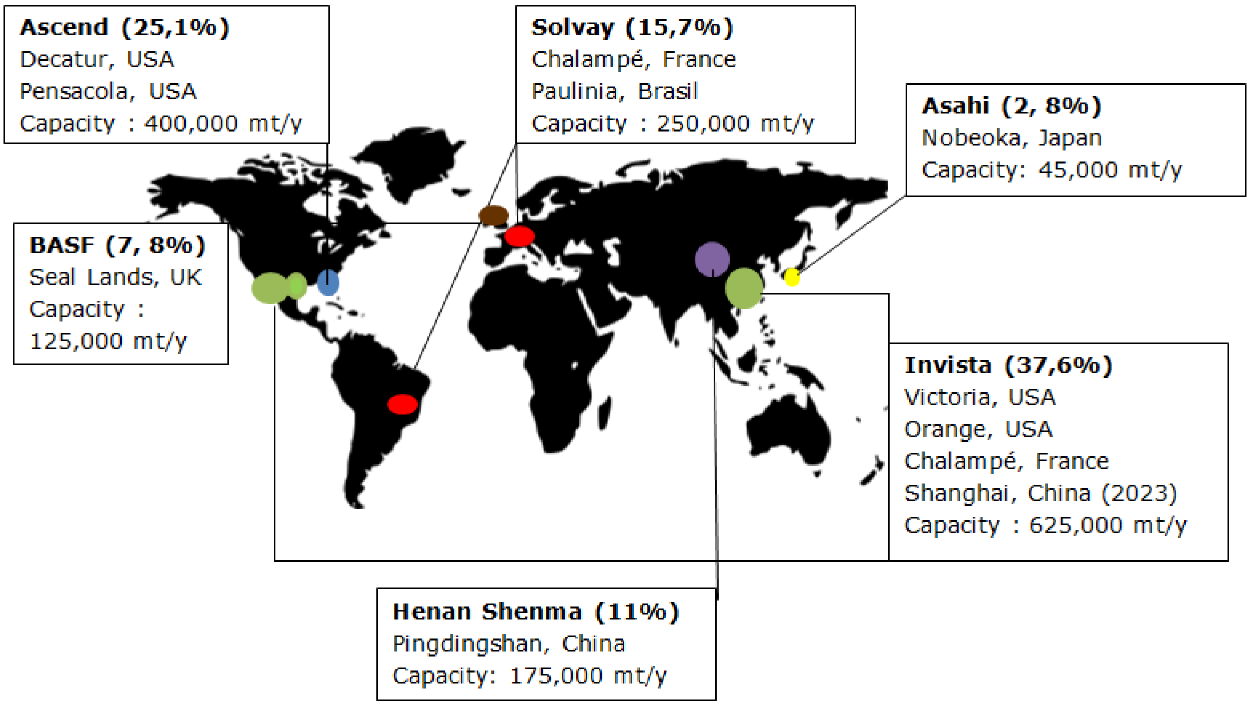
Illustration 5: Global Adiponitrile Capacity in 2015 (Source: Liu Xang, 2015)



Production of HMD is also very geographically limited in the world and in Europe. (as illustrated in Figure 11). HMD production depends on Adiponitrile as ADN is a precursor material on the production process of PA66. Most of HMD production is consumed to produce PA66. Usually, ADN suppliers have their own integrated HMD plant at the the same industrial site.

Invista's hugely dominant position on the ADN market is thus reflected in its dominant position as HMD supplier. By far, Invista is the largest HMD producers with almost 40% of the global production capacity. Other key players include Solvay, Ascend, Asahi, BASF and Henan Shenma.

Figure 11: HMD suppliers plants (Source: Adapted from Nikos Moraitakis, 2017)



Supply chain disruption events

Since August 2017, Force Majeure events (FM) have been recorded throughout the process chain of Polyamide 6.6. Force Majeure are unforeseeable events that prevented producers to fulfill their contractual obligations. Below is a non-exhaustive list of the major FM that have led to significant structural risks on the entire PA66 process chain (*Albis official website*).

1) October 2016: FM for HMD production at Solvay, Chalampé, France
2) August 2017: Technical malfunction in PA 6.6 production at Solvay, Freiburg
3) January 2018: FM for HMD production at ASCEND, USA

On the 5th of January 2018, **Ascend** advised its HMD contract customers that it was declaring Force Majeure due to extreme weather condition in Alabama, USA. The company was hit by bad weather conditions which affected their production capacity in HMD and their hydrogen supply obtained through their supplier.

4) January 2018: FM for PA 6.6 production at BASF, Ludwigshafen

BASF declared Force Majeure on the 24th of January 2018 on HMD, Nylon Salt and PA66. Their HMD operator, Ineos, was subject to unexpected plant failure that had lasting effects on the whole production process resulting in the shutdown of the HMD plant.

5) February 2018: FM for ADN production at Butachimie, Chalampé, France

6) February 2018: FM for PA 6.6 production at Solvay, St. Fons & Blanes, France

On the 9th of January 2018, Solvay declared Force Majeure in PA66 due to polymerization issue in Spain and France.

On the 15th of February 2018, Solvay declare Force Majeure in Adiponitrile (ADN), Hexamethylenediamine (HMD), Nylon Salt, PA66 Polymers and PA66 fibers. The underlying issue was a severe workforce strike at Chalampé (Butachimie) which is a 50/50 joint venture between Solvay and Invista. Butachimie has the largest ADN production capacity in the world and a large scale HMD plant so any disruption has major consequences on the whole European supply.

7) February 2018: FM for PA 6.6 production at Radici, Novara, Italy

8) June 2018: Expansion of the FM for PA 6.6 production at BASF, Ludwigshafen

More recently, Solvay declared Force Majeure on adipic acid, AH salt and HMD in October 2018 due to the extremely low level of the Rhine river. The Rhine River is used to supply raw materials to Chalampé plant in Ottmarsheim (Haut-Rhin).

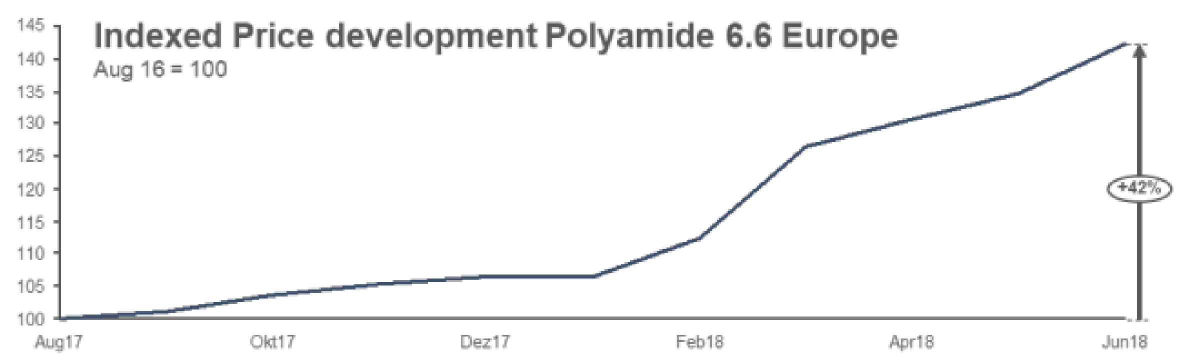
Ascend declared on the 7th of January, 2019 that due to “events beyond the company’s control” as part of their expansion of HMD and ADN project, severe manufacturing delays on the HMD are to be expected. The Force Majeure for all Ascend polymers, compounds and fibers is still ongoing. (*Ascend Materials, Press release, January 2019*).

Invista also announced that in the first quarter of 2019 a technology upgrade of their adiponitrile production process at its Victoria (Texas) plant. Butachimie (Chalampé) is also expected to undergo the same procedure in the second quarter of 2019. Both upgrades will generate planned maintenance and production stoppage. It has been estimated that due to each's plant closure, around 20% less product will be available on the market.

In 2020, Invista will also begin the construction for a brand-new world-scale ADN plant in China which an expected start in production around 2023. Invista has heavily invested in the Chinese market with an input of more than 600$ million including a HMD and PA66 plants in Shanghai.

These Force Majeure events puts the European PA66 market in a precarious situation as illustrated in the index market price below (Figure 12).

Figure 12: Indexed Price development Polyamide 6.6 in Europe between August 2017 and June 2018 (Source: Albis official website)



Between August 2017 and June 2018, the indexed price of European PA66 has seen a increase of 42%. Automotive suppliers have severely hit by the surge in PA66 prices. A rise of 1500€/tons has been observed in some cases over the past few months. They are hit simultaneously by the price surge in PA66, imposed quotas and allocations from their suppliers as well as resistance from their customers unwilling or unable to meet such high prices.

3.3 Semi-guided interviews

In order to bring a more concrete dimension to this paper on supply chain resource dependency and risk mitigation strategies, I have conducted four semi-guided interviews from people involved closely with this subject.

First of all, I defined general objectives before approaching the intended targets which I later used if appropriate as guidelines to conduct my interviews. The mode of interview was semi-guided with a length varying from thirty minutes to 45 minutes.

The first objective was to better identify from a multinational chemical company point a view the opportunities and challenges resource scarcity might pose.

The second objective was to investigate if Solvay had already put into place supply chain strategies to mitigate resource scarcity. It was also a good indicator if people were aware of such strategies.

The third general objective was to analyze and understand the difficulty resource scarcity might lead to in terms or procurement.

The fourth objective was assess the impact resource scarcity can have on the supply chain of Solvay.

Lastly, based on these investigations and assessment, the last objective was to point out attempt or success at risk mitigation that might have been used in a scarcity situation.

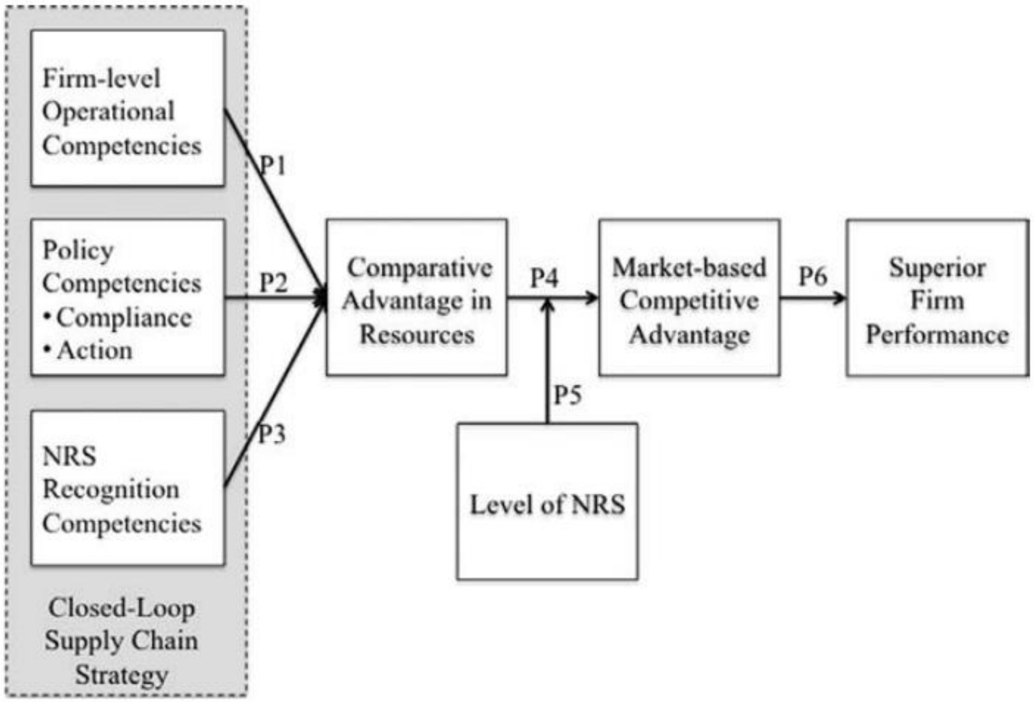
As I laid down my objectives, I searched for meaningful and relevant interviewees. I first interviewed Brigitte Cuq, raw material supplier for the polyamide business at Solvay. I targeted next Pascale Perrin, former customer service representative who works closely with some of Solvay's biggest competitors. And then I interviewed Thierry Meyssonnier who is responsible of the planning and scheduling of the HMD, Salt Nylon and Adipic Acid production to add more technical details to this study. My last interview was conducted with Angelina Vasileva, responsible for sales and operations planning of the PA66 workshop (Technyl) in Belle Etoile.

3.4. Building a framework from resource scarcity to sustainable supply chain

Closed-loop supply chain (CLSC) has so far been built and used by companies in an effort to improve short-term operational efficiency or as a compliance strategy to environmental policy.

A CLSC represents however a huge opportunity to create an optimal supply chain to mitigate the inevitable resource scarcity. Therefore, the following framework in Figure 13 developed by *Bell et Al (2012*) provides the perfect frame to identify mitigation strategies.

Figure 13: Resource-advantage framework for Natural Resource Scarcity in a closed loop supply chain management (Source: Bell et al., 2012)



First of all, implementing **operational process (P1)** that enable the firm to recapture products to secure scarce natural resource is one way to obtain a resource advantage over its competitors. Without a closed loop supply chain, companies will struggle to capture scarce resources or will manage to do so at an increased price.

Information are also invaluable resource advantage in their capacity to scan more effectively for the status of a resource. It allows for a better view of the location and availability of said resource, as well as their status of resources recaptured through reverse logistics.

These advantages will allow planning production better and helping in managing raw materials costs more effectively than their competitors.

Another angle of resource advantage theory is relational proficiency. There is strong value in establishing strong relationships with suppliers and customers on the downstream side of the business as well as third parties enablers. In doing so, recapturing scarce natural resources from the marketplace will be achieved more easily than companies that have not yet developed such relational resource advantages. Internally, it is also interesting for firms to develop human resources competences to manage reverse supply chain processes such as the reverse flow of goods or recycling.

Overall, operational competencies which include finding and purchasing scarce resources, transforming these resources and delivering said transformed products should be addressed through the scope of a closed loop supply chain.

Resource advantage can also be obtained through the ability of a firm to mold their legal environments by proactively addressing regulations and information on resource management. **Competencies and compliance on external policies (P2)** will create momentum towards resource advantage and competitive positioning. Currently, many CLSC developed by firms have been achieved in an effort to comply with regulations and governmental policies. Over the past decades, the European Union has been pressuring companies to reuse and recycle their products and respect European norms and regulations. Resource advantage is not obtained however only by complying with regulations as all firms are obliged to do so. The companies developing a CLSC with ground-breaking and innovative processes in the face of constrained environment to secure scarce resources are the ones achieving resource advantage.

Resource advantages are not only dependent on external resources but internal resources such as knowledge, technical skills, organizational framework and relationships.

As the threat of resource scarcity is growing, firms able to recognize and anticipate these threats will have internal capacity to obtain comparative advantage in terms of resource over its competitors. Resource scarcity foresight and anticipation related to market needs and offerings are key competencies to mitigate resource scarcity. It is too late and not enough to act after suffering a period of shortage. **Scarcity recognition and building**

competencies (P3) which enable to scan and identify potential depletion risks within the firm's supply chain integrated within a closed loop supply chain strategy will become instrumental in anticipating the occurrence of resource scarcity.

Through the investment in operational, compliance and NRS recognition competencies, the firm will increase its **competitive advantages (P4)** including strong and lasting relationships with supply chain partners. By developing CLSC strategies, the firm secures their own access to scarce resource which leads to less acquisition costs and easier access. Firms without a CLSC oriented-strategy will struggle to imitate this process. Recognizing and assessing NRS threats can still result in miscalculations and forecasts errors as the anticipated and the reality of the scarcity are sometimes very different. Unprepared firms will however have a harder time as they will be faced with situations of high costs of resource acquisition or even total lack of resource availability.

As developed in Figure 6, **assessing the status of NRS (P5)** helps firms and managers recognize and even sometimes anticipate impending scarcity and consequently establish closed-loop systems. Even under the constraint of increasing resource scarcity, such a firm will be able to deliver its product offerings to the marketplace. Scarce resources obtained through closed-loop processes will allow firms to **provide their offering to the desired market segments (P6)** at a lesser costs than its competitors who would be forced to pay higher prices to gain access to the same scarce resources.

4. Results and Recommendations

This below section will present the main findings and themes that emerged from the case study analysis on Solvay. Implications of NRS on the supply chain will be reviewed in this section alongside guidelines and recommendations.

4.1. Findings

Market reactions

First reactions to the pricing and supply tight market conditions of the Polyamide 6.6 have led to discussions on replacement and alternatives possibilities. Substituality is a common strategy in the face of resource scarcity. This strategy has gained momentum over the last couple of years with thermoplastics suppliers, manufacturers and distributors to address the issue. Top contenders for the alternatives are the Polyamide 6, which is less resistant to heat, and recycled contents as demonstrated by the trend towards more eco-friendly polyamide (Move4earth grade innovation at Solvay). However while it is true Polyamide 6 offers relatively the same cost, performance and applications possibility as Polyamide 66, PA66 still is a better choice to avoid compromising all three characteristics.

Market structural issue

Supply shortage and scarcity is directly linked to key precursor material: Adiponitrile (ADN). The current ADN supply chain is highly critical with an oligopolistic market structure. Invista is the only firm supplying ADN to the market while other major producers such as Butachimie (joint venture between Invista and Solvay) uses their ADN internally. Recent Force Majeure events since 2016 have proven times and times the structural issue of the market composition.

HMD manufacturing is highly dependent on ADN as ADN cannot be substituted to produce HMD.

End-markets demand

One of the biggest consumer markets for PA66 is the automotive industry. North America, being the largest consumer and producer of PA66, it is no assumption to say that the automobile industry and North America are key determinants for PA66 demand.

The ADN supply is below demand and the trend should continue for at least two years until the largest producers of ADN (Ascend, Invista) fully increase their production capacity which is scheduled for 2021.
Some concerns could be raised as to the long-term trend as producers increase their production capacity in ADN amidst an automobile market slowdown in Europe and Asia. The trend could easily be reversed in the next few years leaving the polyamide market in a situation of oversupply.

Market perception

Overall, supply is a true concern for any business and disruptions related to resource dependency should be anticipated and reacted upon. Innovation and new disruptive technologies to replace outdated ones should always be encouraged. The Polyamide industry suffers from a lack of transparency and a perceived monopolistic supply and supply chain. Due to the severely constrained supply of PA66 and the trust issues brought on by the Forces Majeure, consumers have begun shifting their consumption towards PA6.

Guidelines

To mitigate the increasing dependency on resource in the chemical and plastic industry, stakeholders can implement some guidelines.

First phase: Identification

Proactively scanning and monitoring the company's environment through a resource scarcity risk matrix (Figure 6 and Figure 7) will enable more flexibility to move from one resource to another in case one might be categorized as scarce.

Second phase: Recognition

Understand and identify quantitative and qualitative impacts each resource has on the supply chain. It will enable monitoring and assessing the consumption and dependence level of each resource.

Third phase: Mitigation

Develop and educate on strategies to avoid using scarce resource during the Research & Development stage. Focus also on recovery and recycling of natural and material resources.

Fourth phase: Collaboration

Work closely with the supplier and customer network to easily locate potential scarcity threats which may be upstream or downstream on the supply chain.

Fifth phase: Integration

Working towards resource-efficient and closed loop supply chains with partners that have are also engaged in a strategy of resource dependency mitigation.

Sixth phase: Controlling

Implement internal strategies and policies to control the use of scarce resource in the supply chain when necessary.

Seventh phase: Education

Stakeholders of the company should be educated on the impact of resource scarcity to create their own strategies and endeavor towards a mutually beneficial partnership.

4.1.1. Within case and interviews analysis

As emphasized on the Solvay's case study and its market environment, extracting, processing and resource usage have multiple impacts on the environment and on the society. Optimizing their supply chain to mitigate the high degree of dependency on resources for chemical manufacturers is a critical skill. Below is presented a list of observations and results derived from the Solvay's case study and the semi-guided interviews.

These results will be late categorized in key indicators for mitigating resource dependency and used to offer some strategic recommendations based on the current supply situation of the Polyamide market.

1. Interviewees and the case study on Solvay suggest that price of the natural resource, the supplier framework (number, reliability, situation on the market, cost of finding or switching supplier), legislation as well as geopolitical risks are the main factors which increases resource dependency on the supply chain.

2. Resource monitoring as evidenced in the literature represents one of the pillar of building a resource efficient supply chain. Resource consumption monitoring and criticality resource assessment are already implemented at Solvay. Demand and supply forecasts for each resource are assessed and closely monitored. Solvay takes into account multiple factors including :
    a. Global demand growth : assessment of market trends and related risks
    b. Global production capacity : monitoring competitors production capacity and reassess their own strategy to be able to increase rapidly production input in the short or medium term as a result of demand or price shifts
    c. Concentration of supply : expand their supplier network through strong partnerships and trusts to reduce risks of monopolistic or oligopolistic supply situation
    d. Political and regulation risks: Solvay has a strong risk management tool to assess political instability, geopolitical risks or internal conflicts in a major

supplying country to anticipate and reduce impact these conflicts can have on access to global production capacity.

3. Criticality assessment or defining a resource status through the risk matrix is a major step towards a fully resource efficient supply chain. First and foremost, understanding that depletion, scarcity and criticality are different is fundamental for managers and manufacturing companies. Depleted resources are resources for which natural or geological stocks on Earth are decreasing (e.g: minerals, oil, water…). Scarce resources are resources which are or will soon be present in insufficient quantities. Critical resources are scarce resources essential to the well-being of a society. Solvay has understood the urgency of acting through their water management programs and sustainable portfolio management.

4. The integrity of the PA66 supply was threatened by a recent string of events. Solvay and its environment have been constrained by the ongoing Force Majeure events. The costs of Force Majeure threatened manufacturers because they need to pay to resume or restart their operations as well as for the consequent earning loss throughout the Force Majeure duration. Force Majeure are unavoidable and unpredictable, even for supply chain in overcapacity but in order to minimize their frequency and impacts, some investments can be made. When one firm declares Force Majeure, it is often followed by several other declaration from competitors as firms on the Polyamide industry are intrinsically connected. When customers lose confidence in the supply process, we enter into a vicious circle. Less confidence will mean less investment which in turn reinforce and increase strain and fragility on the supply chain.

5. Evidence of price swings on the PA66 market have been shown as the result of Force Majeure declaration in early 2018. As Solvay and Invista announces FM across their whole PA66 chain, the prices soared, and producers supplied mainly their contracted customers which caused prejudice to the spot market (occasional customers). Buyers were desperate to buy at any price. At the same time, Solvay

Performance Polyamides announced a 300$/t price increase to their PA66 grades (Technyl) effective as of 1st of February 2018 in the whole Asian market.

6. The supply system is also endangered by the concentration of supply by a small number of players. The Polyamide 66 presents a complex and partially oligopolistic upstream supply chains. Critical intermediates, identified as ADN and HMD are polymerized and then compounded into different grades of thermoplastics throughout the different supply chain stages. Major suppliers of ADN, precursor of HMD and consequently of PA66 are few and concentrated on the European and American markets. Suppliers holding the technology to produce ADN often have their own on-site HMD plant and consequently feed the global market with the leftovers.

7. The Chinese market presents a source of potential success and strategic optimization as local availability in raw materials is less under pressure than on the European market. As key intermediates producers are already battling for resources in Europe and America, the Asian market is relatively less constrained. The Chinese market has also put into motion a race to expand production capacity which the European market is trying to catch on. Invista has caught on the potential of the Chinese market as they have invested in building a world-scale production ADN plant in China to meet local demand for 2023.

8. How raw materials are supplied for production matters. Adequate sourcing strategies can alleviate supply chain and logistics related risks. Due to the complex and geographical span of the Polyamide 66 supply, local sourcing strategies are hard or impossible to implement. Local sourcing is often attractive as it improves and facilitates reliability of the supply through geographical proximity, reduces logistics costs and trade/import barriers while providing a higher adaptability level thanks to a better understanding of the local requirements. However, it is often foreign or long-distance suppliers which are able to supply the intricate requirements and needs of multinationals.

9. From the geographical choice of the key players on the polyamide market, it is easy to see that manufacturers of intermediates materials (ADN and HMD) are positioned strategically close to their raw material suppliers which are often each other. On the other hand, polymers producers are spread out to operate more independently and better serve their own regional markets.

10. Recent Force Majeure incidents have emphasized the fragility of the supply for PA66. Contractual customers and key accounts are privileged to the detriment of smaller customers. Customers are keen on reducing transport lead times and consequently require raw materials which are produced closer to them. Through consignment inventory mechanisms, customers are supplied more efficiently and will be less likely to suffer shortage. Safety stocks are also a strong mitigation mechanism in case of demand surges and supply shortages.

4.1.2. Results analysis

Before moving onto strategic considerations, this research's goal was to understand how an optimal supply chain can alleviate resource dependency and resource scarcity on manufacturing firms. Understanding which factors enhance resource dependency first and foremost is essential to offer recommendations towards building a resource resilient supply chain.
The level of resource dependency a company has on natural and material resources can greatly vary.
Based on the observations and results of this paper, we can isolate six indicators of resource dependency which emerged from the literature, case study and interviews transcripts (Annex 2, 3, 4, and 5):

1) **The price of the resource**: Highlighted by the ever fluctuating price of PA66 (Figure 12)

2) **The quantity of the resource**: Adiponitrile and Hexamethylenediamine are two precursors' components to manufacture polyamide 6.6, highly resistant thermoplastics often used in engineering applications. A few actors hold the majority of the global production capacity for ADN and HMD which is inferior to the demand, thus exacerbating shortage situation.

3) **The availability of alternative suppliers for the resource**: As illustrated by the world capacity map of ADN and HMD, few concentrated producers in Europe and US supply the world. Local availability of resources is critical and global supply is tight.

4) **The availability of alternative products:** Substitution is a great mitigation approach in the resource reclamation scheme. However, ADN and HMD are not substitutable to produce PA66. In a roundabout way, the market combining its innovativeness and motivated by supply-demand imbalances, created new grades of PA66 manufactured from recycled materials made of PA66.

   A shift towards the polyamide 6 market from frustrated PA66 customers has emerged but is nonetheless limited.

5) **Switching costs of suppliers:** Emphasized by the interviews, switching suppliers for a scarce resource is not always possible or even remotely doable. Switching costs are often huge but in the case of polyamide 66, suppliers are under contract or tolling/swap agreement as explained in the interviews.

6) **Geopolitical risks:** While this research is not focused on geopolitical risks, it should be considered as a considerable influence on resource dependency. Trade barriers can be used to impede the accessibility of a resource, endangering the supply chain of the receiving end.

4.1.3. Strategic Recommendations

Manufacturing firms and managers needs to implement a two-step approach to mitigate their supply chain dependence on resource and the subsequent issues of such high degree of dependence. The Polyamide industry is a highly fluctuating market with volatile prices and aggravating supply issues which poses new challenges in terms of managing a supply chain.

4.1.3.1. Short term risk mitigation

The resource dependency theory previously discussed states that a firm's ability to leverage their resources usage is key to determine their organizational success.
The RDT theory provides options for firms to respond using either buffering or bridging strategies to mitigate supply chain disruptions.

Buffering is a widespread mitigation strategy to help manage and alleviate any supply chain disruption. This strategy entails keeping sufficient inventory to act as buffer and safeguard any disturbance between the firm and its supply link to a resource. Buffering is a common strategy used in Solvay which maintain high inventory level in specifically chosen locations. This strategy has been helpful in case of Force Majeure coupled with allocation strategies to safeguard a minimum level of inventory.

Bridging strategies are on the other hand long-term strategies which establish contracts to fix supply and price over and extended time period. Integrated within these strategies are partnerships, joint-ventures, relational mechanisms and even vertical integration. By vertically integrating a supplier, the firm gain control and access to a critical or scarce resource.

By taking all these elements into accounts, a set of recommended strategies towards alleviating resource dependency and resource scarcity on the supply chain can be defined.

The first strategic recommendation is to implement reliable and appropriate mitigation actions to match the level of natural resources scarcity, renewability and accessibility. Identifying the risk by correctly assessing the degree of scarcity and renewability on the Natural Resources Status matrix is the first step. Successful mitigation strategies rely on communication and secure partnerships to implement the most relevant approach in managing resource scarcity. From this analysis, internal policies must be put into motion to monitor resource consumption and more critically to control usage of scarce resources.

The second strategic recommendation is derived from the Closed-Loop supply chain theory. Operational processes and competencies must be strengthened to forge a multi-faceted approach able to react to current of future level of resources scarcity. It means using resource reclamation strategies developed above such as discovery, substitution, recovery and reclamation. Closed loop supply chain represents the optimal supply chain management strategy for a supply chain dependent on resource. CLSC allows recapturing more easily scarce resources and protecting the existing renewable resource base. A strong ability to balance supply and demand is also important and should be combined with logistics, allocation/quota and sustainable approaches.

The third recommendation is the ability to think forward. Monitoring market trends will allow anticipating increasing scarcity levels and the first-movers will secure a more comfortable position. Many factors add incremental scarcity challenges to manufacturing companies. Without mentioning the population growth, economic level, geopolitical conflicts and legislation, sometimes one human error can create ripples in the whole supply chain. Force Majeure events, unavoidable as they are, should be mitigated to pose less constraints on the supply chain and a firm’s ability to operate as usual. Demand should be met with adequate supply and how we meet demand matters. By pulling unreasonably on resources, whether material, natural or human, resource degradation can increase and create even more disruptions.

While these strategies may not be revolutionary concepts and whether they have been studied, liked or avoided for many years, it should be reminded that they exist and that they have most often served their purpose well.

4.1.3.2. Long-term sustainability orientation

While day to day operations see the direct repercussions of resource dependency, it is at the firm's organizational level that most supply decisions are taken. We have established a few set of short term t mitigation strategies but a long-term sustainability orientation should also be considered.

The closed loop supply chain explored in the literature and developed in the methodology provides clear and concise step towards the establishment of sustainable supply chain. Incorporating a sustainability orientation to a firm's supply chain enables to face the challenges of resource dependency on the long-run.

First of all, a thorough supply chain analysis should be made. If possible, the firm should make investment to gain access to a critical resource after establishing the importance of the resource on their supply chain.

Measurability is also a key strategy and monitoring carbon emissions, water and energy consumption, chemical waste management will rapidly affect the firm's ability to create a closed-loop supply chain.

This sustainable approach must be implemented at the highest level accompanied with precise targets and metrics to be accountable. Research and Development must also focus their effort on re-engineering end-of cycle products or recycling possibilities.

The Closed loop supply chain is also built on strong and long-term partnerships. In the case of the polyamide industry, competitors often provide assistance to secure raw material alternative sourcing.

5. Conclusion and implications

This part will summarize the major findings of the research as well present the main implications and limitations. This research will be concluded with insights for future research.

5.1. Findings summary

This research first set out to better understand the challenges posed by resource dependency on manufacturing companies. The initial research question was: "***How can an optimal supply chain help companies and managers mitigate their resource dependency?"***

To answer this question, three sub-questions were discussed in the research:

- **Outcomes**: What are the key changes occurring in a supply chain as a result of resource scarcity or limited availability?
- **Mechanisms**: What are the factors driving material and resource scarcity?
- **Strategies**: Which strategies can help companies mitigate their dependency towards natural/material resources?

This research was developed around two resource pillar theories: The Natural-resource based view and the Resource Dependence theory. Based on these theories, the research was angled around building a framework from resource dependency to a sustainable supply chain. The research was combined with a market study of the Polyamide 6.6 and a case study methodology on the Polyamide Intermediates business unit at Solvay.

Manufacturing firms are highly dependent on their environment to supply their resources but these resources can be limited in availability, critical or scarce. Six factors which influence resource dependency were identified: price of the resource, quantity of the resource, availability of alternative suppliers, availability of alternative products (substitution), suppliers switching costs and geopolitical risks.

Understanding how resource dependency works is the first step to mitigate it. From that observation and results, guidelines and recommendations were established. The RDT theory advocates that successful model of supply chains are established by companies able to optimize their resource consumption and create strong supplier-buyer relationships.

The Polyamide 6.6 market is plagued by uncertainty and is built around a small number of major of players. The almost oligopolistic situation of the markets had led to scarcity issues which led consequently to surge in prices over the last couple of months. Amidst such disruptions, suppliers can rely on buffering and bridging strategies. With a limited number of suppliers and limited resource availability, the supply of the PA66 has become tight.

The research also draws emphasis on available strategies, including buffering and bridging but ultimately tends towards establishing a closed looped supply chain. Building a resilient closed loop supply chain takes time but the premise of that has been seen in the trend towards using end-of life products to manufacture brand new thermoplastics.

A closed-loop supply chain will strengthen operational competencies, compliance and policy-making process as well as resource scarcity recognition and assessment. These factors will lead to resource comparative advantage and market based competitive advantage.

5.2. Managerial implications

This paper provides a theoretical and practical perspective on resource dependency for manufacturing firms. The closed-loop framework can be the starting point for firms and managers wishing to determine and work towards a sustainable and successful supply chain to alleviate risks of resource scarcity.

Supply chain and its surrounding environment must assess the risk and implication of a resource and when necessary, mitigate the identified risk with a matching strategy. This research improves understanding of resource dependency, especially the need to anticipate rather than react as highlighted by the recent Force Majeure on the PA66.

Catching on in early scarcity issues will influence the decision-making process of the purchasing department which might develop contingency strategies with their suppliers as emphasized by the tolling and swap strategies currently used by Solvay with its competitors. In the resource-efficient supply chain framework, Matopoulos et al (2015) stressed out the importance of “resource awareness” as the foundation of a resource efficient supply chain. Managers and suppliers should have a more proactive approach to assessing and identifying risk related to a specific resource.

In terms of regulation and policy-making, the European Commission is actively looking to harmonize standards to deal with resource scarcity issues either through their list of rare earth elements and critical materials classification of programs such as European innovation Partnership (EIP) to bring together concerned parties.

Overall, this research was conducted in hope of shedding some light on a systemic framework and set of strategies to help firms and managers understanding resource dependency and allowing them to make enlightened decisions.

5.3. Limitations and future research

The market example and case study is focused on one manufacturing industries and does not allow to generalize the above findings. The research should look for external examples in other industries to validate the findings. It would also be interesting to compare the study with small and medium size business as their approach to supply chain management might differ. As the case study was conducted on a multinational company, further research on SMEs resource dependency might be useful to identify similarities and differences between their strategic approach to mitigating resource dependency.

Future research can determine the effectiveness of a fully resource efficient supply chain in a resource-intensive industry. Steps to build a closed loop supply chain could be implemented and monitored closely within a set environment.

To get a wider view of resource dependency, other type of resources and industries should also be analyzed.

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GLOSSARY

SCM: Supply chain management
NRBV: Natural Resource Based View
NRS: Natural Resource scarcity
RDT: Resource Dependence theory
FM: Force Majeure
R-A: Resource Advantage Theory
CLSC: Closed loop supply chain
HMD: Hexamethylenediamine (key material to produce PA66)

ADN: Adiponitrile (key material to produce PA66)