Modelling the drivers and strategic responses within the platinum industry

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ABSTRACT

The purpose of this research is to model the drivers and strategic responses within the platinum industry. This research attempts to create a model of the impact of industry specific factors on the demand of platinum using Porter's Five Forces model in order to identify opportunities for new revenue streams, evaluate threats to the industry and identify measures to mitigate any negative impacts, while evaluating the imperative of long-term sustainability of the platinum industry.

Data were collected using a semi-quantitative methodology known as Fuzzy Cognitive Mapping (FCM). The FCM depicts causal linkages between variables that are not very clear, or cannot be statistically modelled, and allows directional propagation (both forwards and backwards) showing whether one variable or 'node' has a positive or negative effect on the next. The draft FCM that is constructed based on the literature review conducted is cross analysed and vetted through in-depth interviews with platinum industry experts. A final FCM is produced after these interviews, from which scenarios can be simulated.

There is a positive outlook on the future of the platinum industry providing efforts are made by industry role player to find innovative ways of moving forward. This study stresses the importance of research and development into the formation of new technologies to create new uses and revenue streams for platinum while finding more environmentally friendly mechanisms by which to conduct business.

DECLARATION

I, May Scaria Anthonyrajah, declare that this research report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Signed at …………………………………………………

On the 16th day of June 2017.

DEDICATION

This research report is dedicated to Jerry, for all his understanding, support and encouragement throughout my Masters, and to my parents whose prayers have carried me through.

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To my supervisor, Professor Anthony Stacey, thank you for your advice.

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CHAPTER 1. INTRODUCTION

1.1 Purpose of the study

The purpose of this research is to model the drivers and strategic responses within the platinum industry. Multiple factors have recently dropped the demand for platinum and hence, platinum prices.

> "The platinum sector on the JSE has been a pretty bad place to be for investors in recent times. Share prices have been hammered as negative sentiment towards the industry has become pervasive. The price of platinum has fallen to prices last seen in mid-2009, driven down by the strength of the dollar and concerns about auto catalyst demand. Above-ground metal stocks and efficient recycling of the metal are also having an impact."
>
> Cairns (2015, p. 1)

Platinum is a well-known metal and falls into the category of Platinum Group Metals (PGMs). PGMs consist of six elements which occur together in nature, these being platinum, palladium, rhodium, osmium, ruthenium and iridium (Gunn, 2013; International Platinum Group Metals Association, 2016c). In 2012, 56% of the world demand for the three most used PGMs – platinum, palladium and rhodium – came from the automobile industry as these PGMs are used as catalytic converters or auto-catalysts (International Platinum Group Metals Association, 2016c). Platinum and the other PGMs have a variety of other uses – in the jewellery, electrical and electronics, glass, medical, automotive, and turbine blades industries (Creamer, 2006; Implats, 2005). The largest sources of supply of platinum are in South Africa, in the Bushveld Complex, followed by Russia, Zimbabwe, Canada and the United States of America, with South Africa responsible for extracting 78% of the world's platinum (Investing News, 2016; Sverdrup & Ragnarsdottir, 2016).

In recent months, the platinum industry has been confronted with multiple issues, mainly due to work stoppages in 2014 in South Africa as mineworkers went on the longest strike in South African history – a 5-month long strike over wage disputes (Ryan, 2014). The three primary platinum mining companies in South Africa lost R23 billion in revenue (Bohlmann, Dixon, Rimmer, & Van Heerden, 2014) with impacts estimated to be more widespread.

Looking forward, the question is, will platinum demand remain? For how long will the demand last, based on the introduction of new technologies, some that utilise platinum and others that render it redundant? Are there ways to increase, and mitigate any threats to the demand for platinum?

This study assists stakeholders with interests in platinum to assess the potential future impacts on the platinum industry with the introduction of new and improved technologies and the alternative options available. The study assists organisations to respond appropriately to the changes currently being experienced in the industry as well as what may arise in the future.

1.2 Context of the study

This research starts with a look at the history of platinum and the change in demand and evolution thereof. The study uses the strategy model of Porter's Five Forces to structure the research and focuses on the factors that impact the demand for platinum and particularly, the effect that technological advances will have on this industry.

Since the majority of the platinum extraction industry is based in South Africa, the impacts on, or implications for, demand discovered from the study, will most likely have the greatest consequences for the South African platinum sector and economy.

The Porter's Five Forces model is a tool used to measure the attractiveness of any given industry (Johnson, Whittington, Scholes, Angwin, & Regner, 2014) and was developed by Michael Porter in 1979. According to Porter (2008), competition in the industry is not only determined by rivals, but by four additional forces that impact the firm. These are substitute products, suppliers, customers as well as potential new entrants into the industry. Porter further postulates that as different as industries may appear on the surface, the primary drivers of profitability are the same for all. If all these forces or threats are extreme, the industry is not attractive as stakeholders are unlikely to earn reasonable returns on their investments. Similarly, if the forces are not strong, the industry is likely to be more profitable or more attractive (Porter, 2008).

While this research is structured around Porter's Five Forces model, other factors need to be taken into consideration. The Five Forces model does not take into account issues of sustainability or sustainable development which are a priority in the 21st century (Mohan Das Gandhi, Selladurai, & Santhi, 2006), and is a key global problem (Bielaczyc, Woodburn, & Szczotka, 2014). Mohan Das Gandhi et al. (2006) postulate that there are four more forces, in addition to Michael Porter's five forces, which address sustainable development issues. These are regulatory forces, consumer forces, community forces and financial benefit. In today's economy, profitability arises from the extraction of natural resources from the earth, and natural resources are by their very nature, non-renewable, thus as our economy expands, our resources are dwindling (Mohan Das Gandhi et al., 2006).

1.3 Problem statement

1.3.1 *Main problem*

The research problem is to create a model of the impact of industry specific factors on the demand of platinum using Porter's Five Forces model in order to identify opportunities for new revenue streams, evaluate threats to the industry and identify measures to mitigate any negative impacts, while evaluating the importance of long-term sustainability of the platinum industry.

1.3.2 *Sub-problems*

The first sub-problem is to evaluate the industry specific factors affecting the demand and financial sustainability of the platinum sector using Porter's Five Forces model.

The second sub problem is to identify the importance for environmental sustainability in the platinum mining industry, and how that affects demand and financial sustainability.

The third sub-problem is to identify measures to mitigate risks that mining companies in the platinum industry may face.

1.4 Significance of the study

This research assesses the impact of new technologies on the demand for platinum. Factors, such as automobile industry growth worldwide, and the jewellery industry growth in China and India, will have an effect on the demand for platinum (Johnson Matthey, 2016) and are discussed in the literature review.

This research provides an overview and visually represents relationships between these factors and the platinum demand, and how and the extent to which they affect platinum demand and the industry in general. This study also looks into sustainability factors, both from the perspective of a 'green economy' in which platinum is utilised (Montmasson-Clair, 2015), as well as a 'sustainable green economy' as platinum cannot be utilised infinitely considering it is a non-renewable resource.

The study may provide value to stakeholders of the platinum industry from the mining (extraction) sector. The research aims to provide insight on potential scenarios that could arise and how the industry could position itself to mitigate against the risks as well as to take advantage of the growth opportunities.

Fuels cells are a quickly developing energy conversion technology that utilises platinum as a component and is useful as an alternative energy source (International Platinum Group Metals Association, 2016b), particularly in countries such as South Africa that faces an electricity supply shortage. However, with production of lithium-ion batteries also as an alternate energy source and potentially cheaper than the platinum utilising fuel-cells, the platinum industry faces a threat (Seba, 2015). The future of the platinum industry may be uncertain if technologies continue to expand rapidly.

1.5 Delimitations of the study

- This study is limited to those influencers that will have a substantial influence on the platinum sector, including the automobile industry and new technologies.
- While platinum is a global industry, the majority of the platinum mined is from South Africa, thus the primary focus is on South Africa.
- The main focus of the research is from the lens of platinum mining companies and does not take the other stakeholders into detailed consideration.

1.6 Definition of terms

Table 1: Definition and explanations of terms used in document

Term	**Meaning**	**Reference**
Autocatalyst	Cylinder cross section made from ceramic or metal formed into a fine honeycomb and coated with a chemical solution and a combination of platinum, rhodium and/or palladium. Forms part of the catalytic converter and is installed in a vehicle's exhaust line.	(International Platinum Group Metals Association, 2016d)
Catalytic converter	Emissions control device that converts noxious gases and contaminants in exhaust gas to less toxic pollutants.	(Zimmermann, Messerschmidt, von Bohlen, & Sures, 2005)
Euro 4, 5, 6 and 6b regulations	Regulations that have been passed in order to reduce emissions of greenhouse gasses and other pollutants.	(Bielaczyc et al., 2014)
FCM	Fuzzy cognitive map (used as the research methodology).	(Kosko, 1986)
Hydrogen fuel cells OR fuel-cells OR platinum fuel-cells (used interchangeably	Device, like a battery, that is used to produce electric power and provide thermal energy from chemical energy. Unlike batteries, FCs do not need to be recharged as the materials consumed during the electrochemical process are in continuous	(El-Khattam & Salama, 2004)

Term	Meaning	Reference
	supply from the environment.	
Lithium-ion batteries	A battery that uses lithium in the chemical process that releases energy.	(Lou, Deng, Lee, Feng, & Archer, 2008)
Platinum (Pt)	“Platinum is one of the least reactive metals in the world and is highly resistant to corrosion. It is often used as a catalyst or as a precious metal.”	(The Statistics Portal, 2016a, p. 1)
Platinum Group Metals (PGMs)	Six elements which occur together in nature: platinum, palladium, rhodium, osmium, ruthenium and iridium	(International Platinum Group Metals Association, 2016c)
Water electrolysis	Involves the decomposition of water into its constituent elements: oxygen and hydrogen. It is an easy method of hydrogen production.	(Zeng & Zhang, 2010)

1.7 Assumptions

This research assumes that:

- The knowledge of the industry experts that reviewed the proposed fuzzy cognitive map (the research methodology utilised) was sound and reliable.

- There is no immediate radical or unexpected change in the status quo of the platinum industry and/or the environment

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

Platinum has been responsible for an economic boom in countries where it is mined, countries where it is processed, and countries where it is utilised. It has been used across industries and has created numerous jobs, both directly and indirectly. While platinum discoveries are dated back to ancient Egyptian times, the largest known repository of platinum in the world was discovered in South Africa in 1923 (Hochreiter, Kennedy, Muir, & Wood, 1985).

Platinum, like gold, is considered a precious metal in the financial market, but unlike gold, it has multiple uses in industry – gold is utilised mainly in the manufacturing of jewellery and as a value store (Yang, 2009).

There are two sources of platinum. The primary source is from mining of the metal by mining companies, and the secondary source is from recycling of platinum from discarded automobiles and industry equipment (Johnson Matthey, 2016). Figure 1 depicts the lifecycle of PGMs. As mentioned above, PGMs are sourced from either the primary (mining) or secondary (recycling) means, they are then used in fabrication of industrial equipment, automobiles and jewellery, these items are utilised and are finally, recycled.

Cradle-to-gate life cycle of PGMs
IMAGE CREDIT: ***Platinum Ore.*** Johnson Matthey.

Figure 1: Life Cycle of PGMs (Johnson Matthey, 2016)

In 2012, 56% of the world demand for PGMs came from the automobile industry for use as autocatalysts (International Platinum Group Metals Association, 2016c), while by 2016, 40% of the demand arose from the automobile industry (Johnson Matthey, 2016). The future of platinum is undeniably linked to the automotive industry and thus it is essential to consider future implications of the demand for platinum by studying the potential substitutes for platinum, the impact of pricing and profitability and what new applications for platinum or new technologies will do to the industry.

While platinum is currently necessary for use in automobiles, jewellery, industrial equipment as well as exchange traded funds (discussed later on in the paper), continuous mining of the metal is unsustainable and thus it is essential for discourse to take place on the future of the industry.

The following topics is discussed and reviewed from existing literature, and industry insight in order to gain an understanding of and address the problem statement in section 1.3:

- Competitive rivalry in the platinum industry, the threat of new entrants and factors that affect the supply and pricing of platinum.
- The power held by both buyers and suppliers within the industry including the factors that affect platinum demand.
- Substitutes to platinum and the threat it poses on the industry.
- The concerns around environmental sustainability in the platinum industry.
- Measures to mitigate risks that mining companies may face.

2.2 Definition of topic and background discussion

The world is ever-changing and if industries do not keep up with this change, their lifespans will be limited. The platinum industry has been flourishing but recent events, and potential new disruptive technologies in the industry, can either increase the demand for platinum, or may render it redundant. It is essential for industry stakeholders to be aware of the potential pitfalls and opportunities with which they may be faced and to take steps or put in place policies to mitigate the risks and take advantage of the opportunities within the industry. Strategies need to be put in place to ensure that both aspects of increasing the demand of platinum for increased profitability within companies, as well as aspects of the ‘sustainable green economy’, are addressed.

2.3 Evaluating the industry specific factors affecting the demand and financial sustainability of the platinum sector using Porter's Five Forces mode

2.3.1 *Competitive rivalry and the threat of new entrants*

At the centre of the Porter's Five Forces model is the rivalry between the industry incumbents, and this rivalry is affected by how easy it is to enter the industry (Johnson et al., 2014). Where there are numerous competitors, a low industry growth rate, high fixed costs and exit barriers, and low product differentiation, the competitive rivalry is highest (Johnson et al., 2014; Porter, 1979). The threat of entry by new competitors is lowest in an industry where the incumbents have economies of scale and significant experience, existing access to large supply and distribution networks, product differentiation, high capital requirements and government policies with licencing requirements for example (Johnson et al., 2014; Porter, 1979).

Platinum industry role players function in an environment where there is no differentiation in the product they sell, buyers are all price sensitive, all uses of platinum for buyers are the same, and have the same user requirements, switching costs for buyers are low and if necessary, they can switch to palladium or another metal as and when substitutes arise, and platinum is also sold on metal exchanges (ETFs) through contracts (Van den Berg, 2008).

Existing platinum mining companies have over 100 years of experience in the industry and much research and development has already been conducted for enhancement of efficiency, and cost reduction. As mining companies are forced to be clustered due to their geological locations, there is much knowledge sharing through both professional bodies that are in existence as well as employees who move between competitor companies (Van den Berg, 2008).

The rivalry and management ideologies that are possessed by firms result in forced competitive advantages being formed as rivals are forced to find better, more efficient and cost effective ways in which to conduct business, thus resulting in a world class industry due to a highly competitive environment (Van den Berg, 2008).

Mining companies have an incessant obsession on maximising short-term profits and gains and this often leads to quick fixes in engineering solutions which result in long-term high costs and inefficiencies (Van den Berg, 2008).

For rivals to compete with each other, they need to find innovative ways of cost-cutting (Van den Berg, 2008), but as the world is constantly changing, the question is whether pure cost cutting strategies are enough.

2.3.2 *Factors that affect supply and pricing of platinum*

Like with any other major commodity, the demand for platinum that affects the attractiveness for new entrants and the rivalry between incumbents, is also affected by supply and pricing.

Platinum supply and pricing, like any commodity, are interconnected – when the price is high, there is more incentive to mine the metal and more incentive to recycle (Sverdrup & Ragnarsdottir, 2016). The supply of platinum is likely to drop as future mining projects have been delayed as a result of the labour unrest in South African mines which have driven costs of platinum mining up (International Platinum Group Metals Association, 2016a; Robinson, 2017).

A report commissioned by the World Platinum Investment Council (WPIC) suggests that platinum is likely to be in a deficit till 2021 by an estimated average of 250,000 ounces per year and this deficit should assist in driving up platinum prices during this period (Jollie, 2016). The deficit in supply is likely to increase as the primary source of platinum supply – extraction through mining – is shrinking, however this is likely to be partly offset by the expected increase in recycling (Jollie, 2016). However Johnson Matthey (2016) have found that recycling of platinum from automobiles and jewellery has dropped by 17% as low prices affected scrap metal volumes.

The recent unstable economic environment in South Africa has resulted in mining companies cutting back on capital expenditure (Robinson, 2017) and thus the mines are unlikely to increase production in the medium term (the next six years), with the resulting deficit providing the potential for prices to recover. If the prices are to remain below US$1000/t oz., more extensive cuts in production can be expected (Jollie, 2016).

If there is a rise of the hydrogen economy – stemming from the use of fuel cells – demand will almost certainly outstrip the supply of platinum and thereby increase platinum prices (Yang, 2009).

Genc (2008) states that the platinum price is affected primarily by three factors: 1) the supply and demand of platinum, 2) the price of crude oil and gold and 3) the ratio of the South African rand to the US dollar.

As seen in Figure 2, the devaluing of the South African rand resulted in higher revenues from platinum in South Africa even when the US dollar value of platinum decreased.

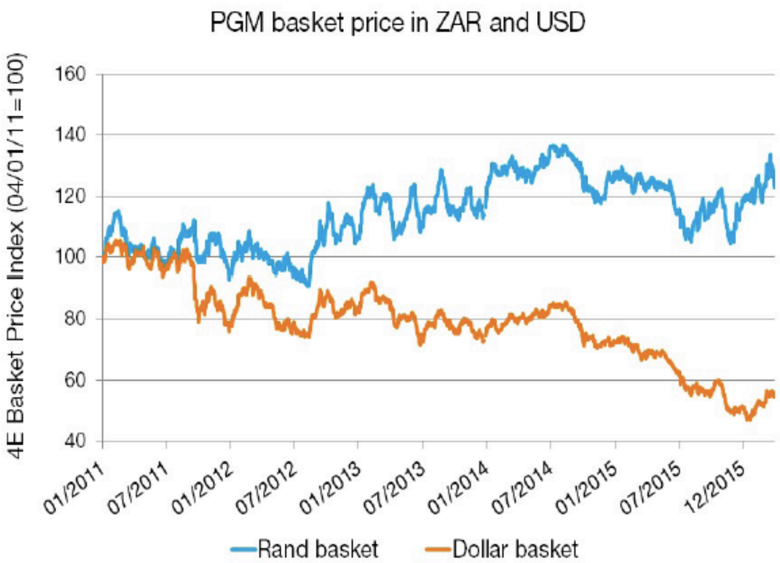
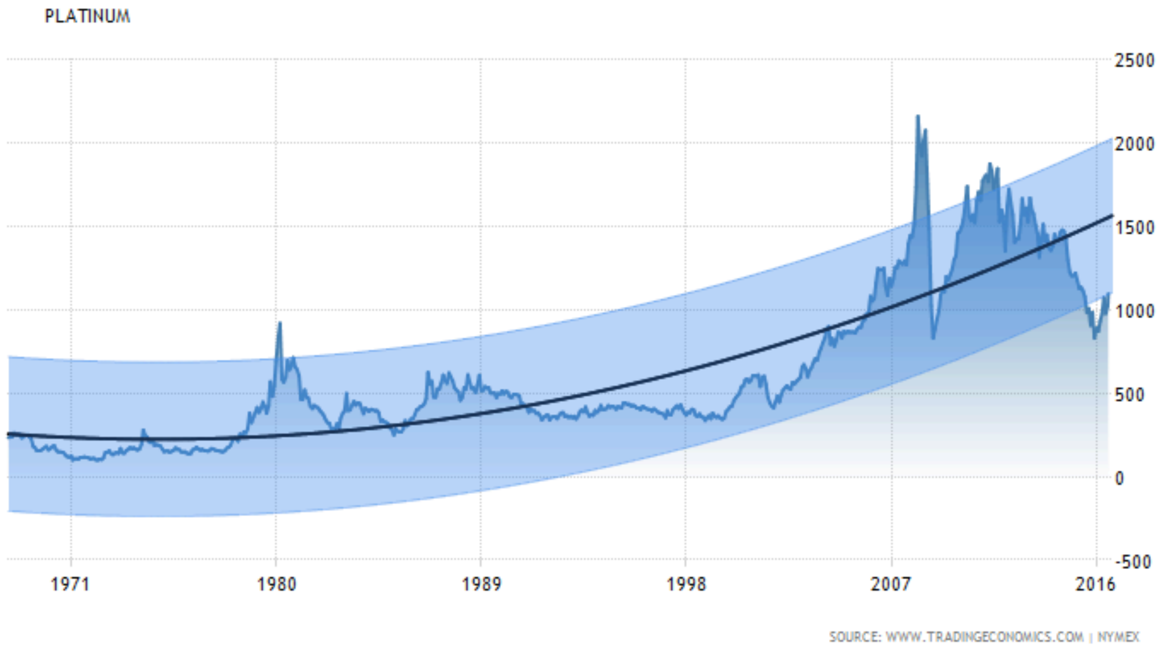


Figure 2*:* PGM basket price in ZAR and USD trended from 2011-2015 (Johnson Matthey, 2016)

A forecast by Trading Economics (2016) as seen in Figure 3, found that platinum prices are expected to drop to US$787 by 2020.



Forecast	Actual	Q3/16	Q4/16	Q1/17	Q2/17	2020	Unit
Commodity	1097	965	955	945	945	787	USD/t oz.

Figure 3: Platinum trading price in US/t oz. from 1971 to 2016 and forecast to 2020 (Trading Economics, 2016)

However, the Economist Intelligence Unit forecasts that the platinum price will increase to US$1230 by 2019 (see Figure 4), which nonetheless is still below pre-2015 levels (Knoema, 2016).

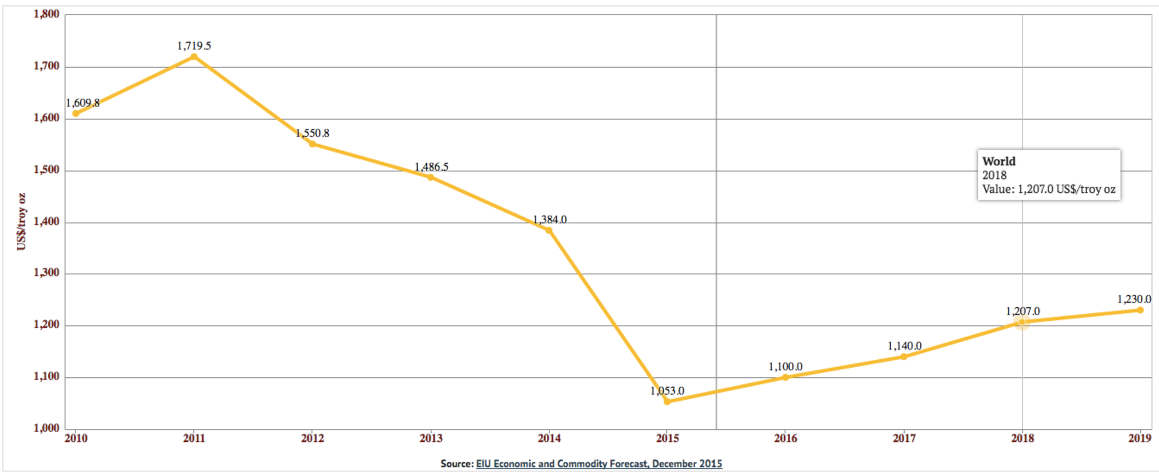


Figure 4: Platinum trading price in US/t oz. from 2010 and forecast to 2019 (Knoema, 2016)

The WPIC suggests that the short term price fluctuation of platinum is less relevant than the longer term price formation of platinum and will be greatly affected by the supply and demand of the metal (Genc, 2008; Jollie, 2016). The report asserts that global economic growth will be strong enough to drive demand till 2021, and that a bullish pricing forecast can be assumed for the period (Brush, 2016; Jollie, 2016).

Historically, platinum has always been priced at a premium to gold by 1.5 times yet, post the recent labour unrest in the platinum industry in South Africa, platinum has been at about 80% of the price of gold however, based on history, platinum has only been priced lower than gold four times in the preceding 40 years and thus a price rebound is likely (Brush, 2016). This rebound is expected as a result of an anticipated market imbalance in the form of a deficit in platinum supply over the coming years. However, Brush (2016) warns that history does not have to repeat itself and there remains the possibility of platinum prices remaining below that of gold.

2.3.3 *The power of buyers and the power of suppliers*

Buyer and supplier power is determined by the pull that each role player has in the industry. Suppliers are powerful when there are only a few suppliers of the product, customers face high switching costs when moving from one supplier to the other and where suppliers can integrate forward and cut out the 'middle man' (the customer) (Johnson et al., 2014; Porter, 1979). Conversely, buyers are powerful when there are concentrated buyers (a few buyers who account for the bulk of the sales), low switching costs, potential for backward integration to cut out the supplier and/or standard or undifferentiated products (Johnson et al., 2014; Porter, 1979).

As mentioned in section 2.3.1., switching costs for buyers are low in the platinum industry as it is easy to switch between mining companies and buyers can switch as and when substitutes arise (Van den Berg, 2008).

There are currently four major categories of uses for platinum in industry today. These are:

1. As an autocatalyst in automobiles
2. For use in jewellery
3. For manufacturing of industrial equipment, and
4. For investments through Exchange Traded Funds (ETFs)

While there is no consensus on the exact estimates of platinum demand, with different sources citing varied numbers, the Johnson Matthey company can be considered an authority in the industry.

1. Autocatalyst

The largest demand for platinum is from the automobile industry for use as an autocatalyst, accounting for 40% of total demand (Johnson Matthey, 2016). Platinum is used to clean emissions from internal combustion engines, particularly in diesel utilising vehicles.

2. Jewellery

The jewellery industry accounts for 34% of platinum demand, stemming primarily from China and India (Johnson Matthey, 2016).

3. Industrial use

Due to its durable nature, platinum is used in equipment across various industries (e.g. in dental equipment) and accounts for 22% of platinum demand (Johnson Matthey, 2016).

4. Investments

Exchange traded funds (ETFs) are an investment vehicle used to buy securities on the stock market and are generally backed by an asset with the return expected to follow a set target (Kosev & Williams, 2011). Similarly, platinum ETFs are investments in securities that are backed by platinum as the asset. However, ETFs only account for approximately 4% of platinum demand worldwide (Johnson Matthey, 2016).

While the platinum industry can be considered an oligopoly as there are only a few major players controlling the supply, it is in fact still a price taker like other commodity markets as prices are determined by demand and pricing in the markets (Van den Berg, 2008).

Van den Berg (2008) posits that unlike Porter's theory of demand conditions, demand in the platinum industry is not originated locally, but rather internationally in the northern hemisphere. However, Van den Berg also states that the investment in the platinum industry is from both local and international role players. With the advent of alternatives to platinum in the automotive industry in particular (discussed later in the paper), there needs to be a view on how the platinum industry can move forward. A potential option is through actively pursuing the development, usage and commercialisation of platinum-utilising hydrogen fuel-cells.

2.3.4 *Hydrogen fuel cells*

A hydrogen fuel cell is a device, similar to a battery, that is used to produce electric power as well as to provide thermal energy from chemical energy. Unlike batteries, fuel cells do not need to be recharged as the materials consumed during the electrochemical process are in continuous supply from the environment (El-Khattam & Salama, 2004).

Platinum is a key component in fuel cells and is used as the catalyst for the chemical reaction for energy creation. A manner in which to reduce the dependency on oil as well as to decrease carbon emissions is through the use of fuel cell powered vehicles.

These vehicles would be 50% more efficient on fuel consumption than traditional internal combustion vehicles and would not require oil as a fuel source (Datta, 2008). El-Khattam and Salama (2004) state that fuel cells are able to convert chemical energy to electric energy with 60% energy which is considered twice that of traditional electricity generating plants. Furthermore, as a result of the increased efficiency of fuel cells, they emit fewer air-pollutants, and as combustion is not involved in the process, there are negligible carbon dioxide emissions, thus making fuel cells environmentally friendly. These fuel cells can be utilised in both residential and commercial buildings as an alternative to traditional electricity-generating mechanisms (El-Khattam & Salama, 2004).

Fuel cell technology could play a fundamental part in the development of a sustainable energy economy (Wang, 2015), however this is also in the medium-term and does not take into account issues of the sustainability of the platinum resource itself.

New product developments are usually successful if they deliver on what is initially promised, however they face numerous financial, legal, technical and competitive challenges to effective commercialisation (Wang, 2015). The problem with lack of widespread adoption of the hydrogen fuel cell is that it is lacking in reliability and durability, and is highly priced (Wang, 2015). According to Sun, Delucchi, and Ogden (2011), hydrogen powered platinum fuel cells have great potential to be the clean energy source of the future. However, there are numerous technical as well as economic barriers facing the commercialisation of fuel cells (Sun et al., 2011). Two of the current deterring factors to research and development into fuel-cell technology and wide acceptance of fuel-cells are the high cost of fuel-cells (Ryan, 2014; Sun et al., 2011) as well as the lack of a sustainable source of hydrogen, which is the fuel necessary for fuel-cells to function (Ryan, 2014).

However, the development of fuel cells would result in an alternate source of demand for platinum and development of the fuel-cells with lower costs, would result in use for mining of other metals as well (gold etc.) (Ryan, 2014). Sun et al. (2011) found that platinum is a substantial portion of the cost of fuel cells, thus the price of platinum affects the price of fuels cells. The dilemma then arises with the needs of investors. While platinum fuel cells are a good source of additional revenue for platinum mining companies, the high cost is a deterrent.

On the other hand, if the price of platinum is not high, it is not worthwhile for shareholders to invest in platinum mining activities. The cost per fuel cell can decrease with improvements and research and development into new technology, however the economics play a large role – as the demand for platinum increases, the price of platinum will increase, which may offset the lower fuel cell prices gained from increased efficiencies (Sun et al., 2011).

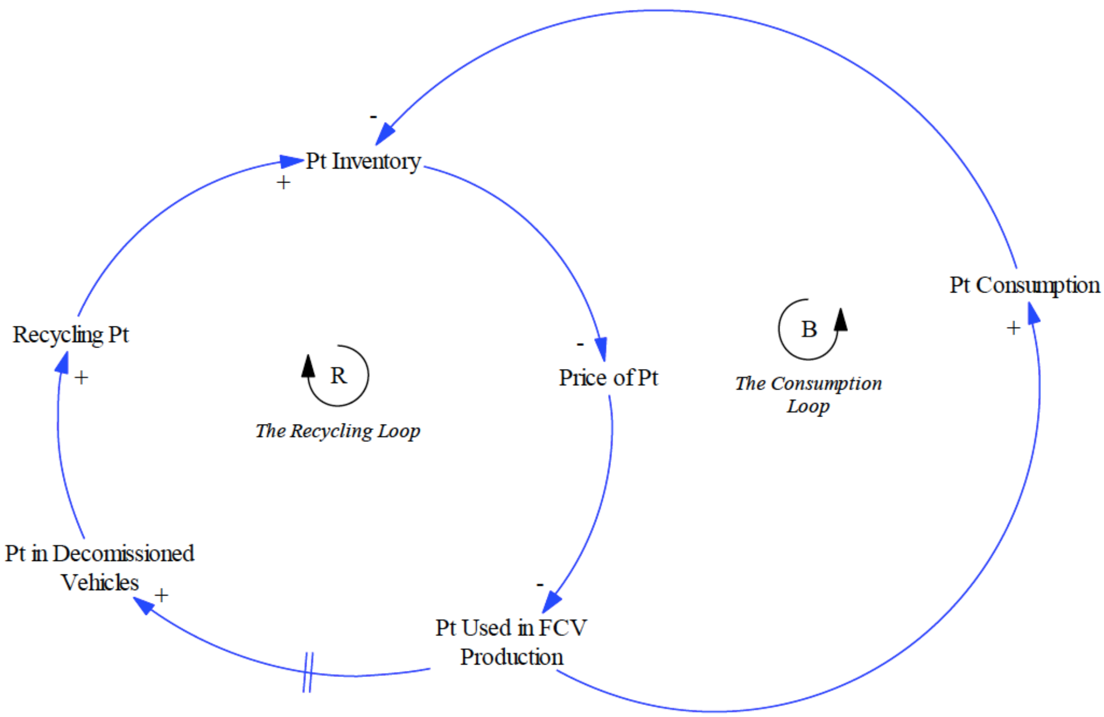


Figure 5: The Recycling and Consumption Feedback Loops (Datta, 2008, p. 9)

As seen in Figure 5, if platinum recycling increases, the quantity available in the market increases (increase in supply), thus the platinum price decreases, encouraging an increase in fuel cell production (Datta, 2008).

The additional costs of setting up hydrogen refuelling stations is sizeable (Wang, 2015). Nevertheless, utilisation of the fuel cell is not dependent on the creation of a hydrogen economy, as alternative fuel sources can be used such as natural gas, ethanol and methanol (Wang, 2015). However, this is not completely environmentally friendly as compared to the use of hydrogen as a fuel source (through water electrolysis).

The CEO of Northam Platinum claims that platinum will be an excellent investment in the coming 30 years (Creamer, 2016). He further stated that the launch of the Mirai fuel-cell car by Toyota is the inflection point for platinum-using fuel-cell demand. According to Bloomberg, Toyota has argued that hydrogen fuel-cells are the future of clean energy and not electric vehicles – vehicle manufacturers Honda and Hyundai have also manufactured fuel-cell powered vehicles (Hull, 2015). Toyota further claims that the Mirai takes 3 to 5 minutes for refuelling and can go for 502 kilometres on a full-tank of hydrogen whereas a plug-in electric vehicle would not be able to go for such a distance on a single charge.

The use of fuel-cells could provide an essential new revenue stream for platinum mining companies, increase mining activity and potentially other manufacturing activities (Hyman, 2015). The Chamber of Mines in South Africa has installed a 100kW platinum fuel-cell company and the mining company, Impala Platinum Holdings Limited (Implats), is looking to run their operations in mines using fuel cells (Hyman, 2015; Ryan, 2014), thus decreasing the load on the current energy supply as well as being more environmentally friendly. If energy costs are very high, platinum fuel cells will look more attractive, and once economies of scale can be achieved, costs will decrease (Hyman, 2015).

In 2014, Amplats invested US$100 million in the Platinum Group Metals Development Fund (PGMDF), which is a private equity fund that promotes innovation for new and sustainable uses of PGMs, with an emphasis on local beneficiation i.e. in Southern Africa (Amplats, 2014; PGMDF, 2014), and the government of South Africa has invested in fuel cell development since 2008 with a 15 year plan and a hope to acquire 25% of the fuel cell market by 2020 (Ryan, 2014).

2.3.5 *Factors that affect demand*

According to the May 2016 PGM report by Johnson Matthey (2016), platinum demand is expected to rise in the coming years as Chinese and Indian demand for platinum in jewellery is expected to increase, and there is an increased need from the automobile sector for platinum after the introduction of the Euro 6b legislation (Johnson Matthey, 2016), which limits the carbon dioxide emissions that are acceptable for motor vehicles in order to reduce the adverse impact on the environment. Mining Weekly is consistent with this view and state that platinum demand in the next five years is thought to be positive and that both the continued requirement for clean vehicles and growing demand for platinum jewellery in India will continue to drive demand (Creamer, 2016). China is introducing the Euro 4, 5 and 6 emission regulations and India who have already implemented Euro 4 are considering leap-frogging into Euro 6, thus the autocatalyst demand in these countries is likely to increase (Creamer, 2016). While demand in the automotive sector is mainly from Europe, demand for jewellery stems primarily from Asia, particularly China and India (Jollie, 2016).

Lithium-ion batteries have entered the hybrid vehicle market and are a serious challenger to power future electric vehicles (Armand & Tarascon, 2008). This may adversely affect the demand for platinum if lithium-ion batteries are faster to market than hydrogen fuel cells. Demand for platinum is highly dependent on the performance of the diesel sector as autocatalysts are used for improving the environmental friendliness of diesel fuelled vehicles. The use of palladium as an alternative, which is cheaper than platinum is attractive in the automotive industry as fuels are becoming cleaner (Jollie, 2016) (platinum is require to neutralise heavy pollutants).

The so-called ‘Chinese slowdown’ has been a reason for the decrease in platinum demand and pricing, however expected job-growth in China will likely uplift the demand for motor vehicles in China, thus increasing the demand for platinum (Brush, 2016).

Table 2 shows that platinum supply is decreasing, while demand, primarily from platinum as an autocatalyst, is increasing. An increased deficit will increase the platinum price and increased industry attractiveness for investments.

Table 2: Platinum Supply and Demand (in 1,000 ounces) 2014-2016 (Johnson Matthey, 2016, p. 1)

Platinum Supply and Demand '000 oz			
Supply	**2014**	**2015**	**2016**
South Africa	3,537	4,569	4,288
Russia	700	670	679
Others	871	837	932
Total Supply	**5,108**	**6,076**	**5,899**
Gross Demand			
Autocatalyst	3,241	3,433	3,497
Jewellery	2,897	2,827	2,929
Industrial	1,755	1,749	1,919
Investment	277	451	332
Total Gross Demand	**8,170**	**8,460**	**8,677**
Recycling	-2,071	-1,725	-1,917
Total Net Demand	**6,099**	**6,735**	**6,760**
Movements in Stocks	-991	-659	-861

While the largest supply of platinum is from South Africa as represented in Table 2, the greatest utilisation of the metal is by China, Europe, North America and Japan as illustrated in Figure 6.

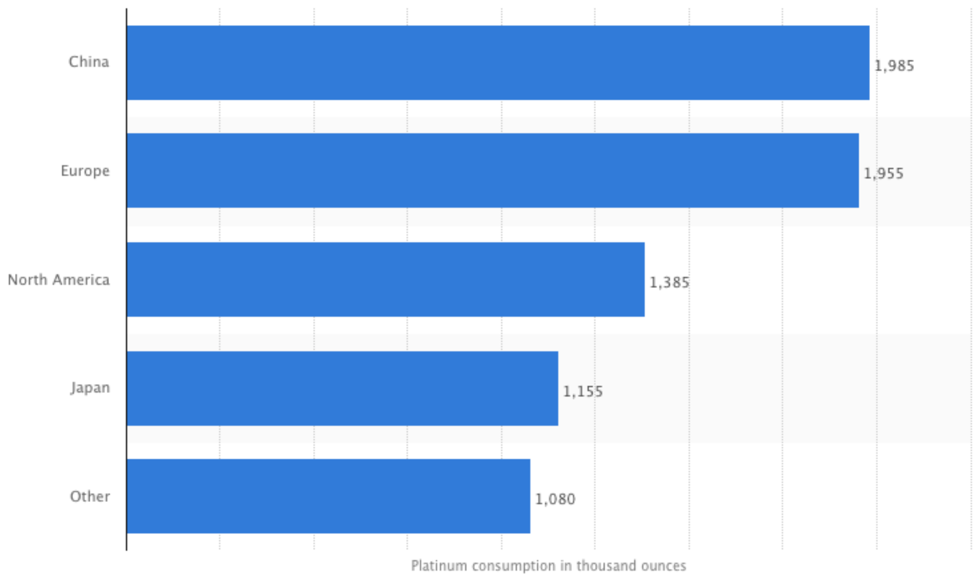


Figure 6: World's top platinum consumers in 2010, by country and region (in 1,000 ounces) (The Statistics Portal, 2016b)

Platinum demand has grown since 2009 (see Figure 7), and Jollie (2016) projects that demand will continue to increase with the greatest increase in demand coming from the automotive industry.

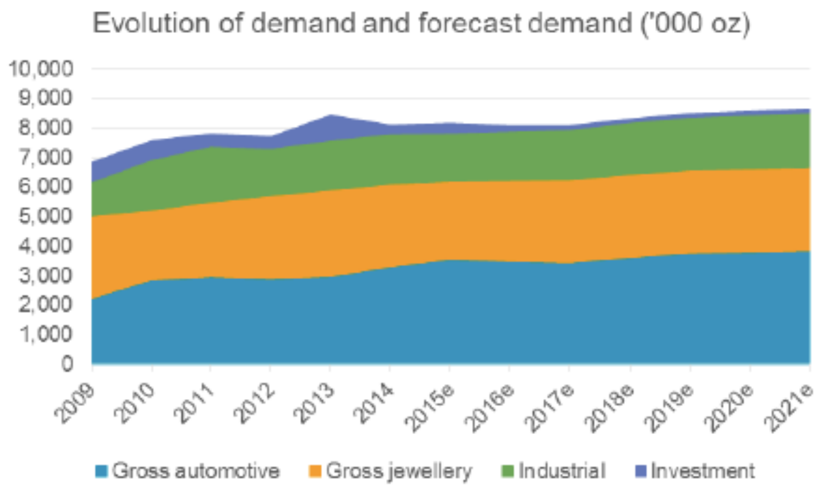


Figure 7: Evolution of demand and forecasted demand to 2021 (in 1,000 ounces) (Jollie, 2016)

2.3.6 *The threat of substitutes*

Substitutes are products that offer comparable advantages to existing products in an industry, but are different in nature or composition (Johnson et al., 2014). Two primary factors affect substitutes, these are the price-performance ratio and extra-industry effects. Substitutes can still be more expensive providing they provide an additional advantage or are differentiated (Porter, 1979). Extra industry effects are substitutes that arise from other industries, thus it is essential for managers to look outside their own industries to consider and foresee potential threats (Johnson et al., 2014).

According to Porter's theory relating to competitive advantage, two additional variables exist that impact on this. These are chance events that completely disrupt an industry such as the discovery of a new and/or more cost effective material that renders platinum redundant, as well as policies or legislation as determined by government that could hinder or enhance the industry (Van den Berg, 2008).

In most applications in industry, platinum is either irreplaceable or can only be substituted by other PGMs, which themselves are not effective to the same extent as platinum (Yang, 2009). While palladium has been used as an autocatalyst, a greater load of the metal is needed in the catalytic converter compared to when platinum is utilised (Yang, 2009) and there is little advantage of mining it in terms of cost and availability of the metal (Datta, 2008). In hydrogen fuel cells, the power output is lower when palladium is used as the catalyst in place of platinum (Yang, 2009). Platinum is an undifferentiated product and buyers are price sensitive, thus differentiation will be necessary for long-term economic sustainability (Van den Berg, 2008).

Lithium is an important element used for many new technologies and particularly, batteries. With the new and expanding market for battery-powered electric vehicles, lithium has come to the forefront (Sverdrup, 2016). According to a report by McKinsey and Company, disruption in the automotive industry can result in up to a 30%, or US$1.5 trillion increase in industry revenue by 2030 (Gao, 2016).

The demand for technology-based minerals such as platinum and lithium will be high over the coming decades given the rapid rate at which technological innovation is occurring (Breytenbach, 2016). Graphite and lithium demand is surging as a result of the rapidly growing battery market and the high growth in the electric vehicle market which makes use of lithium-ion batteries (Breytenbach, 2016). While lithium is in demand by companies such as Tesla Motors for the manufacture of lithium-ion batteries, Tesla only accounts for a fraction of the demand for the metal, thus there is no incentive for lithium producers to supply the metal at lower prices to the company (Matich, 2016).

Tesla claims that the company is likely to produce more lithium-ion batteries than electric cars in the coming years as profitability and regulations in countries do not affect the energy-storage business like it does the vehicle business, and further claims that it will be able to power households and commercial buildings and that the gross margin on batteries is high (Fehrenbacher, 2015).

There has been a swell in the construction of lithium-ion megafactories, one of which is the Tesla gigafactory which is based in Nevada in the USA, thus indicating that there will be a decrease in the cost of production and an improvement in quality over time, further increasing demand in new and existing markets (Breytenbach, 2016). Tesla's gigafactory claims that they will be able to produce batteries 30% cheaper using economies of scale, waste-reduction, innovation and optimisation of location with most manufacturing activities in one area (Tesla, 2016). The projected high demand for electric vehicles in the coming years will increase the demand for lithium vehicles, however Breytenbach (2016) warns that the increasing efficiency in recycling and re-use of materials, as well as disruptive technologies such as driverless cars, will decrease the demand for these raw materials as fewer cars will be demanded. Normal lithium-ion batteries utilised in mobile phones or computers have limited lifespans and start to deteriorate after about 1000 charges, thus this can be expected to happen with lithium-ion batteries used in electric vehicles (Sverdrup, 2016). Electric cars are currently able to go only short distances before requiring a recharge and this distance per charge can be divided by three in countries in the Northern Hemisphere where the temperatures drop very low during the winter months (Sverdrup, 2016). For lithium powered electric cars to overtake current internal combustion engines or even hybrid vehicles, the kilometres per charge needs to increase sufficiently. Lithium itself is also a non-renewable resource (Sverdrup, 2016).

South Africa is at the economic core of Southern Africa primarily, as well as Africa in general, and the country's economy is built mainly on mineral wealth (Robinson, 2017). Platinum generates billions for the South African economy (Van den Berg, 2008). Thus replacing the metal with a substitute, such as lithium-ion batteries, and hence devaluing the platinum metal, could have disastrous effects on the South African economy as the country is responsible for the bulk of platinum mined in the world.

2.3.7 *Proposition 1*

Growth in automotive demand and the need for environmental sustainability will increase demand for platinum through improved fuel-cell technology. Substitutes for platinum, such as lithium-ion batteries, are currently unlikely to drastically reduce the demand for platinum.

2.4 Identifying the imperative for environmental sustainability in the platinum mining industry and how that affects demand and financial sustainability

Griggs et al. (2013, p. 306) define sustainable development as the "development that meets the needs of the present while safeguarding earth's life-support system, on which the welfare of current and future generations depends". From a more commercial perspective, Mohan Das Gandhi et al. (2006, p. 667) define sustainable development as "an attempt to broaden the narrow focus on a single economic bottom line by developing a 'triple bottom line' approach by balancing the traditional economic prosperity goals with social equity and environmental protection concern."

Mining in addition to agriculture, comprises one of the earth's two basic industries (Montmasson-Clair, 2015) and impacts aspects of both the economy and society. Mining and the entire mining value chain have provided multiple benefits to society including employment, new technologies, and increased profits for the economy and companies through opportunities for exports and foreign exchange (Montmasson-Clair, 2015).

The growth in the world population has resulted in increased use of fossil fuels as energy demands in society continue to increase (Robinson, 2017; Wang, 2015). The question on how to make businesses, automobiles and households run without destruction of the environment is a critical one (Wang, 2015). The carbon dioxide emissions from the burning of fossil fuels is unsustainable and thus new energy sources must be researched and developed for future generations (Armand & Tarascon, 2008). Consumption of energy and manufacturing activities that are energy-intensive require fossil-fuel combustion and this is predicted to have a severe future impact on both the economy and the environment (Winter & Brodd, 2004). There is also high pressure on South African manufacturing companies to decrease emissions from manufacturing activities (Mavuso, 2016).

Platinum has played a role in the so called ‘green economy’ as it has been used as a catalytic converter for the purpose of reducing carbon emissions in automobiles through a chemical process (Montmasson-Clair, 2015). However, the extraction of platinum from the earth is an energy intensive process that requires electricity from coal-powered power stations that are responsible for high levels of carbon emissions into the environment that add to global warming (Montmasson-Clair, 2015; Ryan, 2014). While platinum may contribute to the ‘green economy’, the resource itself is finite (Mudd, 2012; Sverdrup & Ragnarsdottir, 2016) and thus cannot be considered part of a sustainable green economy. This can be termed *the sustainability paradox*.

2.4.1 *Limited resources*

Concerns about limited platinum resources are a reality as platinum is one of the rarest metals on earth and for every 7 to 12 tonnes of platinum ore that is mined, only approximately one ounce of platinum is derived (Datta, 2008).

Yang (2009) asserts that even with the most optimistic target, platinum required for a fuel-cell powered car versus the existing gasoline cars, would be ten times more and even with the expectation of platinum recycling, there will be losses of platinum in the process. Thus, to maintain a hydrogen economy and a sufficient supply of fuel cells, a constant flow of platinum from the primary source (the mines) is required. In a study by Gordon, Bertram, and Graedel (2006), they estimate that the platinum resources in the earth’s lithosphere would be exhausted in 15 years for a fleet of 500 fuel cells.

Yang believes that hydrogen fuel cells are not viable for the future if they utilise platinum, given the limited supply of platinum in the earth. However, Cawthorn (2010) posits that the existing PGM deposits in the Bushveld Complex in South Africa are enough to supply the world with PGMs for decades or even the next century when utilising existing mining techniques. Glaister and Mudd (2010) are aligned with Cawthorn's view and suggest that the sustainability aspect of platinum mining is not in terms of the quantity of the platinum resource available in the earth but rather the environmental impact of mining, such as the use of water, solid wastes (waste rock), greenhouse gas emissions and energy consumption. This is as only a depth of 2km of the earth is currently being mined (only this is economically viable currently) and thus, more platinum deposits are likely to be found at greater depths. Adding to this, a study conducted by Sverdrup and Ragnarsdottir (2016) found that platinum available for mining up to a depth of 5km is significantly more than previous estimates and even more platinum deposits are likely to be discovered.

2.4.2 *Recycling*

Due to increased awareness on a public and governmental level of global warming and other environmental sustainability concerns, focus on the need for sustainable energy technologies has risen. The increased need for platinum for green technology will result in supply deficits and thus the platinum metal may become the bottleneck for catalyst production (Hodnik et al., 2016) and similarly, fuel-cell production.

Hageluken (2012) states that due to the high technical reliability of the platinum metal, 95% of it can be recycled but only once the PGM containing metal scrap reaches an excellent refining (recycling) facility. While the automotive industry accounts for the greatest platinum usage, it is the industrial applications of platinum that lead the way in recycling at present (Hageluken, 2012). Metals are not consumed, but merely transferred from one form into another and thus can be recycled. The challenge lies in the different combinations in products that makes efficient retrieval of metals more difficult (Hageluken, 2012).

Hageluken (2012) suggests that a 'recycling chain' consists of different stakeholders necessary for the effective recycling of metals. These range from those collecting the scraps to the final extraction of the metal. The challenge here is that the final process requires metallurgy and thus large capital outlays (Hodnik et al., 2016). Improvements have been made to increase the yield from the process, thus making it more efficient (Hageluken, 2012). The degree to which platinum is recycled is based on platinum pricing – the higher the price, the more incentive there is to recycle the precious metal (Sverdrup & Ragnarsdottir, 2016).

2.4.3 *The hydrogen economy*

The use of hydrogen as a fuel source is sustainable when it is produced via water electrolysis that uses solar or tidal energy – when hydrogen is utilised as a fuel, the by-product is water (Wang, 2015). This then provides large potential to reduce greenhouse gas emissions as well as decrease the reliance on fossil fuels (Wang, 2015).

Hydrogen fuel cells have been recognised as a nearly model solution to clean-energy issues of motor vehicle manufacturers and non-utility and utility generators (Winter & Brodd, 2004). With the increase in greenhouse gasses and particle emissions, decarbonising the transport industry is one of today's greatest challenges (Pollet, Staffell, & Shang, 2012). Platinum is a vital element for the future, particularly in clean-energy technology (Ryan, 2014).

Hydrogen can be produced by water electrolysis using solar, wind or tidal energy, thus making the fuel-cells that use hydrogen produced in this manner, environmentally friendly (Wang, 2014). This would significantly reduce both reliance on fossil fuels, and carbon dioxide emissions from internal combustion vehicles.

According to Hydrogenious Technologies, a company founded in 2013 for the production of hydrogen through electrolysis as a clean energy solution, hydrogen is the energy carrier of the future (Hydrogenious Technologies, 2016b) and the company is investing in what has been termed the 'hydrogen economy'. Anglo American Platinum (Amplats) has invested in Hydrogenious Technologies for the further development of the hydrogen storage technology (Hydrogenious Technologies, 2016a) and this will aid in the increased fuel cell use.

The current challenge with developing a hydrogen economy however, is ensuring that there is an adequate supply and source of renewable energy (solar, wind and tidal), effective storage of hydrogen, effective electrolysis of water into the elements oxygen and hydrogen, as well as the aforementioned technology and costs associated with fuel cells (Wang, 2015).

2.4.4 *Proposition 2*

Efficient, cost-effective recycling practices will increase both environmental and financial sustainability of the platinum sector and contribute positively to the hydrogen economy.

2.5 Identifying measures to mitigate risks that mining companies in the platinum industry may face

2.5.1 *Fuel-cell economic viability*

Wang (2015) posits that there are two primary steps to achieve successful commercialisation of fuel cells and these are (1) addressing concerns around durability, reliability and cost; and (2) building a new business model for the industry, and setting standards. The economic viability of fuel cells will depend on the ability to manufacture them at lower costs by reducing the costs of catalysts and other materials used (Winter & Brodd, 2004). Shao, Liu, Wang, and Lin (2008) found that while platinum is used as a catalyst in fuel-cells, there are many other components that are used as support for the catalyst, and there is much room for improvement of the quality, functionality, cost and lifespan of these supporting elements.

Two of the major challenges that face fuel-cell technology are durability and cost (Chalk & Miller, 2006). There have been findings that the use of platinum alloy as opposed to platinum singularly as a catalyst, has been more cost effective and more functional (Chalk & Miller, 2006). Even though this is a reduction in the content of platinum used per fuel cell, it nevertheless results in additional demand for platinum and decreases the cost of the fuel cell technology. There is high potential for the fuel cell market, particularly in Africa, and the commercialisation of products that are reliant on fuel cell technology is essential to increase demand for the fuel cells (Ryan, 2014).

The greatest measure for viability is the cost of production of fuel cells versus that of substitutes such as lithium-ion batteries. If the cost, durability, reliability and robustness of fuel cells are not improved, the market will not accept them as a viable alternative to current energy sources, such as the existing internal combustion engines in the automotive industry that utilise fossil fuels (Wang, 2014).

2.5.2 *Sustainable mining practices*

Ryan (2014) found that the platinum industry accounts for 33% of the electricity sold to mines in South Africa and the mines are highly dependent on electricity for operations with most producers using more than 70% electricity in their energy mix. Furthermore, electricity prices have soared with a 287% increase in the electricity price in South Africa between 2007 and 2012. An additional challenge to the electricity supply industry in South Africa is its substantial carbon foot-print and the carbon tax implementation that is imminent in the country, which will further exacerbate mining company electricity costs by bestowing a considerable tax risk (Ryan, 2014).

Ryan further states that if the management of energy is reduced to increasing the efficient use of energy alone, it will not make significant differences in costs in the longer term and that mitigation and management mechanisms should be inclusive of platinum production technologies and processes. The focus on research and development, however, is costlier than focussing on ways to increase energy efficiency. One of the methods that Ryan recommends to reduce electricity costs in mines is through investment in, and the use of, alternate energy sources, an option being the use of platinum fuel cells in operations. This would decrease dependence on electricity from the national power provider and reduce carbon emissions, thus reducing the carbon tax liability.

Amounts of platinum lost annually are approximately 32% of the mined amount (primary source) or 22% of the amount actually supplied into market, and this drastically reduces any long-term conservation goals that platinum industry stakeholders may have (Sverdrup & Ragnarsdottir, 2016). Awareness of issues of sustainability and climate change as well as the role that companies have to play in this global problem is at the forefront of discourse in today's economy (Gond, Grubnic, Herzig, & Moon, 2012), made more prevalent by the advent of globalisation. Sustainability requires that organisations renew their existing strategies to incorporate this element in order to achieve a positive so-called 'triple bottom line' (Gond et al., 2012).

2.5.3 *Proposition 3*

In order to increase fuel cell demand, durability and reliability have to be increased and manufacturing costs decreased, through increases in efficiency which must contribute to sustainability. Platinum recycling and investment in the hydrogen economy will improve financial sustainability.

2.6 Conclusion of Literature Review

Even with the volatility in the platinum industry in recent years, platinum is a metal of the future as the world moves toward green technologies and green energy. Platinum is an important component of autocatalysts, which are essential in ensuring that fossil fuels are cleaned and less toxic emissions are released into the environment. Platinum demand is likely to increase in the coming years as hydrogen fuel cells – which require platinum as a key component – increase in demand. However, it is critical for platinum industry stakeholders to move fast in order to find more cost effective ways of manufacturing fuel cells and to be cognisant of lithium-ion batteries and other substitutes that are being developed in the market. Platinum supply deficits are expected in the coming years, while demand is expected to increase, thus a bullish outlook on the platinum price can be adopted.

However, concerns around sustainability have to be recognised and dealt with as longevity of the platinum industry depends on availability of the metal. Thus focus on recycling the metal as well as investment in efficiency increases is crucial. With investment in the 'hydrogen economy' through research and development, the demand for platinum will increase.

2.6.1 *Proposition 1:*

Growth in automotive demand and the need for environmental sustainability will increase demand for platinum through improved fuel-cell technology. Substitutes for platinum such as lithium-ion batteries are currently unlikely to drastically reduce the demand for platinum.

2.6.2 *Proposition 2:*

Efficient, cost-effective recycling practices will increase both environmental and financial sustainability of the platinum sector and contribute positively to the hydrogen economy.

2.6.3 *Proposition 3:*

In order to increase fuel-cell demand, durability and reliability have to be increased and manufacturing costs decreased, through increases in efficiency which must contribute to sustainability. Platinum recycling and investment in the hydrogen economy will improve financial sustainability.

CHAPTER 3. RESEARCH METHODOLOGY

This research utilises a semi-quantitative research methodology to address the research problem stated in the previous section. The methodology that is utilised will assist in the analysis and interpretation of causal linkages between multiple variables that affect the demand for platinum. Detail of the methodology, its application, how and why the sample is chosen, and the reliability of this methodology is explained below. Lastly, the structure of this research report has largely been adapted and modified from research conducted by Pillay (2008).

3.1 Research methodology / paradigm

A semi-quantitative approach using Fuzzy Cognitive Mapping (FCM) was followed and utilised as the research methodology in this study. A FCM is a chain of fuzzy-graph structures that represent causal relationships between hazy variables or variables that are not completely clear, and allows for methodical causal propagation, both backwards and forwards (forward and backward chaining) (Kosko, 1986). FCMs allows for identification of relationships between variables that are not exactly known and where there is insufficient knowledge for statistical modelling (Hobbs et al., 2002). Thus a model is build based on expert knowledge as opposed to statistical data (Knight, Lloyd, & Penn, 2014).

> "A Fuzzy Cognitive Map or FCM draws a causal picture. It ties facts and things and processes to values and policies and objectives. And it lets you predict how complex events interact and play out."
>
> (Kosko, 1993)

The platinum industry is a complex system and cannot be calibrated or standardised and thus the logic is 'fuzzy'. As there are numerous uncertainties between the relationships between different variables, a standardised questionnaire, for example, will not provide valid or reasonable data for analysis. Thus statistical modelling is not appropriate when dealing with the platinum industry, and this research therefore relies on the expertise of role players within the industry.

The causal link or connection in a FCM are represented by plus (+) or minus (-) signs as seen in Figure 8. A plus (+) means that there is a positive relationship or a causal increase whereas a minus (-) means that there is a negative relationship or a causal decrease (Kosko, 1993). Thus, if variable a goes up, variable b will go up to some degree, and conversely, if variable c goes up, variable d will go down to some degree (Kosko, 1993).The concepts used or 'nodes' (input variables), can be 'switched' on or off, thus allowing for analyses of multiple scenarios (Kosko, 1993). A higher numeric value assigned to a node indicates a stronger presence of that concept or node, a negative value indicates a negative relationship and a 0 value indicates that the concept is not relevant at the time (Mohr, 1997). This paper uses the colour green for positive relationships and red for negative relationships.

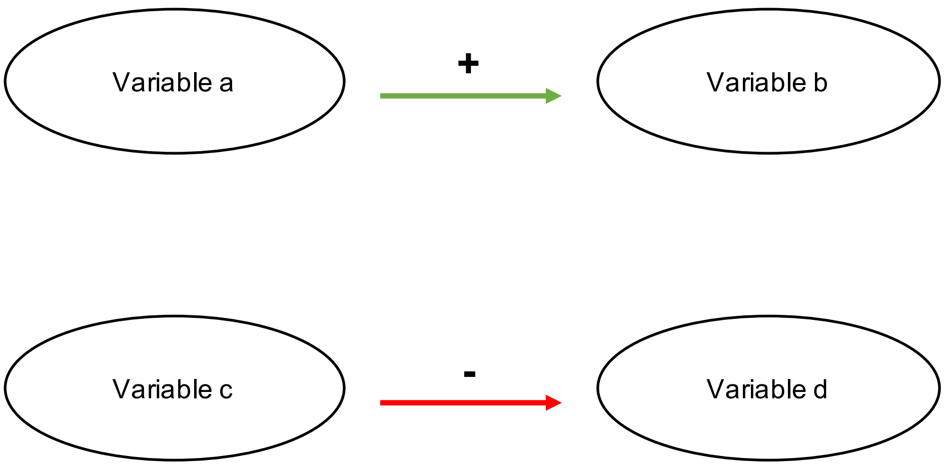


Figure 8: Depiction of positive and negative relationships between causal relationships. Adapted from Kosko (1993)

This research is based on causal relationships between demand for platinum and the factors – particularly technological changes and new applications for platinum – that affect this demand. The draft FCM that was developed as part of this research proposal was then vetted by industry experts in the platinum sector.

Since all the platinum industry experts involved in this research can have input in the outcomes of FCM, it is a useful tool for planning as well as decision making (Kosko, 1993).

3.2 Research Design

This semi-qualitative research drew on the review of the literature in chapter 2 to develop a draft FCM that showed the cause and effect relationships between the different concepts or input nodes chosen.

Once the draft FCM had been drawn up, it was evaluated by platinum industry experts to gain their input and feedback on the draft FCM. Following this, a final FCM was drawn up. This final FCM was an expansion and refining of the draft FCM, based on the input that was received from the experts. The input from industry experts ensured that the final FCM – that was then used for simulation and analysis of multiple scenarios – incorporated an accurate depiction of the realities of the industry.

Industry expert feedback was obtained by one of two means:

1. An email with an explanation of what a FCM is and what is expected of the individual was sent along with the draft FCM, or
2. A personal visit to the individual to do as in point 1 above.

After feedback was obtained, it was integrated into the draft FCM to form the final FCM. This was then used for the simulation, testing and analysis of the various scenarios.

The draft and final FCMs utilised in this research were constructed on a computer-based tool called *Mental Modeler* (Gray, Gray, Cox, & Henly-Shepard, 2013).

The following are the potential advantages and disadvantages of the use of this methodology in this research paper, as shown in Table 3

Table 3: Advantages and disadvantages of simulation and the use of a FCM as research methodology

Advantages	Disadvantages
Several scenarios that impact the demand for platinum can be tested.	There may be errors in the simulation.
Allows a big-picture view that will assist in looking past the complexity that is part of the FCM.	Simulation is not tangible.
Allows input from platinum industry experts and hence, can be fine-tuned to reflect reality and thus improve accuracy.	The accuracy of the results is limited to a given period and must be remodelled if revisited at a much later stage.

Source: Adapted from research conducted by Pillay (2008)

3.3 The draft fuzzy cognitive map (FCM)

The draft FCM (see Figure 9) has been fashioned based on the literature review conducted in chapter 2. This draft was the FCM that was given to industry experts for assessment, input and feedback in order to produce the final FCM that was used for simulation and analysis. The input nodes are highlighted in yellow. The green lines show an increase in the receiving node as a result of the transmitting node and the red lines show a decrease in the receiving node as a result of the transmitting node. Table 4, shown after the draft FCM, shows the causal relationships between the input and output nodes and whether these relationships are positive or negative (marked with a tick).

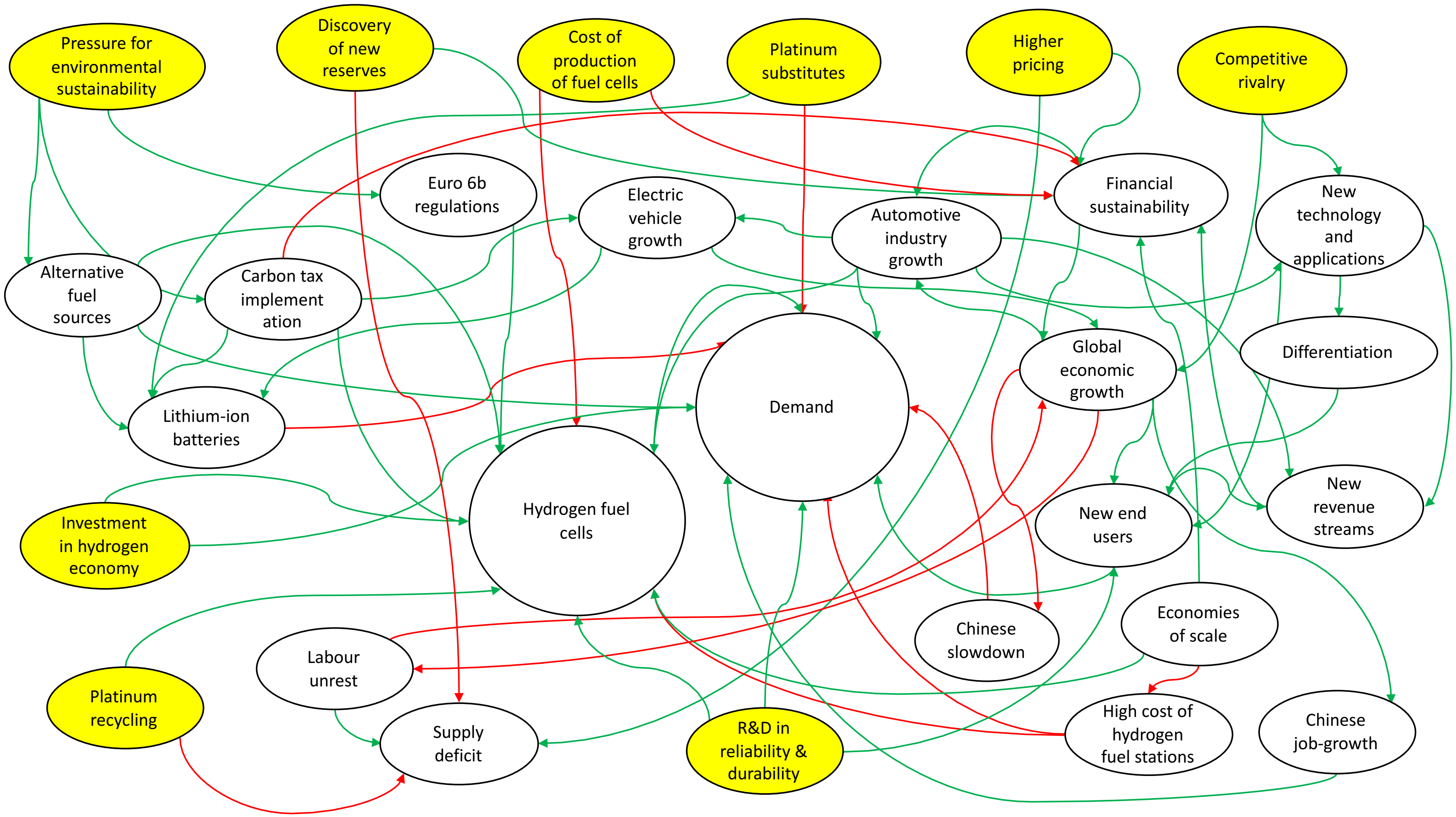


Figure 9: Draft Fuzzy Cognitive Map

Table 4: Table of causal relationships and links between nodes for draft FCM

From (input/transmitter node)	To (normal/receiver node)	Positive relationship	Negative relationship
Alternative fuel sources	Hydrogen fuel cells	✓	
Alternative fuel sources	Lithium-ion batteries	✓	
Automotive industry growth	New technology and applications	✓	
Automotive industry growth	New revenue streams	✓	
Automotive industry growth	Hydrogen fuel cells	✓	
Automotive industry growth	Demand	✓	
Automotive industry growth	Electric vehicle growth	✓	
Carbon tax implementation	Hydrogen fuel cells	✓	
Carbon tax implementation	Financial sustainability		✓
Carbon tax implementation	Lithium-ion batteries	✓	
Carbon tax implementation	Electric vehicle growth	✓	
Chinese job-growth	Demand	✓	
Chinese slowdown	Demand		✓
Competitive rivalry	New technology and applications	✓	
Competitive rivalry	Global economic growth	✓	
Cost of production of fuel cells	Hydrogen fuel cells		✓
Cost of production of fuel cells	Financial sustainability		✓
Differentiation	New end users	✓	
Discovery of new reserves	Financial sustainability	✓	
Discovery of new reserves	Supply deficit		✓
Economies of scale	Hydrogen fuel cells	✓	
Economies of scale	Financial sustainability	✓	
Economies of scale	High cost of hydrogen fuel stations		✓
Electric vehicle growth	Lithium-ion batteries	✓	
Euro 6b regulations	Hydrogen fuel cells	✓	
Financial sustainability	Automotive industry growth	✓	
Financial sustainability	Global economic growth	✓	
Global economic growth	New end users	✓	
Global economic growth	Automotive industry growth	✓	
Global economic growth	Labour unrest		✓
Global economic growth	Chinese job-growth	✓	
Global economic growth	Chinese slowdown		✓
High cost of hydrogen fuel stations	Hydrogen fuel cells		✓
High cost of hydrogen fuel stations	Demand		✓
Higher pricing	Financial sustainability	✓	
Hydrogen fuel cells	Demand	✓	
Investment in hydrogen economy	Hydrogen fuel cells	✓	

From (input/transmitter node)	To (normal/receiver node)	Positive relationship	Negative relationship
Investment in hydrogen economy	Demand	✓	
Labour unrest	Supply deficit	✓	
Lithium-ion batteries	Demand		✓
New end users	New revenue streams	✓	
New end users	Demand	✓	
New revenue streams	Financial sustainability	✓	
New technology and applications	New revenue streams	✓	
New technology and applications	New end users	✓	
New technology and applications	Differentiation	✓	
Platinum recycling	Hydrogen fuel cells	✓	
Platinum recycling	Supply deficit		✓
Platinum substitutes	Lithium-ion batteries	✓	
Platinum substitutes	Demand		✓
Pressure for environmental sustainability	Carbon tax implementation	✓	
Pressure for environmental sustainability	Euro 6b regulations	✓	
R&D in reliability and durability	New end users	✓	
R&D in reliability and durability	Hydrogen fuel cells	✓	
R&D in reliability and durability	Demand	✓	

3.4 Population and sample

3.4.1 *Population*

The population from which the sample is derived were those individuals who are considered to be experts in the platinum industry and who are able to assess the draft FCM for accuracy and exhaustiveness.

3.4.2 *Sample and sampling method*

The population used was specifically selected based on their industry expertise and hence, authority, in order to evaluate the draft FCM that was given to them.

Table 5 is a list of the profiles of five industry experts that were approached to assist in this study in order to evaluate and scrutinise the draft FCM that was given to them.

Table 5: Profile of respondents (experts)

Position of expert
Head of Commercial at major platinum firm
Former Lead Researcher for a consulting firm for Mining and Metals Practice
Mining, energy and natural resources specialist at major platinum firm
Senior researcher on sustainable development at a parastatal
Mineral economist at a parastatal

3.5 Procedure for data collection

The draft FCM in this proposal was constructed from literature and industry knowledge that has been reviewed. This was then sent to industry experts, who had specifically been chosen for their industry knowledge, to validate the FCM.

The linkage between new technology and the demand for platinum has not been extensively researched, and thus expert opinion is required to validate the FCM.

The draft FCM was personally delivered to three respondents and two respondents were dealt with over 'Skype' interviews. An explanation of what a FCM was and what was expected of the respondent was given. The respondents were informed verbally that their names would be kept confidential. Respondents were asked to comment on whether they agree or disagree with the causal linkages presented in the draft FCM, and whether or not there were any nodes, concept, inputs or pertinent factors that they felt were excluded from the FCM.

3.6 Data analysis and interpretation

Once the refined and validated FCMs were received from the experts and consolidated, the FCM was ready for simulation analysis.

The final FCM was used to test various scenarios and the impact that these scenarios have on platinum demand. These scenarios were compared to the literature to test whether they made sense or not.

3.7 Limitations of the study

- The study depended on the accuracy of the expert opinions and their ability to correctly judge the information presented in the FCM.
- The experts chosen could be based on incorrect assumptions of their ability.
- The outcome from the simulation exercise could be incorrectly interpreted, thus skewing the results.
- Since not all factors that may impact the demand of platinum are considered in this study, there could be important causal linkages that are excluded unintentionally.

3.8 Validity and reliability

Reliability and validity of this research ensured that the study is trustworthy and that appropriate procedures have been followed so as to, as far as is possible, avoid incorrect results.

> "Reliability and validity are ways of demonstrating and communicating the rigour of research processes and the trustworthiness of research findings."
>
> (Roberts, Priest, & Traynor, 2006, p. 41).

Bryman (2001) and Roberts et al. (2006) posit that firstly, reliability depicts how the research methodology and tools, can be replicated and if it will produce similar results in a separate study, under the same conditions. Secondly, validity measures the disparity or closeness of what the study measures versus what it intends to measure.

External validity measures whether the findings from the research can be applied to other research and be replicated, whereas internal validity addresses the reasons for the outcomes (Roberts et al., 2006). Roberts et al. (2006) mentions three approaches to assessing internal validity; these are content, criterion-related and construct validity.

This research strove to ensure validity by ensuring that the email or cover letter that describes a FCM, was clear to respondents and as simple as possible so that they were able to assess the draft FCM in a standardised way.

To ensure reliability as far as is possible, a simple test FCM was constructed (the draft FCM) with known outcomes, to ascertain that the correct results were obtained.

Two test scenarios were conducted to ensure reliability and validity of the FCM using the adjacency matrix in Appendix A. Test scenarios were conducted by activating only one input node at a time in isolation in the adjacency matrix to ensure that the results made sense in relation to the literature review and expected results.

The first scenario was to switch on the ‘discovery of new reserves’ node. The results showed – as expected from the literature review – that new technology and applications, new revenue streams, new end users, hydrogen fuel cells, financial sustainability, global economic growth and platinum demand would increase. It also showed that the supply deficit would increase. This made sense as the discovery of new platinum reserves would result in an increase in platinum utilising good, such as fuel cells, thus increasing revenues generated from platinum and would also decrease the supply deficit.

The second scenario was to switch on the ‘research and development in reliability and durability’ node. The results – also as expected – showed that new technology and applications, new revenue streams and end users, product differentiation, platinum demand and financial sustainability would increase.

This made sense as increased investment in R&D would result in new technologies being developed and the possibility of product differentiation, thus increasing financial sustainability and demand for platinum.

The use of these two scenarios demonstrates the reliability of the results from the FCM.

3.9 Ethical considerations and unintended consequences

- There are no procedural ethical issues with this research.
- Informed consent was obtained verbally from the respondents (experts) and their confidentiality but not anonymity (from the researcher), was guaranteed.
- As the respondents remain anonymous to the audience of this research, there is no conflict of interest on their part.
- The researcher has no affiliation with and has never worked in the platinum or related industries, thus no conflict of interest arises from this avenue.
- An unintended consequence of this research could potentially be the basing of managerial decisions on the findings that ultimately turn out to be erroneous.

CHAPTER 4. RESULTS

4.1 Introduction

The draft FCM was largely supported by the experts (respondents) interviewed with some criticisms regarding relationships and omissions. This chapter provides a description of the results from the interviews relating to each hypothesis and at the conclusion of the chapter, provides a refined and final FCM that was built based on the expert opinions of respondents (see Figure 10). The descriptions under each hypothesis are derived from opinions of experts centred around the original draft FCM (see Figure 9).

4.2 Results pertaining to proposition 1

Respondents agreed that the growth in automotive demand is likely to increase the need for fuel cells in the long term. Based on existing technology with lithium-ion batteries, respondents agree that this is unlikely to have a significant impact as a scalable substitute for platinum in the automotive sector in the foreseeable future. With platinum being such a significant part of the cleaning of fuels with its use as an autocatalyst, the experts agree that it will be required as a part of the ‘green economy’ as an important element of reducing carbon emissions. The rise of new platinum substitutes would decrease the demand for platinum. However, respondents agree that in the short term, this is unlikely.

Respondents recommended that the node ‘higher pricing’ be replaced with ‘financial markets’ – the broader definition is more applicable as markets are not only concerned with pricing. The need for good financial markets leads to the need for financial sustainability, which leads to the growth of the automotive industry. The growth in the automotive industry will result in the growth of both existing vehicles as well as electric vehicles, which will inadvertently result in increased demand for lithium-ion batteries. However, lithium-ion batteries can currently not compete with existing combustion engines due to the scale and battery life that would be required for the technology to be considered worthwhile for widespread use. Respondents agree that platinum fuel cells are likely to grow, but add that it would also depend on how sustainably hydrogen can be produced, transported, stored, and distributed. Similarly, the node 'pressure for environmental sustainability', increases the associated environmental regulations such as carbon tax, which both decrease financial sustainability as well as increase the need for alternate fuel sources. The resulting need for improved financial sustainability as well as new fuel sources, increases the need for fuel-cells, which then increases platinum demand.

4.3 Results pertaining to proposition 2

Respondents agreed that improved cost and process efficiencies in platinum recycling would increase the environmental and financial sustainability of the platinum industry as well as contribute to the promotion of the so-called hydrogen economy. The experts state that it is important to differentiate between primary and secondary supplies of platinum on the FCM.

Recycling (secondary supply) will increase the platinum available (decrease the primary supply deficit) for use in fuel cells and other applications of platinum. They also stated that platinum recycling is not an 'input node' on the FCM as whether or not platinum recycling is attractive, is driven by the state of financial markets (if platinum is lucrative, there will be increased recycling and vice versa).

Cost effective recycling practices will lead to more profitable platinum available which can be utilised in the manufacturing of fuel cells, which in turn, eventually stimulate the growth of the hydrogen economy. The general consensus among the respondents was that new discoveries of platinum are likely and that with continuous research and development, means to cost-effectively mine platinum without serious threats to the environment or the mine-workers, are possible. Discovery of new reserves leads to a decrease in the primary supply deficit and leaves more platinum available for use in fuel cells and future technological advances. This would then increase financial sustainability.

4.4 Results pertaining to proposition 3

Respondents agreed that durability and reliability of platinum fuel cells are essential to increase its demand. They further agree that manufacturing costs have to decrease. Without these factors (improved durability and reliability, and decreased cost of production) in place, there is no possibility of large-scale commercial realisation of fuel cell technology.

The experts recommended that the input node ‘research and development in reliability and durability’ be subdivided. Research and development can be conducted into all aspects of the industry (in the uses of platinum as a whole) and not solely for the improvement of reliability and durability. The experts stated that the input node ‘research and development’ would lead to increased ‘reliability and durability’, ‘economies of scale’ and reduced ‘cost of production of fuel-cells’. Hence ‘cost of production of fuel cells’ is no longer an input node.

Thus, increased research and development eventually leads to increased need for platinum fuel cells, and thus platinum demand. This will lead to increased investment in the hydrogen economy as manufacturing costs decrease and reliability and durability of the fuel cells increase. Research and development will also lead to new technologies and/or applications for platinum and thus new users. Consequently, respondents recommended that these two nodes be combined.

New technologies and applications also result from competitive rivalry. This stems from the needs of the financial markets, therefore the node ‘competitive rivalry’ is no longer an input node, but linked to the node ‘financial markets’. The new technologies and applications will likely then result in differentiated uses of and for platinum, also as a result of the increased competitive rivalry.

The experts recommended that jewellery be included in the FCM as it is a driver of the platinum industry, specifically within China, as the country, together with India, is the primary consumer of platinum in the jewellery industry. Jewellery accounts for the second largest use of platinum after the automobile industry. As such, the node ‘Chinese slowdown’ results in a decrease in ‘platinum jewellery demand', which then has an overall effect of decreasing the demand for platinum. Respondents also argued that it is not necessarily global economic growth that impacts the Chinese economy, but the Chinese economy that impacts global economic growth. The general consensus was that each of these nodes impacts the other and thus the arrow will go both ways. They also recommended that the node 'Chinese job-growth' be removed as it is purely the equal and opposite effect of the node 'Chinese slowdown' and therefore redundant.

4.5 The final FCM

Using the above results obtained from the interviews with respondents, the following improved/final FCM was constructed. The input nodes are highlighted in yellow. The green lines show an increase in the receiving node as a result of the transmitting node and the red lines show a decrease in the receiving node as a result of the transmitting node. Table 6, after the final FCM, shows the causal relationships between the input and output nodes and whether these relationships are positive or negative (marked with a tick).

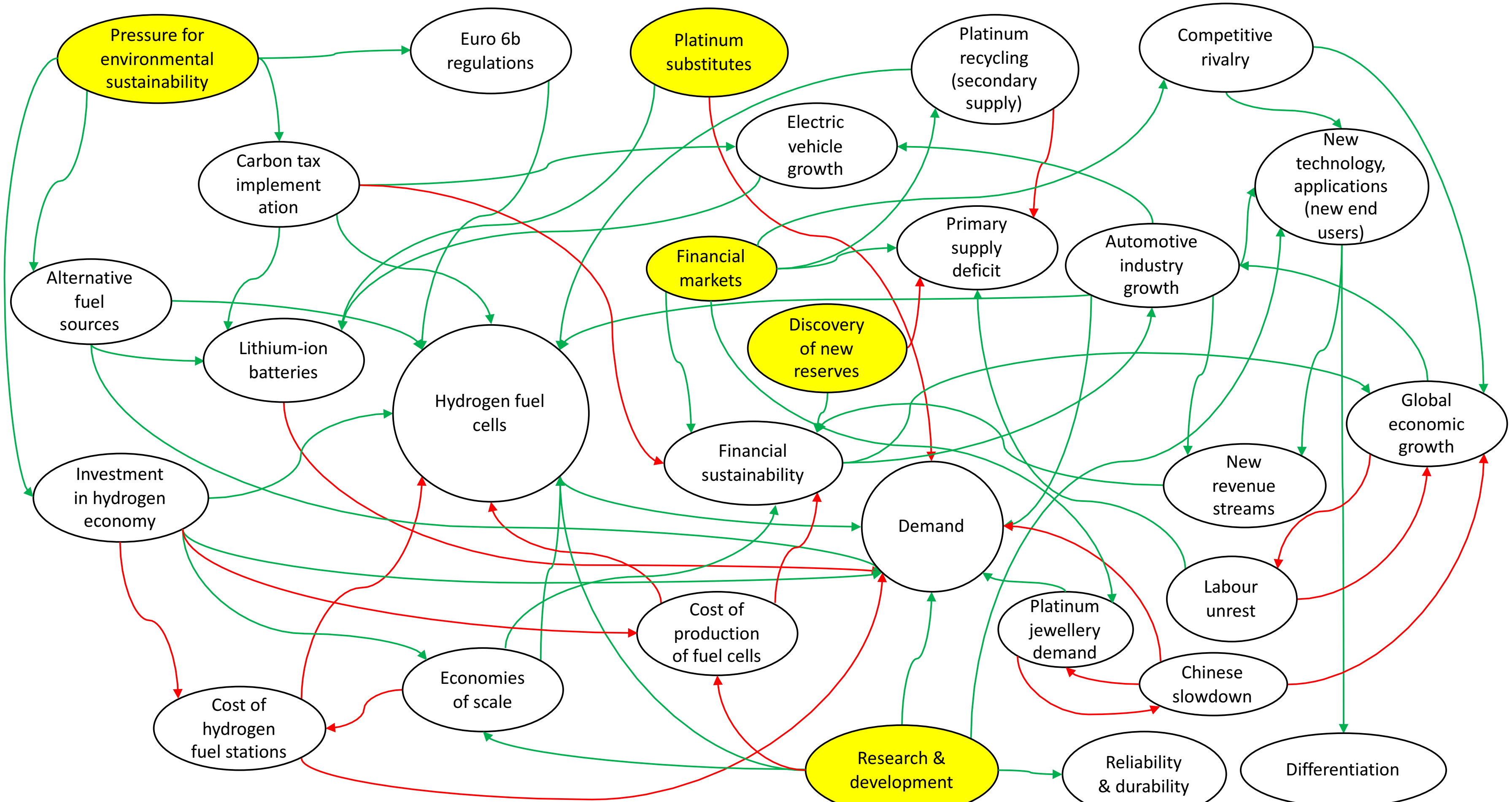


Figure 10: Final Fuzzy Cognitive Map

Table 6: Table of causal relationships and links between nodes for final FCM

From (input/transmitter node)	To (normal/receiver node)	Positive relationship	Negative relationship
Alternative fuel sources	Hydrogen fuel cells	✓	
Alternative fuel sources	Lithium-ion batteries	✓	
Alternative fuel sources	Demand	✓	
Automotive industry growth	New technology and applications (new end users)	✓	
Automotive industry growth	New revenue streams	✓	
Automotive industry growth	Hydrogen fuel cells	✓	
Automotive industry growth	Demand	✓	
Automotive industry growth	Electric vehicle growth	✓	
Carbon tax implementation	Hydrogen fuel cells	✓	
Carbon tax implementation	Financial sustainability		✓
Carbon tax implementation	Lithium-ion batteries	✓	
Carbon tax implementation	Electric vehicle growth	✓	
Chinese slowdown	Demand		✓
Chinese slowdown	Global economic growth		✓
Chinese slowdown	Platinum jewellery demand		✓
Competitive rivalry	New technology and applications (new end users)	✓	
Competitive rivalry	Global economic growth	✓	
Cost of hydrogen fuel stations	Hydrogen fuel cells		✓
Cost of hydrogen fuel stations	Demand		✓
Cost of production of fuel cells	Hydrogen fuel cells		✓
Cost of production of fuel cells	Financial sustainability		✓
Discovery of new reserves	Financial sustainability	✓	
Discovery of new reserves	Primary supply deficit		✓
Economies of scale	Hydrogen fuel cells	✓	
Economies of scale	Financial sustainability	✓	
Economies of scale	Cost of hydrogen fuel stations		✓
Electric vehicle growth	Lithium-ion batteries	✓	
Euro 6b regulations	Hydrogen fuel cells	✓	
Financial markets (higher platinum price)	Financial sustainability	✓	
Financial markets (higher platinum price)	Primary supply deficit	✓	
Financial markets (higher platinum price)	Platinum recycling (secondary supply)	✓	
Financial markets (higher platinum price)	Competitive rivalry	✓	
Financial markets (higher platinum price)	Platinum jewellery demand	✓	
Financial sustainability	Automotive industry growth	✓	
Financial sustainability	Global economic growth	✓	
Global economic growth	Automotive industry growth	✓	

From (input/transmitter node)	To (normal/receiver node)	Positive relationship	Negative relationship
Global economic growth	Labour unrest		✓
Hydrogen fuel cells	Demand	✓	
Investment in hydrogen economy	Hydrogen fuel cells	✓	
Investment in hydrogen economy	Demand	✓	
Investment in hydrogen economy	Cost of hydrogen fuel stations		✓
Investment in hydrogen economy	Economies of scale	✓	
Investment in hydrogen economy	Cost of production of fuel cells		✓
Labour unrest	Primary supply deficit	✓	
Labour unrest	Global economic growth		✓
Lithium-ion batteries	Demand		✓
New revenue streams	Financial sustainability	✓	
New technology and applications (new end users)	New revenue streams	✓	
New technology and applications (new end users)	Differentiation	✓	
Platinum jewellery demand	Demand	✓	
Platinum jewellery demand	Chinese slowdown		✓
Platinum recycling (secondary supply)	Hydrogen fuel cells	✓	
Platinum recycling (secondary supply)	Primary supply deficit		✓
Platinum substitutes	Lithium-ion batteries	✓	
Platinum substitutes	Demand		✓
Pressure for environmental sustainability	Carbon tax implementation	✓	
Pressure for environmental sustainability	Euro 6b regulations	✓	
Pressure for environmental sustainability	Alternative fuel sources	✓	
Pressure for environmental sustainability	Investment in hydrogen economy	✓	
R&D	New technology and applications (new end users)	✓	
R&D	Hydrogen fuel cells	✓	
R&D	Demand	✓	
R&D	Economies of scale	✓	
R&D	Cost of production of fuel cells		✓
R&D	Reliability & durability	✓	

CHAPTER 5. FCM INTERPRETATION

5.1 Introduction

This chapter includes ten scenarios as modelled by the data (adjacency matrix) that formulated the final FCM. This FCM measures the impact that both strategic responses and potentially uncontrollable elements within the platinum industry, will have on the demand for platinum. Some of the different 'input nodes' (as determined by researcher and experts) are 'switched on' to measure the directional impact (positive or negative) that the node has on the FCM. However, since nothing happens in isolation in a system, credible combinations of events are modelled.

The researcher has selected these combinations in correspondence with the expert respondents and hence findings are open to interpretation as it is based on the knowledge of the experts chosen and the assessments of the researcher. The different scenarios are graphically represented as charts in the appendices.

As the relationships between the nodes in a system are not simple or straight forward, the usefulness of such a model can potentially be found in those results that were unexpected or not previously considered. Stakeholders in the platinum industry may be able to utilise this FCM to consider the potential consequences of strategic choices made and what additional steps may be taken to obtain favourable results.

The results of the scenarios modelled are discussed below.

5.2 'Discovery of new reserves' only

When the node 'discovery of new reserves' is switched on in isolation (see Appendix B), half of the receiver nodes are activated (i.e. less than or greater than zero).

Discovery of new reserves would allow for increased opportunity for the development of new technologies and applications of the metal, thus generating new sources of revenue and hence increased financial sustainability. This would also increase the platinum available for use in platinum fuel cells, which would result in growth of the automotive industry. To ensure a sufficient supply of fuel-cells and to maintain a hydrogen economy, a constant source of platinum is required from mining (Yang, 2009). A growth in the automotive industry would contribute to higher global economic growth. These factors would result in an increase in the demand for platinum.

Discovery of new reserves would logically also decrease the primary supply deficit. There is currently only a depth of 2km being mined and there is likely more platinum at greater depths (Sverdrup & Ragnarsdottir, 2016). Glaister and Mudd (2010) also state that platinum availability will be substantial and it is not the sustainability of the platinum resource that is a problem, but rather the environmental impact of the mining process.

As it is generally unrelated, discovery of new reserves would have limited impact on the nodes related to manufacturing costs, economies of scales or environmental regulations.

5.3 'Research and development' only

When the node 'research and development' is activated in isolation (see Appendix C), the majority of the receiver nodes are activated.

Based on this research, research and development (R&D) can be seen as one of the most important factors in the environmental and financial sustainability of the platinum industry. Increased investment in R&D impacts multiple different areas of the platinum industry. The costs of setting up hydrogen fuel stations is sizeable (Wang, 2015). R&D will likely result in a reduction of costs associated with both hydrogen fuel stations and the manufacturing of the fuel cells, by achieving economies of scale (Hyman, 2015). The current problem with the widespread adoption of fuel cells is the lack of reliability and durability, the high price and a sustainable source of hydrogen (Ryan, 2014; Sun et al., 2011).

Costs of fuel cells can decrease with the development of new technology (Sun et al., 2011). Investment in R&D will thus improve the reliability and durability of platinum fuel cells. This will increase the demand for and scaled use of fuel cells in vehicles thus increasing growth of the automotive industry and encouraging global economic growth. With the growth of the automotive industry in general, associated growth of electric vehicles and lithium-ion batteries can be expected, particularly since R&D into improvements of lithium-ion batteries is also being conducted (Breytenbach, 2016).

Platinum buyers are price-sensitive and the metal is undifferentiated, thus differentiation will be necessary for long term economic stability and viability (Van den Berg, 2008). R&D results in the discovery of new technologies and applications of platinum, which encourages differentiation. The use of platinum fuel cells could provide an essential new revenue stream for platinum mining companies (Hyman, 2015). New technologies and applications result in new revenue streams, consequently increasing financial sustainability.

5.4 'Pressure for environmental sustainability' only

When the node 'pressure for environmental sustainability' is activated in isolation (see Appendix D), almost half of the receiver nodes are activated.

Increased pressure for environmental sustainability results in more stringent environmental regulations, which effectively increase carbon taxes. South Africa has a substantial carbon footprint, partly due to the country's extensive mining practices and carbon tax implementation is imminent (Ryan, 2014). This also results in an increased need for alternate fuel sources. Alternate fuel sources can arise from both an increase in lithium-ion batteries and hence electric vehicles, as well as an increase in the use of hydrogen utilising fuel cells as an alternative to oil in internal combustion engines.

An increase in the need for lithium-ion batteries, electric vehicles and platinum fuel cells would result in automobile industry growth as well as increased platinum demand from increased use of fuel cells. The increased use of fuel cells would have to be preceded by a decrease in manufacturing and associated costs, and an increase in reliability and durability of the fuel cells. Similarly, for lithium ion batteries to be scalable, it would also require improved longevity. This is currently not viable for large scale use as lithium-ion batteries are unable to provide energy for long periods of time (Hull, 2015). Pressure for environmental sustainability is likely to encourage an investment in the hydrogen economy to enable more efficient and cost-effective use of hydrogen fuel cells and the related costs, such as that of setting up hydrogen fuel stations.

5.5 'Platinum substitutes' only

When the node 'platinum substitutes' is switched on in isolation (see Appendix E), only two nodes in this FCM are activated.

Platinum substitutes would encourage R&D in substitutes such as lithium-ion batteries. This would then decrease the demand for platinum. Platinum substitutes can arise from either chance events or government regulations (enforced) (Van den Berg, 2008). If lithium-ion batteries are first to market, the demand for platinum would be under threat. There is R&D being conducted into lithium-ion batteries (Breytenbach, 2016) however, lithium-ion batteries are not as efficient as internal combustion engines and would not be able to go for long distances on a single charge, unlike hydrogen powered fuel-cells (Hull, 2015; Sverdrup, 2016). These batteries are not expected to threaten platinum in the immediate future.

5.6 'Pressure for environmental sustainability' and 'platinum substitutes' only

When the node 'pressure for environmental sustainability' and 'platinum substitutes' are switched on together (see Appendix F), just under half of the receiver nodes are activated.

The pressure for environmental sustainability causes a need for alternative fuel sources and this leads to an increase in lithium-ion batteries as well as hydrogen fuel cells as these are both alternates. Increased need for hydrogen fuel cells increases demand for platinum. However, substitutes for platinum would decrease demand. However, in this scenario, the pressure for environmental sustainability outweighs the impact of the substitute-effect and there is a net increase in demand for platinum. Higher environmental sustainability pressure also leads to more stringent regulations, such as carbon tax, which decreases financial stability of platinum.

However, the net increase in demand and increased use of fuel cells will increase the financial sustainability of platinum. The result is net zero. Hence, the financial sustainability node is unaffected in this scenario. This would differ if one of the factors were to be stronger than the other, but is outside scope of this research. For the success of hydrogen fuel cells, as in scenario 5.4 above, the pressure for environmental sustainability would encourage investment in the hydrogen economy such that cost-effective, efficient use of hydrogen fuel cells can be achieved.

5.7 'Pressure for environmental sustainability' and 'research and development' only

When the nodes 'pressure for environmental sustainability' and 'research and development' are switched on together (see Appendix G), almost all the receiver nodes are activated.

This combination has a very positive outlook for platinum demand. As the pressure for environmental sustainability increases, the environmental regulations become more stringent which affect financial sustainability as carbon taxes grow. Needs for alternative fuel sources – lithium-ion batteries and hydrogen fuel cells – as well as investment in the hydrogen economy, rise. This, together with R&D and the economies of scale achieved, decreases costs of fuel cells and hydrogen fuel stations, and increases reliability and durability of the fuel cells. New uses and applications of platinum are developed from the R&D, resulting in product differentiation and new revenue streams from platinum, thus increasing financial sustainability. The impact is growth in the automobile industry as a whole (including electric vehicles), global economic growth and high demand for platinum. R&D efforts need to be conducted into increased efficiencies as 32% of platinum mined is lost annually, thus reducing long-term conservation efforts (Sverdrup & Ragnarsdottir, 2016).

5.8 'Financial markets' and 'research and development' only

When the nodes 'financial markets' and 'research and development' are switched on together (see Appendix H), three quarters of the receiver nodes are activated.

When the price is high, there is increased incentive to both mine and recycle platinum (Sverdrup & Ragnarsdottir, 2016). Positive financial markets (higher platinum prices) result in increased recycling due to the increased value, with higher investments in hydrogen fuel cells and the hydrogen economy. This, together with the R&D, decreases associated costs of platinum fuel cell production. If there is a rise in the hydrogen economy, demand for platinum will outstrip supply, thus increasing the price (Yang, 2009).

This is a positive scenario for platinum demand as there is improved financial stability and decreased costs of fuel cell manufacturing from economies of scale which further increases demand for platinum. The automotive industry will grow (including electric vehicles and lithium-ion batteries) leading to global economic growth. Global economic growth is predicted to be strong enough to drive platinum demand and a bullish price forecast can be expected (Brush, 2016; Jollie, 2016).

The resultant increases in product differentiation and competitive rivalry that arise from R&D, will further provide new revenue streams from the new applications of, and new technologies for, platinum. Management ideologies possessed by firms will force competitive advantages as rivals are forced to find better and more cost efficient manners in which to conduct business, and for rivals to compete, they must find innovative ways to cut costs and develop new technologies (Van den Berg, 2008).

5.9 'Discovery of new reserves' and 'research and development' only

When the nodes 'discovery of new reserves' and 'research and development' are switched on together (see Appendix I), two thirds of the receiver nodes are activated.

As with the previous two scenarios, R&D into the platinum industry results in decreased costs of fuel-cell production and increased durability and reliability of these fuel cells. It also enables economies of scale which further reduce costs. New technologies and applications arise from the R&D providing new revenue sources and higher competitive rivalry resulting in product differentiation.

The new revenue sources and new users increase financial sustainability of the platinum industry. The financial sustainability is further increased with the new platinum reserves discovered as the continuity of supply of the raw material is ensured. However, environmental implications of platinum mining must still be considered.

5.10 'Pressure for environmental sustainability' and 'financial markets' only

When the nodes 'pressure for environmental sustainability' and 'financial markets' are switched on together (see Appendix J), most of the receiver nodes are activated.

The impact of these two nodes in combination is very similar to that of 'research and development'. Both financial markets and environmental sustainability lead to recycling practices. Recycling from financial markets (higher pricing and profitability) comes from the higher value of platinum. When platinum is lucrative, increased investment in the hydrogen economy will occur as platinum fuel cell demand will increase and hence an increase in platinum demand (Sverdrup & Ragnarsdottir, 2016).

The pressure for environmental sustainability further leads to increased demand for hydrogen fuel cells, as it can be used as an alternative fuel source to reduce carbon emissions. Investment in the hydrogen economy, like R&D, results in economies of scale being achieved which then decreases costs associated with hydrogen fuel stations and platinum fuel cell manufacturing. When platinum is seen as lucrative to financial markets, there may be an increase in the supply deficit as more platinum is mined, however this is countered by the increase in recycling. These investments in the environment and in platinum may result in new technologies and hence new users, for the platinum industry. The resultant growth in the automobile industry increases global economic growth. The overall outlook for platinum demand is positive in this scenario.

CHAPTER 6. CONCLUSION & RECOMMENDATIONS

6.1 Introduction

This final chapter highlights the most prominent findings from the research that utilised the FCM that was constructed and refined in conjunction with platinum industry experts. It attempts to provide guidance to platinum industry stakeholders by utilising the map to address certain events that may arise in the platinum sector.

6.2 Conclusions of the study

Respondents surveyed in this research paper all agree that the future of the platinum industry looks bright and that 'doom and gloom' for the industry is not imminent. A bullish outlook can be taken for the platinum price, and research and development into new technologies and applications for platinum as well as differentiation will provide new revenue streams. I

Additionally, research and development into the discovery of more efficient, durable, reliable and cost effective ways of manufacturing and utilising platinum fuel cells, will make them commercially viable and scalable. A boom in the platinum industry will be followed by a boost for the South African economy as the country is the most affected by changes in the platinum mining industry.

Caution must be taken with regard to issues on sustainability, as any mining of non-renewable resources is, as a given, not sustainable. However, the paradox lies in that for a reduction in carbon emissions that result from internal combustion engines and other technologies that utilise fossil fuels, platinum is a necessity.

Hydrogen fuel cells do not require fossil fuels to function and hydrogen can be obtained via water electrolysis through sustainable energy sources such as wind or water energy. For as long as people inhabit the earth and profitability is a requirement across industries that utilise metals and other non-renewable resources, it is inevitable that there will be carbon emissions and associated negative impacts such as climate change. However, the imperative is to shrink these to an absolute minimum, and this can only be achieved through investment in research and development into sustainable mining practices, recycling, cost reductions and improved efficiencies.

The primary conclusion from this research is the reiteration of the extreme importance of research and development into the platinum sector and mining as a whole. This will result in increased revenue sources for mining companies through the discovery of new uses for platinum, cost reductions and improved efficiencies, as well as the most environmentally sustainable way in which it is possible to conduct business.

For financial sustainability, the platinum sector must remain ahead of the competition who has invested in the development and improvement of platinum substitutes.

6.3 Recommendations

The future of the platinum industry is optimistic, but to remain that way, mining companies must invest in the industry's future through significant research and development for both financial and environmental sustainability, to achieve a favourable triple bottle line. This research and development is necessary to increase and sustain platinum demand. Differentiation in platinum is tied to new product uses or applications that can only be found through research and development.

Investment is required into improved recycling practices throughout the recycling chain. If mining companies do not take this on, someone else will. Research and development must be conducted into improved means of producing (water electrolysis), transporting, storing and distributing hydrogen as a fuel in order to promote the hydrogen economy. Due to the capital-intensive nature of this investment, mining companies can benefit from collaborative efforts in achieving a shared benefit.

While lithium-ion batteries and other substitutes may not be an immediate threat, an eye needs to be kept on them as it is essential, in the ever-changing marketplace, to innovate faster than both competitors and other industries, in order to remain profitable and financially viable.

It is advisable that research and development into more effective and sustainable mining practices be conducted prior to deeper excavation or the search for new platinum-rich geographies so as not to recreate existing financially and environmentally unsustainable practices.

6.4 Suggestions for further research

The South African economy is highly dependent on mining, however, beneficiation of the metals is not significantly carried out in the country, thus research can be conducted on how to make this a reality and thereby grow the South African economy.

This research showed negative and positive causal relationships between different nodes, however, there would be more insight in providing weightings for these arrows to show which nodes have greater impact than others. This would improve stakeholder decision making as the most important nodes can be prioritised.

Platinum substitutes have not been extensively researched in this paper and thus the opportunity exists to research further on all substitutes from platinum (and not only lithium-ion batteries), both within the Platinum Group Metals as well as in other industries.

While this paper places extreme emphasis on the imperative for research and development, it does not go into detail on how this research and development could be carried out. Thus, more research into implementation and method for research and development can be conducted. This could give further insight in how platinum could possibly be differentiated as well as what practices could allow for efficient recycling of platinum.

Other threats to the industry can be researched besides substitutes.

The impact of other commodities on platinum, such as oil, can be delved into, in order to understand in detail, the impact that this has on the platinum industry.

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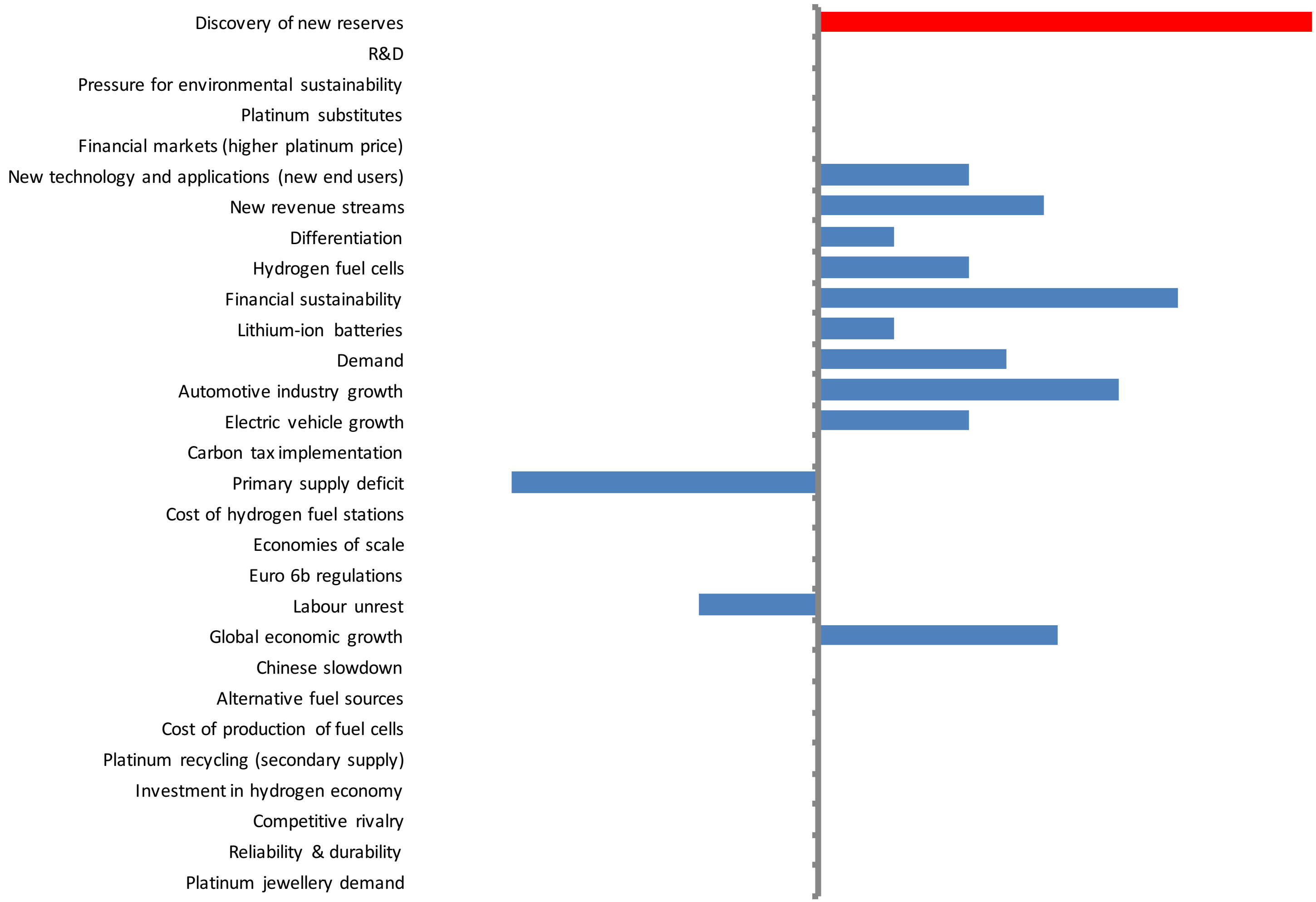
APPENDICES

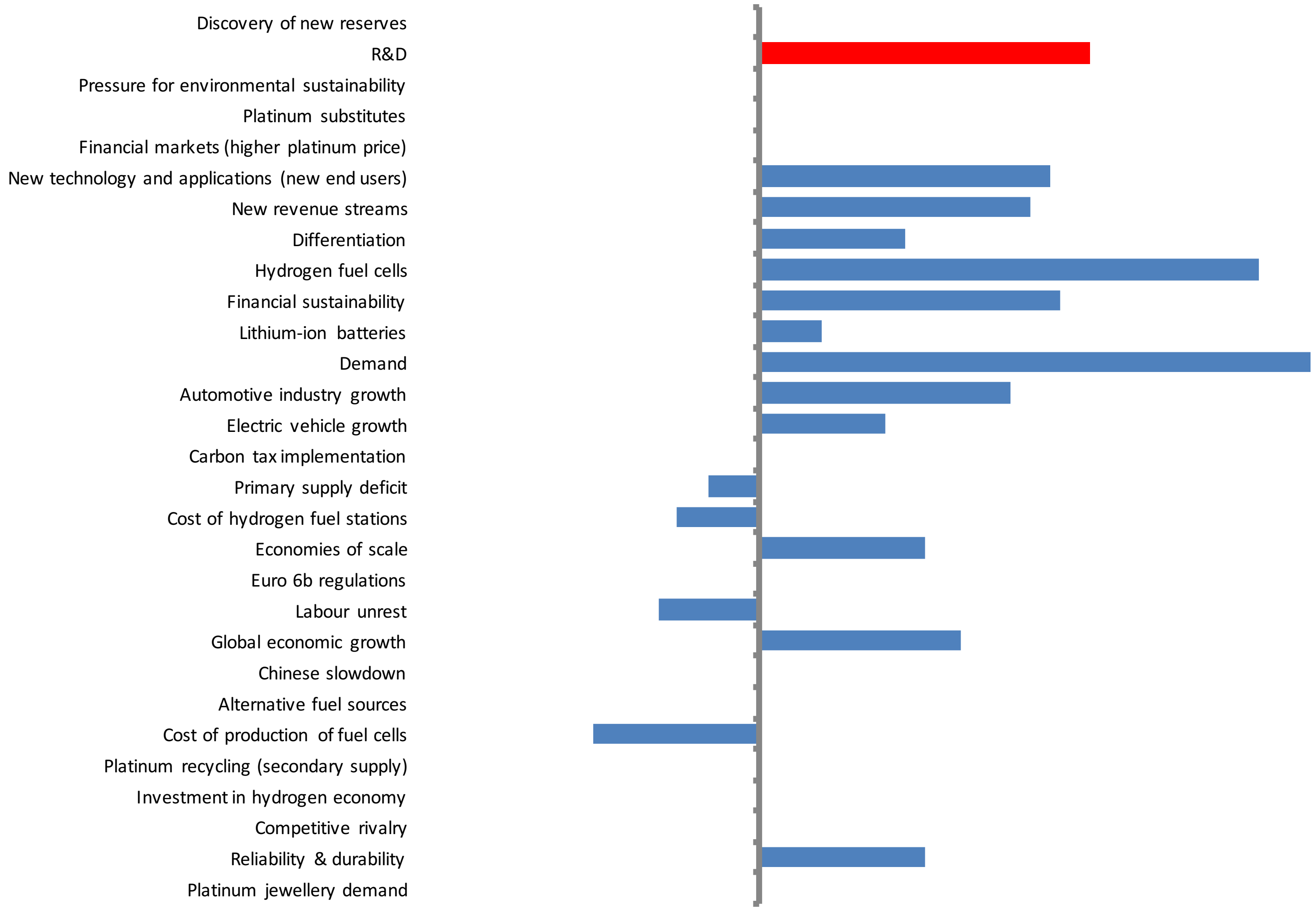
Appendix A: Adjacency matrix for FCM scenario modelling

Adjacency Matrix	Discovery of new reserves	R&D in reliability and durability	Investment in hydrogen economy	Platinum recycling	Cost of production of fuel cells	Pressure for environmental sustainability	Platinum substitutes	Higher pricing	Competitive rivalry	New technology and applications	New revenue streams	New end users	Differentiation	Hydrogen fuel cells	Financial sustainability	Lithium-ion batteries	Demand	Automotive industry growth	Electric vehicle growth	Carbon tax implementation	Supply deficit	High cost of hydrogen fuel stations	Economies of scale	Euro 6b regulations	Low cost alternatives to hydrogen	Labour unrest	Global economic growth	Chinese job-growth	Chinese slowdown	Alternative fuel sources
Discovery of new reserves															1						-1									
R&D in reliabilty and durability												1		1			1													
Investment in hydrogen economy														1			1													
Platinum recycling														1							-1									
Cost of production of fuel cells					Transmitter nodes									-1	-1															
Pressure for environmental sustainability																				1				1						1
Platinum substitutes																1	-1													
Higher pricing															1															
Competitive rivalry										1																	1			
New technology and applications											1	1	1																	
New revenue streams															1															
New end users											1						1													
Differentiation												1																		
Hydrogen fuel cells																	1													
Financial sustainability																		1									1			
Lithium-ion batteries																	-1													
Demand																														
Automotive industry growth										1	1			1			1		1											
Electric vehicle growth																1														
Carbon tax implementation					Normal and Receiver Nodes									1	-1	1			1											
Supply deficit																														
High cost of hydrogen fuel stations														-1			-1													
Economies of scale														1	1							-1								
Euro 6b regulations														1																
Low cost alternatives to hydrogen																														
Labour unrest																					1									
Global economic growth												1						1								-1		1	-1	
Chinese job-growth																	1													
Chinese slowdown																	-1													
Alternative fuel sources														1		1														

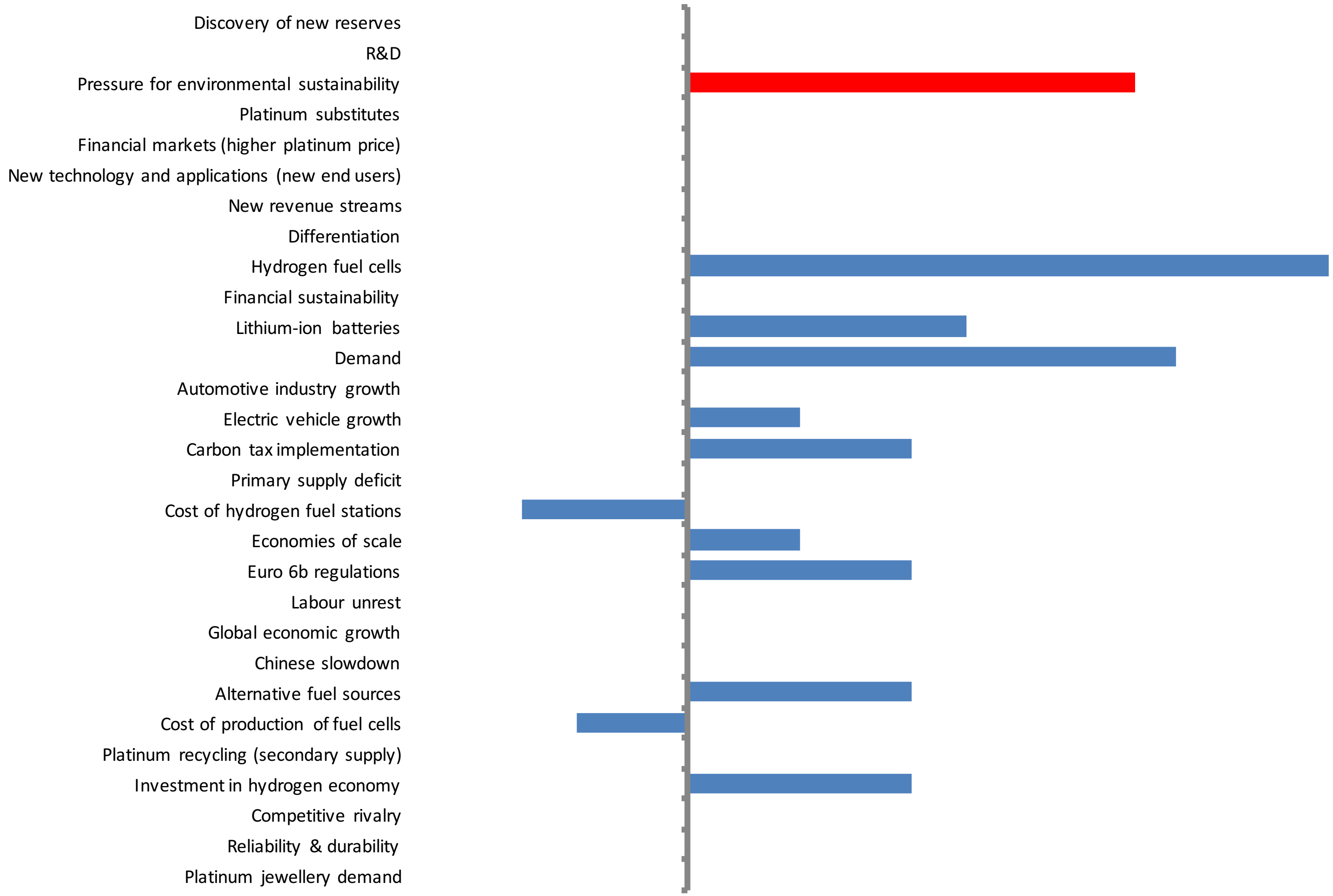
Appendix B: 'Discovery of new reserves' only



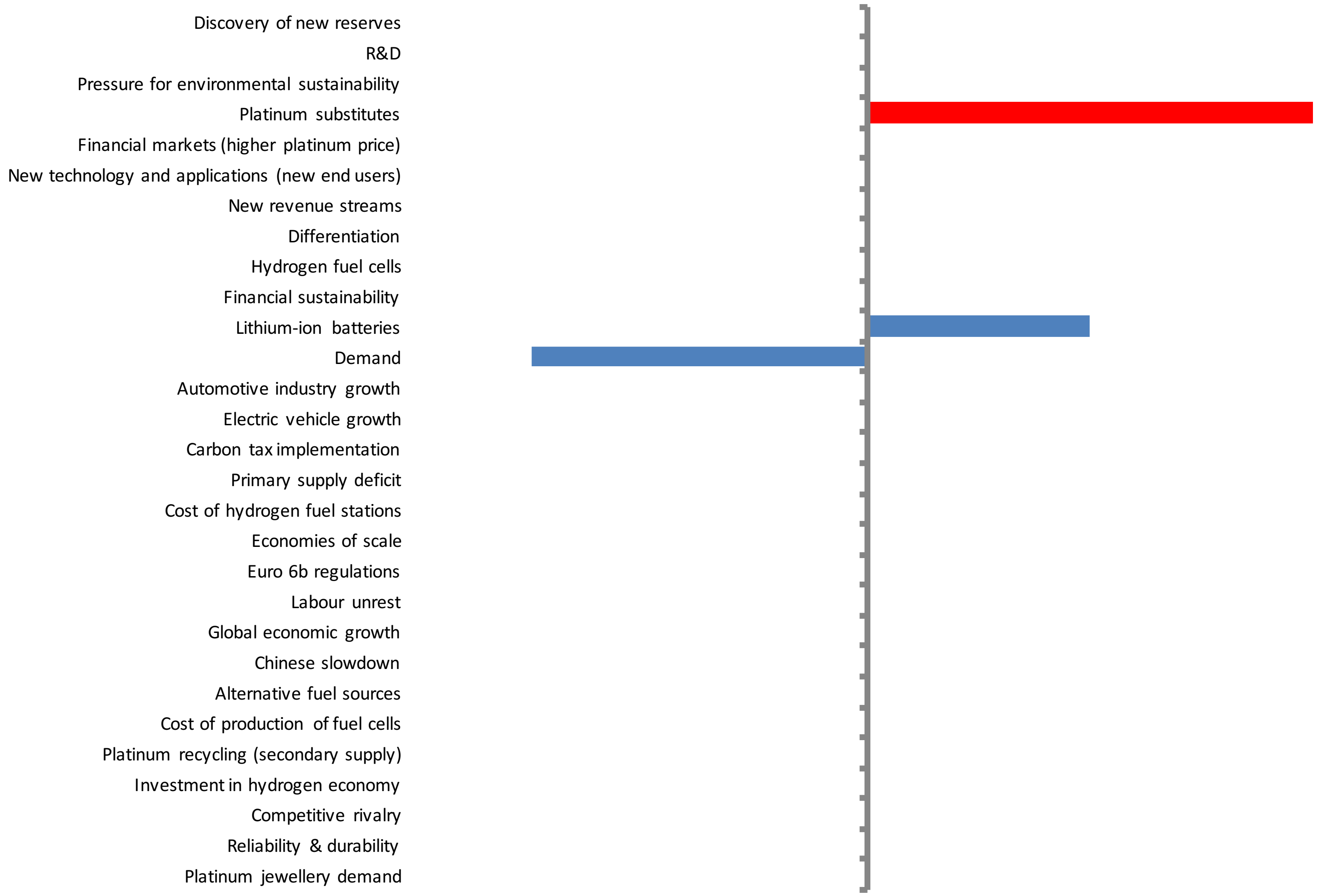
Appendix C: 'Research and development' only



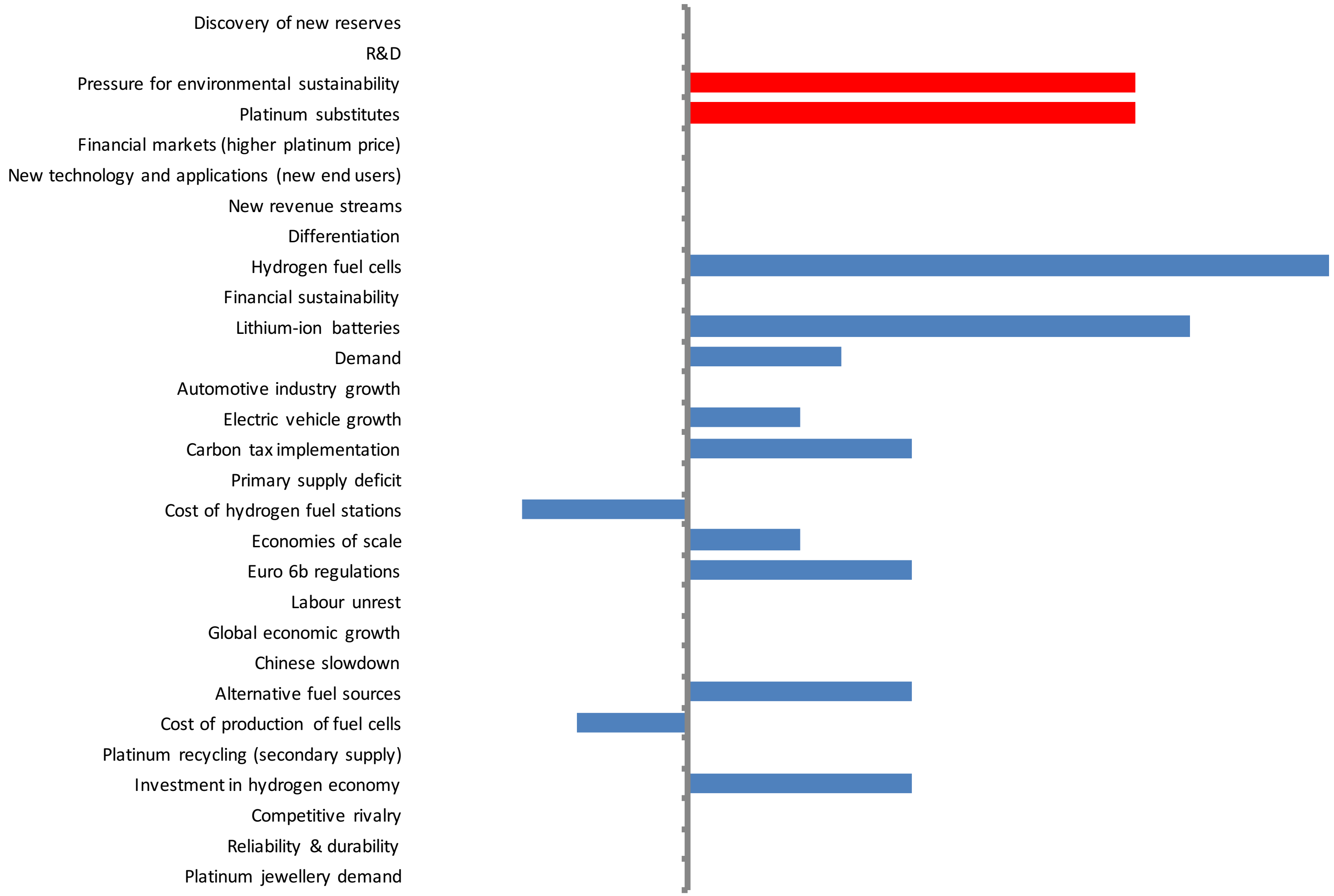
Appendix D: 'Pressure for environmental sustainability' only



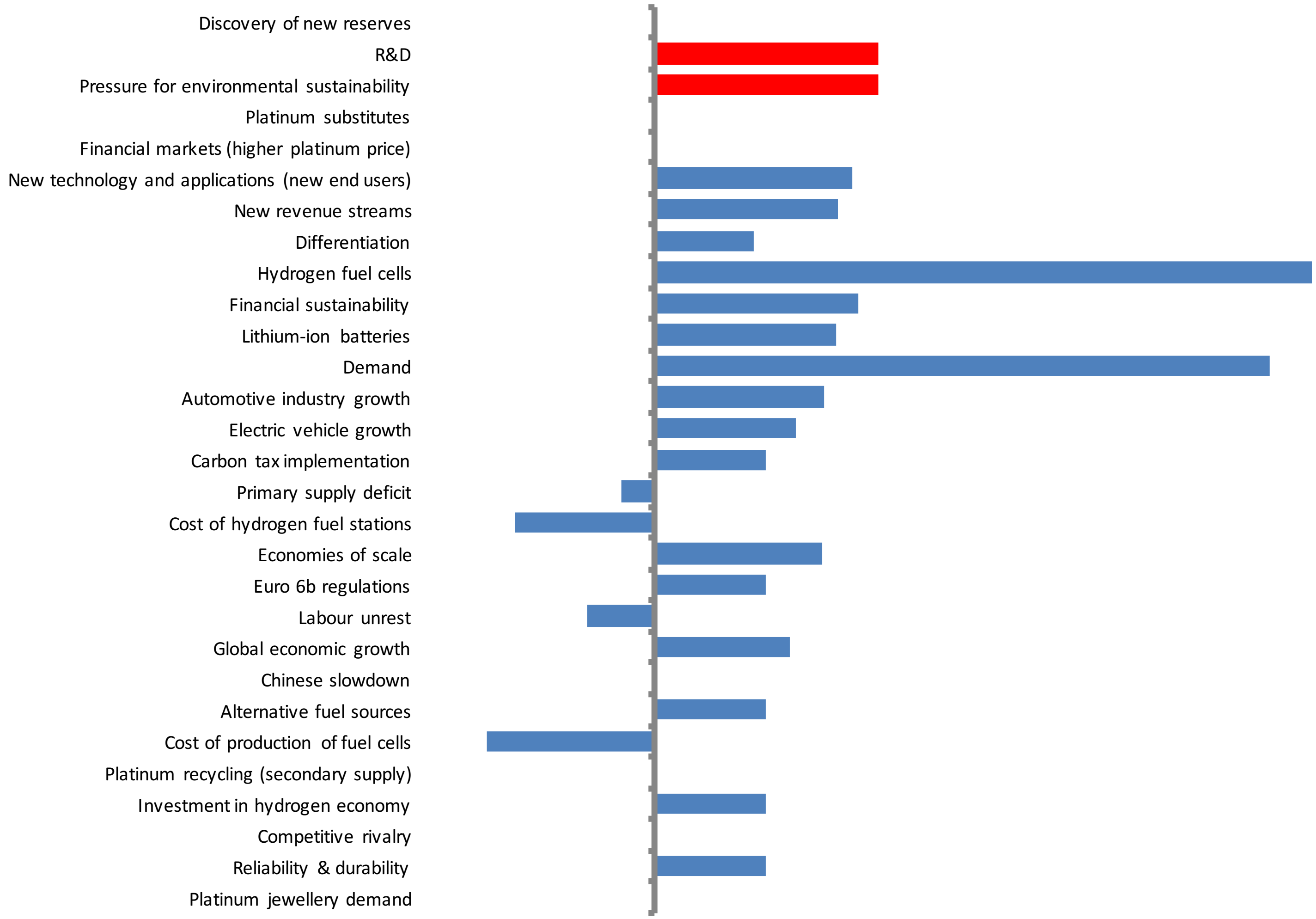
Appendix E: 'Platinum substitutes' only



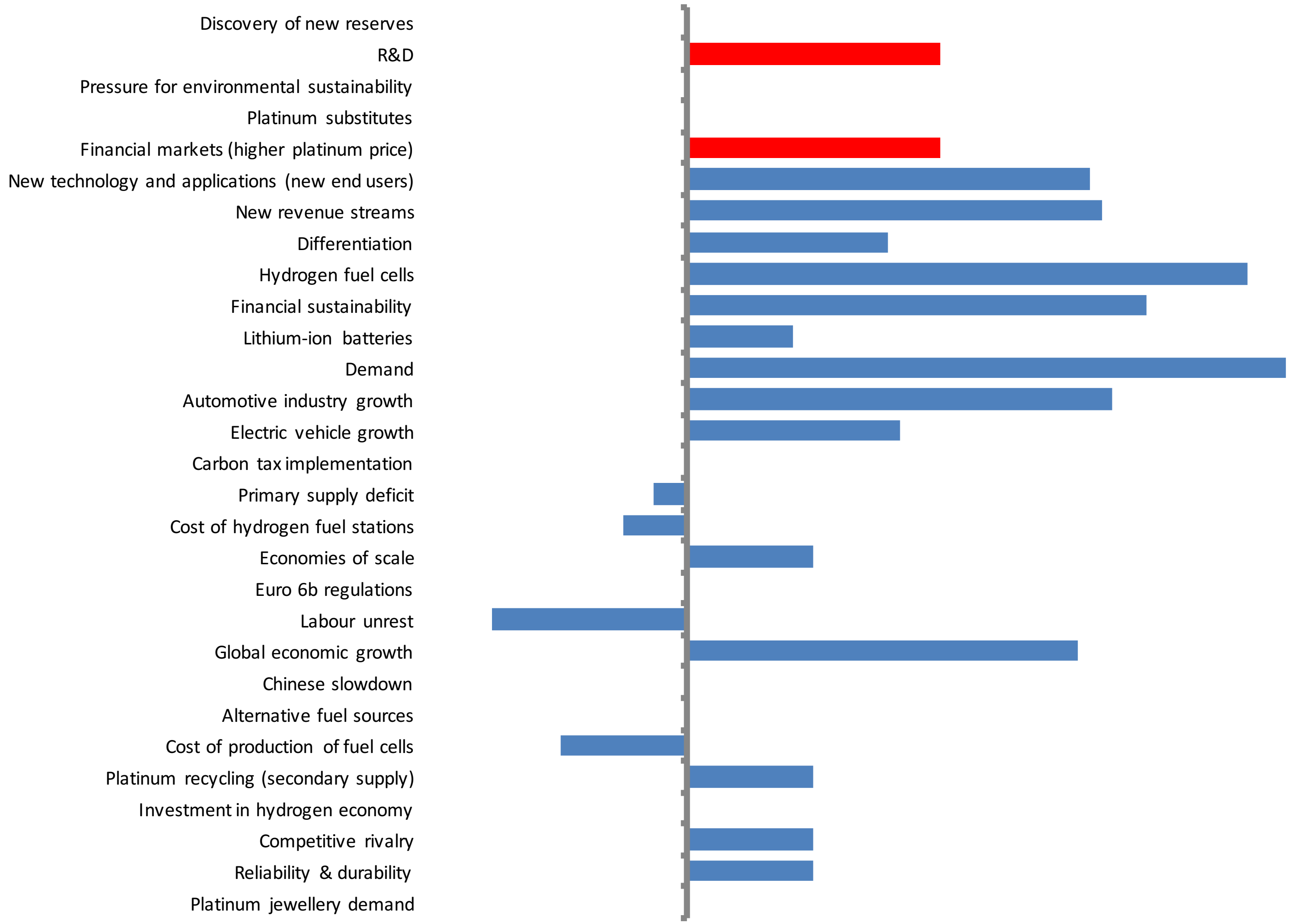
Appendix F: ‘Pressure for environmental sustainability & ‘platinum substitutes’ only



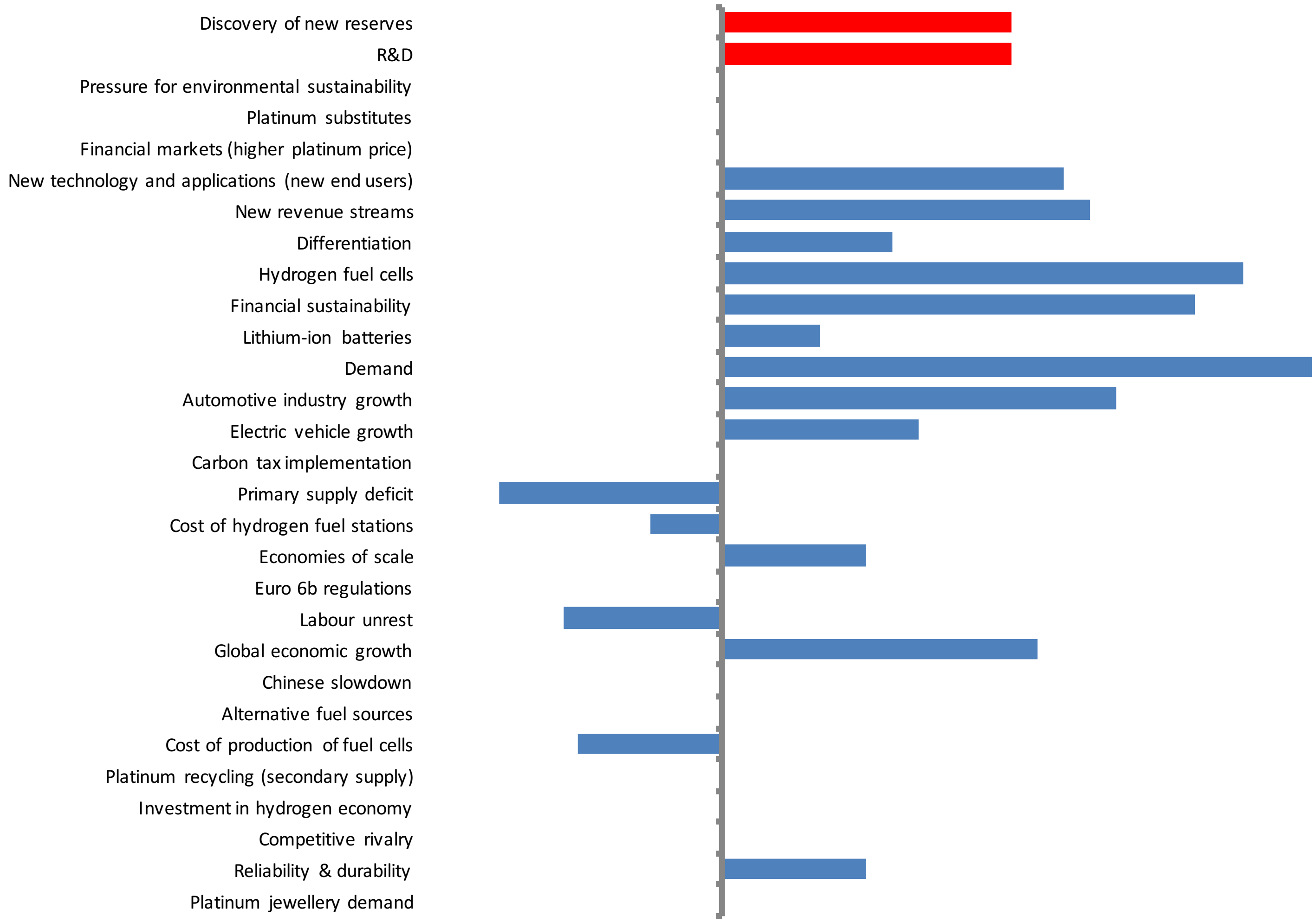
Appendix G: 'Pressure for environmental sustainability' & 'research & development' only



Appendix H: 'Financial markets' & 'research and development' only



Appendix I: ‘Discovery of new reserves’ & ‘research & development’ only



Appendix J: 'Pressure for environmental sustainability' & 'financial markets' only