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Abbreviations

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<tr>
<td>BiH</td>
<td>Bosnia and Herzegovina</td>
</tr>
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<td>BRIC</td>
<td>countries - grouping acronym that refers to Brazil, Russia, India and China</td>
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<td>CF</td>
<td>Cash Flow</td>
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<td>CRM</td>
<td>Critical Raw Material</td>
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<td>DTM</td>
<td>Digital Terrain Model</td>
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<td>EAC</td>
<td>Equivalent Annual Costs</td>
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<td>EIA</td>
<td>Environmental Impact Assessment</td>
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<td>EIP-RM</td>
<td>European Innovation Partnership on Raw Materials</td>
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<td>EIT</td>
<td>European Institute for Innovation and Technology</td>
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<td>ERA</td>
<td>European Research Area</td>
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<td>ERC</td>
<td>European Research Council</td>
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<td>ETP SMR</td>
<td>European Technology Platform for Sustainable Mineral Resources</td>
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<tr>
<td>HHI</td>
<td>Herfindahl-Hirschmann Index</td>
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<td>IRR</td>
<td>Internal Rate of Return</td>
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<td>KIC</td>
<td>Knowledge and Innovation Community</td>
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<td>Acronym</td>
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<td>KIC-RM</td>
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<td>NMP</td>
<td>Marine Management Organisation</td>
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<td>NGO</td>
<td>Non-Governmental Organisation</td>
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<td>NPV</td>
<td>Net Present Value</td>
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<td>RMI</td>
<td>Raw Materials Initiative</td>
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<td>ROI</td>
<td>Return On Investment</td>
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<td>SIP</td>
<td>Strategic Implementation Plan</td>
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<td>SLO</td>
<td>Social License to Operate</td>
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1 Executive Summary

¡VAMOS! aspires to enable the provision of a sustainable, stable and competitive supply of raw materials for Europe by increasing the production of raw materials within the EU with the help of a breakthrough underwater mining system.

Deliverable 6.1 focuses on exploring the macro and micro economic and feasibility aspects of the ¡VAMOS! technology. At the same time, the economic and feasibility factors and numbers of the ¡VAMOS! technology are compared with the ones of conventional mining in order to give proper comparison opportunities. This deliverable contains models and tools developed to monetarise the macro and microeconomic feasibility of the ¡VAMOS! Innovations, as applied to the Vares site, including projections on an EU and a global level.

To build the ¡VAMOS! macro-economic models variables such as 1) Impact of natural resources extraction on macro-economic volatility, 2) impact of mining operations on the development of other sectors and 3) impact of existing policies on appropriate allocation in society of the revenues from this sector were considered. On the other hand, to develop the micro-economic comparisons, the costs of mine operation using ¡VAMOS! technology was compared to conventional open-pit mining techniques.

The modelling of the impacts of the mineral resource extraction sector on macroeconomy is not easy. It is specific for each country, dependent on its government, policy, mineral abundance and economic diversification. Creating a global model is impossible, while national models can be developed similarly to AUS-M, TRYM, ORANI, GTAP and G-Cubed models (Downes et al., 2014).

Influence of commodity prices on macroeconomy and its volatility is connected to resource cycles which are driven by supply-demand balance. Ineffective supply will boost the price of commodities which will be translated as higher revenues from existing mines and higher investments in exploration, but will also negatively influence some manufacturing sectors.

It is shown through the different analysis done that the greatest savings of the ¡VAMOS! technology when compared to conventional open-pit mining techniques can be found in personnel costs, followed by blasting and equipment costs. ¡VAMOS! technology also reduces the open mining area, minimizing dumps and giving an advantage when aiming for a EIA or Social License to Operate.

A global sensitivity analysis shows that the ¡VAMOS! technology seems to be more robust against changes in input parameters than its conventional counterpart. This would give the ¡VAMOS! technology an advantage in volatile market situations. This is in line with what was identified in respect of the macroeconomic considerations.
2 Introduction

2.1 The ¡VAMOS! Project

Estimates indicate that the value of unexploited European mineral resources at a depth of 500-1,000 meters is ca €100 billion, however, a number of physical, economic, social, environmental and human constraints have as yet limited their exploitation. ¡VAMOS! will provide a new safe, clean and low visibility mining technique and will prove its economic viability for extracting currently unreachable mineral deposits, thus encouraging investment and helping to put the EU back on a level playing field in terms of access to strategically important minerals. Deriving from successful deep-sea mining techniques, the ¡VAMOS! mining solution aspires to lead to: re-opening abandoned mines; extensions of opencut mines which are limited by stripping ratio, hydrological or geotechnical problems; and opening of new mines in the EU. ¡VAMOS! will design and manufacture innovative automated excavation equipment and environmental impact monitoring tools that were tested in two mine sites across Europe with a range of rock hardness and pit morphology. ¡VAMOS! has:

1. Developed a prototype underwater, remotely controlled, mining machine with associated launch and recovery equipment
2. Enhanced currently available underwater sensing, spatial awareness, navigational and positioning technology
3. Provided an integrated solution for efficient Real-time Monitoring of Environmental Impact
4. Conducted field trials with the prototype equipment in abandoned and inactive mine sites with a range of rock types and at a range of submerged depths
5. Evaluated the productivity and cost of operation to enable mine-ability and economic reassessment of the EU's mineral resources.
6. Maximized impact and enable the Market Up-Take of the proposed solutions by defining and overcoming the practicalities of the concept, proving the operational feasibility and the economic viability.
7. Contributed to the social acceptance of the new extraction technique via public demonstrations in EU regions.

2.2 Deliverable D6.1 Macro and microeconomic feasibility

2.2.1 Objectives

The goal of this deliverable is to showcase the ¡VAMOS! technology mining potential when compared to conventional mining methods and to test for its macro-economic impact. The work developed includes both macroeconomic impact analysis and microeconomic feasibility considerations of the technology. This deliverable develops the necessary models and tools to discuss macro and microeconomic feasibility of the ¡VAMOS! innovations as applied in representative mine sites, including projections on an EU and a global level.
2.2.2 Approach

In order to deliver a high-quality report, partners agreed on a common approach and action plan, which were approved by the WP leader.

The first challenge faced was to indicate critical macroeconomic factors driving the global mining industry. Extensive literature search and review was conducted in order to select the most important ones. After that stage the most relevant factors were assessed by their impacts on global mineral’s macroeconomic environment, and by their relevance to the ¡VAMOS! project. Special emphasis was put on looking out for the specific cases of interactions between mining industry and countries or global macroeconomic environments, to pinpoint relevant causes and effects on macroeconomic environments. This was needed in order to assess impacts of the global macroeconomic situation to the micro economy of the ¡VAMOS! approach in mining.

For a lot of abandoned mines in Europe there is no digital data available. Therefore, it was necessary to find proper exemplary datasets in order to create mine design models and a calculation template. Participants from other work packages were involved here (with permission of the project coordinator) to collect the data. This information was then used a) to create a digital model of the deposit and mining site used for mine planning and b) to calculate several financial profitability indicators for assessing a microeconomic impact.

Another challenge was to synchronize the approach and results with other work packages’ tasks, such as T 6.2. or T 5.6.

3 ¡VAMOS! Macroeconomic impact and microeconomic feasibility

3.1 Macroeconomic impact analysis

The macroeconomic feasibility of the ¡VAMOS! technology was studied while considering three main impact variables: a) impact of natural resources extraction on macroeconomic volatility, b) impact of mining operations on the development of other sectors and c) impact of existing policies on appropriate allocation in society of the revenues from the mining sector. The macro-economic analysis provides impact measuring models for all the studied variables.

3.1.1 Impact of natural resources extraction on macroeconomic volatility

3.1.1.1 What is macroeconomic volatility?

Volatility in economy is a statistical measure of the possible variation or movement in a particular economic variable or function of that variable, such as growth rate (Aizenman and Pinto, 2004). The key connotations of volatility are variability and uncertainty while it is considered as a complex and multidimensional phenomenon (Wolf, 2005; Cariolle, 2012). Volatility is usually measured using the
standard deviation of observed realizations of inspected variables over some historical period (Aizenman and Pinto, 2004).

Macroeconomic volatility can be measured by different arrays of macroeconomic variables. The most common macroeconomic variables are: gross domestic product, economic growth, inflation, exchange rate, interest rates, unemployment rate, money supply, among others. Most researchers agree that macroeconomic volatility has a negative impact on long-term economic growth and wellbeing, meaning that the greater the macroeconomic volatility, the lower is a country’s economic growth (Aizenman and Pinto, 2004; Cariolle, 2012).

The mineral resources sector has a complex impact on each of the macroeconomic variables; values of some variables will increase, while others will decrease. It needs to be acknowledged that the mineral extractive sector pushes most of the variables to the extremes (either positive or negative), increasing variations of the variables and thus increasing macroeconomic volatility.

3.1.1.2 Impact of mineral extraction on national macroeconomy

Exploration and/or extraction of mineral resources should, in principle, generate a great amount of fresh income and investment money into the country where the mining activities are developed and therefore accelerate its economic growth and welfare. However, past experiences generally prove otherwise. Many mineral rich countries and countries that experienced a quick mining boom on reached lower and more volatile economic growth in the longer term in comparison with mineral resource poor countries (Poelhekke and Ploeg, 2007; Jefferis, 2014). Booms in the mineral extraction sector or new discoveries of deposits often bring civil unrest, armed conflicts and corruption, each of them more a curse than a blessing for citizens of the country.

Main reasons for this contradiction are phenomena known as “Resource Curse” and “Dutch Disease”. The resource curse emerges when a country, rich in non-renewable mineral resources, focuses its economy solely on mineral extraction and neglects other sectors (e.g. manufacturing sector). Consequently, the country’s economy becomes overly dependent on commodity prices and their volatility, which is reflected in extreme volatility of gross domestic product (Frankel, 2010).

Additionally, the resource curse can advance into the Dutch Disease, where exports of mineral resources and major foreign investments significantly increase the influx of foreign currency into the country, causing greater demand for local currency and thus increasing in real exchange rate. Usually, this condition weakens other export-oriented sectors as they become less competitive on global markets.

National economy can be generally divided into three sectors. Two traded goods sectors with exogenously given world prices – first, the booming export sector (mineral resources) and second, the lagging export sector (manufacturing) and one nontraded goods sector such as construction, retail trade and services, which supplies domestic demand on internally determined pricing (Corden and Neary, 1982; Ebrahim-Zadeh, 2003). If the influx of foreign currency is converted into local currency and spent
on domestic nontraded goods, an appreciation of the real exchange rate will happen, independently of whether the exchange rate is fixed or flexible – it differs only in the mechanism.

In the case of fixed exchange rates, the country’s money supply is increased, which consequently rises domestic demand for goods and services, inflating their prices. A unit of foreign currency will therefore buy fewer goods than before. With flexible exchange rates, an increased inflow of foreign currency boosts the nominal exchange rate, which again means that a unit of foreign currency buys less than before (Ebrahim-Zadeh, 2003). More expensive exported goods cannot compete in a global market with other cheaper economies and the export sector of manufactured goods start shrinking. The second blow for export of the manufacturing sector is the shift of capital and labour force into the mineral resource sector and domestic nontraded goods sector to meet the increased demand (Frankel, 2010; Isakova et al., 2012).

A lagging manufacturing export sector weakens national economic growth and makes it more volatile. Decline of national export product competitiveness on global markets reflects itself on an increased rate of unemployment as more and more companies stop their production or move it elsewhere. The mineral extraction sector itself generates few jobs despite its capital insensitivity, so workers must be reassigned to the nontraded goods sector, which is again highly dependable on the mineral extraction sector. This transition, no matter how long or how successful, is very stressful for national economies, people, and can also hinder long-term growth potential as some manufacturing sectors and human capital development die off.

Countries that allow this scenario to develop, can suffer serious implications when the prices of mineral resources in the global market drop, as well as when the country runs out of high quality or easily/cheaply extractable mineral resources. There is no backup traded goods sector that could mitigate the consequences of such fluctuations for macro economy and national economic growth becomes extremely volatile and unstable. At this point, two major drivers that impact national macroeconomics’ volatility can be discerned – a volatility of commodity prices and national (macroeconomic) policy. The latter, later if wisely constructed and managed, can eliminate effects of the first, as well as it can transform mineral resources into genuine blessing and wealth (as seen in Australia, Norway and Botswana for instance).

Windfall revenues from the mineral resources extractive sector and the increased inflow of investments may encourage governments to spend in excess, increase rates of imports and spread the government sector and monumental projects with no or limited added value. These conditions can also be fertile territory for corruption spreading, autocratic regimes and, ultimately, can result in extreme forms, which are unfortunately not so rare, such as armed conflicts between different political factions. All the above mentioned factors can have a big negative impact on national economy and thus contribute to the increase in macroeconomic volatility.

3.1.1.3 Dealing with the macroeconomic impact of the mineral extraction sector

Strong government institutions, governance and transparent money flows are inevitable for a stable and steady growing national economy. Governments need to have a clear vision on how they will invest the
revenues from the mineral extraction sectors, how they will set monetary and fiscal policy to prevent appreciation of the exchange rate and how they will keep or improve economic diversification. The first step in preventing the negative effects of the Dutch Disease is to limit the inflow of foreign currencies into the country. Good instruments for doing this are stabilization funds established outside of the country, which can prevent short-term increase in spending, and establish reserves, which can keep the national economy stable during a crisis in the mineral sector. Similarly, funds can be established for future generations, providing money income after depletion of mineral resources (Jefferis, 2014). Such funds sufficiently mend the impact of commodity price volatility on national macro economy, despite the fact that they can crowd-out private sector investments (Basu et al., 2013).

![Figure 1: Economic growth and mineral abundance. It is clearly evident, that mineral rich countries have much lower growth in comparison to mineral poor countries (Sachs and Warner, 2001)](image)

Part of the revenues should be invested into the country, but outside the mineral sector. Doing this will keep the economy diversified and tradable goods’ sectors competitive on global markets. However, this can be a challenging task, as it is in some way, opposite to the processes triggered by mineral extraction. Development of other industrial or service’ branches is important to keep historically developed knowledge in the country, to keep unemployment rate low and, nevertheless, this can be crucial for national economy in the period of shocks in the mineral market and after the depletion of mineral resources, when a country can no longer hope for revenues from the mining sector (Poelhekke and Ploeg, 2007). Equally important, are investments into the educational system to encourage innovations which can help the country’s economy and improve equality between people. Unfortunately, mineral rich countries tend to be less innovative, with lower entrepreneurial activity, poorer government and lower growth (Figure 1) (Sachs and Warner, 2001).
3.1.1.4 Modelling the mineral extraction impact on national macroeconomy

Downes et al. (2014) tried to assess the effects of the mining boom on the mineral extraction intensive Australian economy. The most recent mining boom is one of the greatest shocks that hit the Australian economy in generations. Using the AUS-M model (large-scale structural model of the Australian economy), they figured out that the mining boom substantially increased Australian standards with 13% raise of household disposable income, 6% raise of real wages and 1.25% decrease in unemployment rate. The verified negative impact has been the appreciation of the Australian Dollar, which diminished the traded sector (a slight indication of Dutch Disease).

For the modelling Downes et al. (2014) used real data and at the same time tried to develop a scenario without a mining boom. The main factors chosen, to influence the Australian macroeconomy, were world industrial production (driving the demand of resources), commodity prices (inefficient supply of resources) and mining investments. With the decrease of these three factors’ scores, they achieved the expected condition of economy if there was no mining boom.

The main conclusion of the research is that a mining boom has a great positive effect on the economy, together with some minor effects of Dutch Disease.

However, the modelling of the impacts of the mineral resource extraction sector on macroeconomy is not easy. It is specific for each country, dependant on its government, policy, mineral abundance and economic diversification. Creating a global model is impossible, while national models can be developed similarly to AUS-M, TRYM, ORANI, GTAP and G-Cubed models (Downes et al., 2014).

3.1.1.5 Commodity prices and influence of their volatility on macroeconomy

Cyclicity of mining booms and busts and their intermediate fluctuations seem to have the most direct impact on macroeconomic volatility. However, a closer look into these fluctuations in the mineral extractive sector reveals that they are driven by numerous factors in the supply and demand loop. On the mineral supply side, affecting factors such as geological and technical problems in mines, labour strikes, mining costs, fuel prices, infrastructure and environmental issues, political instability and supply with scrap resources are relevant. The demand side is affected by global domestic products consumption, global industrial production and economic strength of key fast-growing economies such as China and India. Additionally, commodity prices are also affected by currency exchange rate and investment factors such as hedge and index funds (Figure 2) (Trench and Sykes, 2014). All of these supply-demand factors and investment factors are reflected in commodity prices and therefore we can assume that cyclicity in the mining sector can be described via commodity price volatility on the world market.

The above mentioned means that an upshift in prices can result in opening new greenfield mineral deposits, as can conversely downward shifts in prices reflect in closure of specific mines or entire mineral districts (Trench and Sykes, 2014). Understanding that commodity prices influence the macroeconomic impact of the mineral extraction sector on national economy and its volatility, they can then be used as one of the variables describing macroeconomic volatility.
Global commodity prices are a function of international demand for specific commodity and their available supply. An increase in demand will increase the commodity price and, on the long term, encourage investments to new mines or expansion of already existing ones, as it will result in new discoveries and technological development in an even longer time span (Maxwell, 2013). The opposite scenario is verified with a falling in demand and low commodity prices, that would shrink the mineral sector and force the high price producers to exit production.

Trench and Sykes (2014) divide the general cycle in the mining industry into four stages. The first stage is when the commodity price (and demand) is low and the profit margin across the cost curve is minimal. Lower cost producers have substantial advantage towards the uneconomic and near-margin producers causing more and more of the last, stopping their operation. It is often the case that companies involved in new projects’ development or mine expansions, experience rising costs at the same time as commodity prices are falling. That leads to a cost cutting and paves the road for “race to the bottom” as it was the case in 1990s. This is the start and ending point of each small or big scale cycle in the mining sector. An upturn in commodity prices due to increased demand in developing markets, adoption of new materials for other reasons and increased mining operational margins even for high cost producers, leads to the mining boom.

The second stage however, is not long lasting, as operating costs start to increase (extraction of lower grade ore, deeper ore deposits or mines in remote locations), particularly for higher cost producers. The operational margin therefore begins to thin. Such production supports high commodity prices which provide substantial revenues especially for low cost producers.

The third stage shifts to the fourth phase when high prices encourage new investments in low cost supply which eliminates near margin producers out of business, allowing prices to fall, or because substantial reduction in commodity demand with supply, fairly exceeding demand. Prices can also be reduced due to external reasons. An example is The Global Financial Crisis in 2008, when the financial market...
collapse generated the collapse of industrial production, sharply diminishing demand for mineral resources. Mineral producers were not able to cut costs as quickly as needed, and many of them soon become uneconomic, with tight cost margins also for low cost producers.

General mining cycles and commodity price volatility can therefore plainly generate substantial macroeconomic volatility. Quick escalation of commodity prices boosts new investment in the mineral extraction sector, multiplies the national tax revenues from the mineral sector, strengthens the sectors supporting those activities, but also induces the appreciation of exchange rate, increases the rate of unemployment and inflation and shrinks other production sectors. Conversely, a drop in prices, cuts off the incomes in very short time periods, stunts the national economy, especially in cases where governments do not pay enough attention to economic diversification and induce a steep fall in economic growth. Recent research showed that commodity price volatility has increased in recent years (Arezki et al., 2014), making national economies in mining intensive countries more prone to macroeconomic volatility and consequently to lower economic growth.

Hazards of the undesired economic impact of volatility can be decreased with more accurate and precise forecasting of commodity prices, which would be beneficial for both mining companies and national governments. Mining companies would be able to adjust their business plans and prevent loss of revenue or margin opportunities – commodity price is nowadays used as a critical metric for the ore reserve models (Trench and Sykes, 2014). Early reactions can smooth the painful consequences if commodity prices drop unexpectedly or can multiply the revenues if the right moment is cached at the rising prices. Accurate forecasts are difficult to obtain, as a financial disclaimer that “past performance is no indication of future performance” definitely apply (Canuto, 2014; Trench and Sykes, 2014). This has been proven in the gold industry when forecasts for gold prices in recent years have been regularly under forecasted, generating lower growth in gold mining as it could have been (Holland, 2012; Lassonde, 2012). Similarly, accurate forecasts would be useful for governments to prepare their economies for negative shocks as well as for increased economic growth.

3.1.1.6 Resource super cycles

The supply of mineral resources has an inelastic nature and is progressively less able to adjust to increased demand. New reserves are more challenging and expensive to assess, new ore bodies are explored and exploited in remote areas with insufficient infrastructure, more sophisticated or unconventional methods must be used for mineral extraction and projects are developed in more politically unstable areas. These factors can make the supply of mineral resources increasingly unresponsive to demand and even small changes in demand can result in significant changes in prices (Dobbs et al., 2013).

This incoherence in the demand-supply loop, forms cycles of different duration in the mineral sector. They are known business cycles with duration up to 8 years, intermediate cycles with duration between 8 and 20 years and mineral super cycles with duration between 20 and 70 years (Cuddington et al., 2015). All cycles have approximately the same course as was described above, with resource super cycles being a bit more mysterious than the other two.
Super cycles represent a prolonged trend rise driven by urbanization and industrialization of a major economy and are always demand driven – as a consequence of inelasticity of supply towards increased demand (Heap, 2005). In the past 150 years there have been two general resource super cycles; first at the turn of the 19th century to the 20th century, driven by economic growth in the USA, and the second between 1945 and 1975 as a result of post-war reconstruction of the European and Japanese economic renaissance. Most researchers agree that the third super cycle is in progress with its peak right now. The main reason for the most recent super cycle is the intensive economic growth seen in China since the millennium, connected to the demand for mineral resources (Heap, 2005; Cuddington et al., 2015).

Super cycles influence macroeconomic volatility over longer periods of time, and they produce commodity price maximums and minimums, which deviate greatly from the multiannual price average. Each commodity has its own super cycles, which are not necessarily connected with super cycles of other commodities. Crude oil has undergone three super cycles (Figure 3), while coal has already had 6 super cycles (Cuddington et al., 2015).

Price volatility can also be increased with abrupt changes in commodity prices. The World Economic Crisis in 2008 caused a substantial drop in mineral resource prices, which were near the peak of the super cycle. However, despite the serious consequences of the crisis on the global economy, commodity prices quickly recovered almost to the pre-crisis level (Canuto, 2014).
3.1.1.7 Flooding the market

Inability of supply towards commodity demand, especially during super cycles, can also cause other macroeconomic problems and increase economic volatility. Supply inelasticity keeps prices high for long periods, encouraging investment and development of new projects, especially marginal ones (McGugan, 2015). As fresh projects need the initial time to be pushed into production (minimum of 5 years), it can often happen that they start their operation right at the time when demand is in decline, or supply has already caught up with the demand on account of increased production in existing mines and new projects already in operation.

This floods the already saturated commodity market, causing a substantial drop in already declining commodity prices. A good example is the Roy Hill iron ore mining project in West Australia with an annual production capacity of 55 Mt, which is one of the world’s major iron ore projects. Project development, from first exploration activities in 1993 to the first excavated iron ore in 2014, lasted more than 20 years, with the project entering the market when it was already flooded with iron ore, causing an additional drop of iron ore prices (McGugan, 2014; Roy Hill official web site).

Second, a more speculative option is to flood the commodity market purposely, in most cases to crowd-out competitors or to weaken them and after that cheaply buy them or their projects. Actions like this can be done only by big players, the ones who cover most of the supply. But flooding the commodity market has global consequences and can have serious macroeconomic implications that can even generate an economic crisis. One of the recent examples of such strategy is the flooding of the iron ore market by BHP Billiton and Rio Tinto (which have most of the iron ore mines in Australia) in 2014 and 2015. Despite the abrupt fall in the iron ore price and general oversupply, they increased their production and put even more ore on the market (Els, 2015; Forrest, 2015).

This is especially important for the Australian economy as it is the lowest-cost iron ore producer with over 50% share of the world’s traded iron ore. For every $1 fall in price of iron ore, the Australian economy loses $800 million in foreign income and $300 million is lost for Federal budget. However, at that particular time prices did not fall just for $1, but for $60 in only six months (Forrest, 2015). The consequences were not only the loss of income, but also extensive lay off of workforce, with more than 10,000 lost jobs in the mining sector (Forrest, 2015).

If one combines such conditions with the staggering economic growth seen in China, the very strong US dollar (in which most of the commodities are traded) in comparison to other currencies and increase in the interest rate, a new economic crisis can rise (McGugan, 2014; Janda, 2015). Janda (2015) exposed the fact that macroeconomic volatility is at the highest level since the US sovereign debt crisis in 2011 and that many major players in the mineral business may have substantial problems with their existence due to their enormous debts. If they were not be able to pay back their creditors, a commodities crisis may quickly turn into a financial crisis with great impact on global macro economy.
3.1.2 Impact of ¡VAMOS! to macroeconomic volatility

Because numerically based assessment of the impact of specific factors on global economic volatility is within the scope, frame and budget of this deliverable, we can still qualitatively assess the impacts of the ¡VAMOS! concept to global volatility of commodity prices.

¡VAMOS! technology has the potential and capacity to decrease macroeconomic volatility in the short to long term. Despite many factors, as seen in the previous chapters, that can influence global commodity prices, one specific factor was identified to be crucial to assess ¡VAMOS! potential to influence global macroeconomic volatility in commodity prices: **time**.  

The time needed to make an abandoned mining site operational again.  

Other factors, mentioned in the previous chapters of this document, seem not to be as relevant as the aforementioned one.

¡VAMOS! main and key difference is that it can be deployed very quickly into existing open-pits, when compared to traditional mining in open-pits. The time between the project idea, and actual extraction, is drastically decreased. While for traditional mining operations at least 5 years are needed between ore discovery and actual ore extraction, the time for ¡VAMOS!, if legislative frameworks are favourable, can decrease to less than 6 months (estimation). As a proof for this statement we can say, that a decision not to conduct tests in Vareš was adopted in May 2018, and a new site (Silvermines) was selected in July 2018. Nevertheless, the ¡VAMOS! machinery was operational in the newly selected test site in October 2018. Only 4 months were needed to acquire all of the permits, to make appropriate site preparation, to assemble the mining system and to start extraction. However, these were only tests, which is far from commercial extraction. But with a favourable legislative framework, the ¡VAMOS! consortium believes that the time between the mining project idea and mining project implementation by using the ¡VAMOS! concept could be less than 6 months, which gives a huge advantage over the traditional open-pit mining concept. Since the ¡VAMOS! mining system can be quickly deployed when prices are high, and quickly dismantled when prices are low, it could help larger mining companies to harvest revenues during the time of high commodity prices, and to quickly adopt to changing economic situation.

In such a way, mining companies operating with ¡VAMOS! machines, could easily adopt to the price fluctuations on the global mineral market, without the need to spend several years before new mineral projects are operational. The drawback for ¡VAMOS! is that its production capacity is currently insignificant, when compared to the production capacity of conventional open-pits, so at this stage we cannot estimate how large the influence of ¡VAMOS! to the global volatility of commodity prices is. However, in the next 10-20 years, with the improvement of the underwater miner and other ¡VAMOS! components, with increased production and use of such machines, this can potentially change. Therefore, we can conclude, that the ¡VAMOS! mining solution has the promising potential to decrease global macroeconomic volatility –i.e. to decrease shorter term (1-5 years) fluctuations of raw material prices on global markets.
3.2 Models to calculate microeconomic feasibility

The microeconomic feasibility of the ¡VAMOS! technology was studied taking into consideration four key activities: a) scaling the relationships from the prototypes results, b) invitation to and selection of a representative sample of operating mines, c) collection of base details for these mines and, d) presentation of results to those mines’ representatives and the advisory board. The microeconomic feasibility analysis provides cost-calculation tools and investment comparison models for estimating submerged costs with variable deposit input parameters. A comparison between the ¡VAMOS! and conventional techniques was also assessed.

The evaluation of mineral properties could be as simple or sophisticated as the circumstances dictate (Gentry and O'Neil 1984). In the mining business the assessment of microeconomic feasibility is a case-by-case decision and strongly linked to local conditions of the mining site in focus. To assess the microeconomic feasibility of the ¡VAMOS! Technology, reliable cost and investment calculation methods are key.

The provided calculation model might be used as a template for the evaluation of other mining sites suitable for ¡VAMOS! technology. Possible sites for the use of ¡VAMOS! Technologies are:

- Open cast mines with operation below ground water level
- Open cast mines which were flooded; deeper areas can be mined by the ¡VAMOS! technology
- Diamond mining operation with Kimberlite Funnels (e.g. Diavik Diamond mine – see Figure 4 and Figure 5)
- Underwater resources in depths down to 200m in lakes or coastal shelf offshore
- Underwater construction work for trenching of cables/pipelines/etc and harbour construction

Figure 4: Diamond Mining at Diavik (Foto: Diavik Mining)
3.2.1 Cost-calculation and investment comparison models

To be able to define proper cost values and calculations as well as good investments comparison between the ¡VAMOS! mining technology and conventional ones, a set of methods was selected and used for both approaches.

In order to gather information from the selected test sites a survey template was created to collect relevant background information of conventional mining activities (Portugal, Bosnia and the UK). However, for the creation of the calculation template and the exemplary mine planning and scheduling the data set, the Vareš Smreka mine (BiH) proved to be the only one where sufficient data is available, and thus it was used to develop the cost models and investment comparison models (see Annex).

As written in the task description, input parameters for the calculations should be variable. This will keep a high yield of flexibility to adjust the calculations to more or different target values for new calculations. To address this variability of input parameters, several standard calculation methods were used. They are ranked by the target values as shown in Table 1 below.

The following dynamic calculation methods have been used:

- **NPV (Net present value)**
  - The NPV method consists in discounting the present value of all forecasted operating surplus from the investment over the project life period, at a predetermined discount rate, and then comparing the cumulative sum of the discounted CFs to the initial investment.
  - Go/NoGo criteria: NPV should be greater than zero. When comparing several alternatives, NPV can be negative (i.e. when sales are the same). In this case the least negative NPV is the preferred one.

- **EAC (Equivalent annual cost)**
  - An “equivalent annual cost” is the payment of equal cash flows per period for a specified amount of time. The method converts the result of an investment into equivalent annual cost.
Go/No Go criteria: see NPV

- ROI (Return on Investment)
  - Basically, the ROI defines the relation of profit to capital invested, with several types available (depending on how profit and capital invested are defined).
  - Go/NoGo criteria: the ROI should be greater than the interest rate.

- IRR (Internal Rate of Return)
  - The internal rate of return is the discount rate, which, when applied to the future cash flows of a project, will produce an NPV of precisely zero.
  - Go/No Go criteria: the IRR should be higher than the discount rate used for the NPV calculation.

- Payback period
  - This method is no solid decision criteria on its own. It is used to rank results from other calculation methods.
  - Go/No Go criteria: Payback period should be less than lifetime of the project.

Table 1 shows the calculation methods, ranked by the target values.

<table>
<thead>
<tr>
<th>Target value and unit</th>
<th>Calculation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total profit [monetary unit]</td>
<td>NPV</td>
</tr>
<tr>
<td>Average profit per period [monetary/timely unit]</td>
<td>EAC</td>
</tr>
<tr>
<td>Average costs per period [monetary/timely unit]</td>
<td>Average periodical costs</td>
</tr>
<tr>
<td>Average profit [money/time]</td>
<td>Average profit</td>
</tr>
<tr>
<td>Average costs [money/time]</td>
<td>Average costs</td>
</tr>
<tr>
<td>Internal rate of return</td>
<td>IRR</td>
</tr>
<tr>
<td>Payback time</td>
<td>Payback</td>
</tr>
</tbody>
</table>

For cost-calculation and investment models only dynamic calculation methods were applied. Although it would be possible to use simpler, static calculation methods – usually giving the same ranking between alternatives than dynamic methods – they would lack in accuracy and sufficient logging of the discount rate.

Mining business is strongly linked to the local conditions and, therefore, the influence of the geotechnical attractiveness plays a major role in assessing costs. In order to reflect that in the calculations, a link between a 3D-model and the cost calculation is favourable.

Based on the 2D map of the Vareš mine and respective geological profiles, a 3D-model of the mining site as well as a very simplified deposit (block) model have been digitized. This block model was used as basis for creating mine designs for both options (conventional mining and submerged mining). Using Datamine Studio OP software, output values for the NPV calculation were created.
The comparison of the methods does not cover an optimization of existing conventional mining methods or equipment in use nor for the ¡VAMOS! technology. For the Vareš mine, the assumption was to use existing equipment on site for two years and then invest in new machines. Machines are replaced in several waves and a rebuild prolongs the total life time.

Closure costs were not taken into account. It is possible that the use of a former mining site may differ according to the mining technique (i.e. ¡VAMOS! or conventional). In some cases, there might be no immediate post-use of the mining site and, given the fact that the mining area would be flooded, a wide variety of possible recultivation and renaturation techniques is unlikely. This will give very similar closure costs for conventional mining as well as for the ¡VAMOS! technology.

Costs for labour, equipment investment expenses and operating costs are based on Mining Costs from year 2017. The figures in Mining Costs are given in US- or Canadian-dollars. It is assumed that the costs are valid for Europe, using an exchange rate and adjustment factor.

A range of other costs (i.e. mining permit, taxes, etc…) were excluded from the calculations as they are assumed to be the same for any mining technique and wouldn’t influence the results.

Other assumptions, mainly concerning costs are listed in the spreadsheet “CalculationTemplate_VAMOSW6.xlsx” on tab “Assumptions”. (See Annex)
3.3 Calculation results

The calculations for the defined models were done using an Excel spreadsheet. Figure 6 shows the summary of the calculation results, ranked by the target values and grouped by variant.

Besides the fact, that NPV- and ROI-Calculation give negative values – meaning that both are not profitable with the given assumptions – the results show clearly the economic advantage of the ¡VAMOS! method. Compared to a conventional mining approach, the ¡VAMOS! method gives a 37% better NPV. The Internal Rate of Return and the Payback Period couldn’t be calculated, because not enough iteration steps could be processed. Even if a value could be calculated, the values would be ridiculously high. Further optimization processes on the mine design and mine planning are required to get positive values. The same planning and calculation steps should also be followed when evaluating any other site.

A closer look at the calculated costs (Figure 7) gives more details on the savings of the ¡VAMOS! method. The greatest impact is caused by personnel costs (31%), followed by blasting costs (30%) and equipment costs (18%). Further studies should focus on decreasing personnel and equipment costs of the conventional mining method by using optimization and also comparing the ¡VAMOS! method to conventional mining with no blasting. In any variation the ¡VAMOS! method would keep the advantage of a more contained mine design, giving a lower stripping ratio and the lack of need of haulage roads. In the case study of Vareš Smreka Mine, the stripping ratio of the ¡VAMOS! method is less than half the ratio of the conventional technique. Also, the impact on the surface is reduced by 78%. This fact might also positively influence the closure costs for the ¡VAMOS! technology in comparison to other alternatives.
Processing costs are only included for the conventional mining method. It is assumed, that blasted material is crushed in one step to the same grainsize as cut material from the ¡VAMOS! machine. Therefore, one sieve and one crusher are included in the costs.

### 3.3.1 3D Model
The flow-sheet in Figure 8 demonstrates the creation of the digital model and the mine plans.
Starting with a geological map (2D scan), the first step was to create a 3D model giving the current shape of the mine. Based on information from available geological cross sections, a very simplified block model was generated. This block model only respects the outlines of the 25%-Siderite lithology. For the evaluation it is assumed, that all ore mined from inside the 25%-Siderite zone contains 25% of iron and 75% of vein waste. The material mined outside the zone is assigned as waste. This assumption seems proper, given the range of geological input and is sufficient for the calculation to compare the two mining techniques.
Based on the block model a mine design for each alternative was worked out. Geotechnical parameters for both designs are listed in Table 2 below.

Table 2: Design parameters used for ¡VAMOS! and conventional mining techniques

<table>
<thead>
<tr>
<th></th>
<th>¡VAMOS!</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom of Pit</td>
<td>560</td>
<td>575</td>
</tr>
<tr>
<td>Face angle</td>
<td>85°</td>
<td>65°</td>
</tr>
<tr>
<td>Bench height</td>
<td>30m</td>
<td>15m</td>
</tr>
<tr>
<td>Berm width</td>
<td>1m</td>
<td>5m</td>
</tr>
<tr>
<td>Ramp</td>
<td>None</td>
<td>10m width, 10%</td>
</tr>
<tr>
<td>File</td>
<td>Pit101</td>
<td>Pit201</td>
</tr>
</tbody>
</table>

In case of conventional mining, it is assumed that water pumps assure safe mining. For the ¡VAMOS! technology, the groundwater table on level 817 does not change and therefore the additional water pressure is believed to increase wall stability and allow improved geotechnical parameters. The absence of blast vibrations and absence of blast over-break might also influence the wall stability positively. This has to be verified via field tests for all sites where the ¡VAMOS! technology is to be applied.

![Figure 10: Conventional mine design with block model](image-url)
Figure 10 and Figure 11 show the ultimate pit design for each alternative with a section view of the block model. Brown blocks are located outside the 25%-Siderite zone and green blocks represent ore blocks. The pit shell for the conventional mining method (Figure 10) results in an open area of 939,911 m². Compared to that, mining with ¡VAMOS! technology results in a very contained pit design, minimizing the impact on the surface to 204,706 m².

The ¡VAMOS! technology allows following the vein more precisely resulting in a very contained pit design and a very low ore to waste ratio (stripping ratio).

For a more detailed analysis the 3D Model of the pit designs can feed short-term scheduling. Using the automated scheduling tool of Datamine Studio OP more profound machine hours directly linked to the geological circumstances could be created. These machine hours can be used in the calculations.

3.3.2 Bosnia and Herzegovina

In Bosnia and Herzegovina field trials were planned in the Smreka open-pit, in Vareš. Unfortunately, the test couldn’t take place and modification factors were introduced to adjust the power consumption and productivity of the ¡VAMOS! technology.

Current estimates are that the mine itself contains 135 million of tons of iron ore reserves. The open pit was closed in 1992 during warfare and is currently flooded with approximately 5 million m³ of water in the pit itself, with additional flooding of underground mines. The depth of the lake is approximately 200m. The Bosnian government is considering the possibility to re-open the mine.

Possible costs emerging from an acquisition of a Social Licence to Operate or an Environmental Impact Assessment are not included in the calculations as it is assumed that these costs would be the same for both alternatives.

The mining data for Bosnia and Herzegovina was collected with the help of ‘Federalni zavod za geologiju’ (FZG) and ‘Fondacija za obnovu razvoj regije Vares’ (FORRV).
3.4 Sensitivity and risk analysis

Mining provides a special set of risks deriving from geological exploration data, local conditions, prices and the long-term nature of the mining projects. Local conditions include legal and environmental risks as well as political stability. Figure 12 shows the increase of political stability and government effectiveness of Bosnia and Herzegovina from 1996 to 2016. Geological data and local conditions would have a similar impact on both alternatives. The impact of price changes is part of the sensitivity analysis. To reduce risks according to the long production periods and the amount of fixed capital, long-term service and customer contracts would protect the production site from costly claims and unfavorable price development (Gentry and O'Neil 1984).

![Worldwide Governance Indicators](Figure 12: World Governance Indicators for Bosnia and Herzegovina (www.govindicators.org))

The global sensitivity analysis helps to identify the input parameter with the greatest influence on the target value. For this project, the sensitivity of the NPV and costs of both methods on the variation of several input parameters (see
Table 3) was investigated.
The analysis shows that the NPV of the conventional mining method is more volatile compared to the ¡VAMOS! technology. Minor changes of the “conventional NPV” (two to three percent) origin in changes in wage increase, explosive costs and density, whereas the NPV of the ¡VAMOS! technology does not change. Both NPV are affected by changes in production increase, varying sales prices and yearly production. Changes in the discount rate affect only the conventional method noticeably. The most significant impact is experienced when changing the stripping ratio (for conventional mining) and the ore content (for ¡VAMOS! technology).
Table 3: Input parameters used for sensitivity analysis

<table>
<thead>
<tr>
<th></th>
<th>Lower</th>
<th>Base Case</th>
<th>Higher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Price</td>
<td>0.4 $/l</td>
<td>0.52 $/l</td>
<td>1 $/l</td>
</tr>
<tr>
<td>Discount Rate</td>
<td>12 %</td>
<td>14 %</td>
<td>16 %</td>
</tr>
<tr>
<td>Sales price per ton</td>
<td>27 €/tonFe</td>
<td>30 €/tonFe</td>
<td>33 €/tonFe</td>
</tr>
<tr>
<td>Planned production</td>
<td>6300 t ore/day</td>
<td>7000 t ore/day</td>
<td>7700 t ore/day</td>
</tr>
<tr>
<td>Wage increase</td>
<td>0 %</td>
<td>1 %</td>
<td>2 %</td>
</tr>
<tr>
<td>Production increase</td>
<td>-1 %</td>
<td>1 %</td>
<td>2 %</td>
</tr>
<tr>
<td>Ore content/Grade</td>
<td>23%</td>
<td>25%</td>
<td>28% iron in Siderit</td>
</tr>
<tr>
<td>Stripping ratio</td>
<td>10 waste:ore</td>
<td>30 waste:ore</td>
<td>40 waste:ore</td>
</tr>
<tr>
<td>Cost explosives (ANFO)</td>
<td>0.0009 €/g</td>
<td>0.0010 €/g</td>
<td>0.0011 €/g</td>
</tr>
<tr>
<td>Costs ignition</td>
<td>3.6 €/unit</td>
<td>4 €/unit</td>
<td>4.4 €/unit</td>
</tr>
<tr>
<td>Density Siderit</td>
<td>3.7 t/m³</td>
<td>3.8 t/m³</td>
<td>3.9 t/m³</td>
</tr>
<tr>
<td>VAMOS Operating Costs</td>
<td>5 €/h</td>
<td>5.391 €/t</td>
<td>10 €/t</td>
</tr>
<tr>
<td>Power station</td>
<td>9 €/t</td>
<td>9.73 €/t</td>
<td>12 €/t</td>
</tr>
</tbody>
</table>

3.5 Conclusions and recommendations

The modelling of the impacts of the mineral resource extraction sector on macroeconomy is not an easy task. It is specific for each country, dependant on its government, policy, mineral abundance and economy diversification. Creating a global model is impossible, while national models can be developed similarly to AUS-M, TRYM, ORANI, GTAP and G-Cubed models (Downes et al., 2014).

In most cases, growth in the mining extraction sector has a negative long-term impact on national economy and makes it more volatile despite increased revenues. For such situations, one can more blame bad and inefficient government institutions and corruption than the mining sector itself. Of course, discovery of new mineral deposits or escalation of prices on the global market brings changes and novelties which should be properly addressed, but that cannot be considered as an excuse for poor economic performance in such circumstances.

Mineral wealth is not necessarily destructive for national economies, if governments put enough effort to reform their monetary policies, make their legal institutions strong, respect the law and stimulate the economic sectors that face problems. Nevertheless, there are some quite successful countries in the world which succeed in spreading wealth among citizens and develop institutions, social programs as well as other sectors of the economy with money from mineral resources. These countries reached the state where they will stay successful even without mining. In other cases, where short-sighted economic policy, corruption, elitism or even armed conflicts prevail, the country falls into the loop of poor economic performance and poverty. Having this in mind, it can be concluded that generally, decisions of governments and national policy making determine if mineral extraction activities strengthen their economy or make it more volatile with lower growth.
Influence of commodity prices on macroeconomy and its volatility is connected to resource cycles which are driven by supply-demand balance. Ineffective supply will boost the price of commodities, which will be translated as higher revenues from existing mines and higher investments in exploration, but will also negatively influence some manufacturing sectors.

Finally, an important question shall be asked: does the mineral extraction sector influence macroeconomic volatility or is the macroeconomic volatility an important factor that drives the mineral extraction sector? There is no clear answer to that, as both are intertwined. Foresight of important events, early warnings of potential troubles, depletion of deposits and prediction of future demand and their centres can, however, be a key feature to diminish investment risk as well as decrease volatility on the economy.

It is shown through the different analyses done that the greatest savings of the ¡VAMOS! technology when compared to conventional open-pit mining techniques can be found in personnel costs, followed by blasting and equipment costs.

Using ¡VAMOS! technology for open-pit mining enables a reduction of the open mining area, which could give advantages when aiming for a positive EIA or Social License to Operate. Also, the reduced stripping ratio does minimize the waste material, which has to be dumped.

In the exemplary calculation used for the Vareš Smreka Mine neither the ¡VAMOS! technology nor the conventional mining would provide an economic way to operate the mine. However, further optimization, like change of production rate or an update of the deposit model could improve the economic exploitability of the Vareš Smreka Mine with the ¡VAMOS! technology. Also, the resulting picture could look different, if the commodity mined is not iron ore, but a more expensive mineral.

Supporting this data, is the global sensitivity analysis that shows that the ¡VAMOS! technology seems to be more robust against changes in input parameters than its conventional counterpart. This would give the ¡VAMOS! technology an advantage in volatile market situations. This is in line with what was identified in respect of the macroeconomic considerations.

Despite its foreseen benefits when compared to conventional mining, it is still recommended to create a feasibility study, including a more detailed investment plan, EIA and market analysis, before implementing the ¡VAMOS! technology on any site. Moreover, to create a ‘safe and sound’ mine design, geotechnical and design parameters (i.e. stable slope angle, minimum berm width, and maximum bench height) for under-water-conditions have to be verified in labour and field tests.
### Calculation Spreadsheet (Screenshots)

**Diesel Price**: 0.468 €/l

**Working days**: 240 days/a

**Discount Rate**: 14%

**Hours per shift**: 8 h/shift

**Shifts per day**: 2 shift/day

**Days per week**: 5 days/week

**Sales price per ton**: 30 €/ton Fe

**Planned production**: 7000 t ore/day

**Production**: 3500 t/shift

**Personnel cost factor**: 1.25

**Exchange rate $ --> €**: 0.9

**Wage increase**: 1 % p.a.

**Production increase**: 1 % p.a.

**Price increase**: 0 % p.a.

**Ore content/Grade**: 25% iron in Siderit

**Blastability**

- **Stripping ratio VAMOS**: 12 waste:ore
- **Stripping ratio**: 30 waste:ore
- **Cost explosives (ANFO)**: 0.001 €/g
- **Costs ignition**: 4 €/unit
- **Densidad Siderit**: 3.8 t/m³

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**Figure 13: Screenshot of Tab "Costs"**

**Figure 14: Screenshot of Tab "VCosts"**

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**Figure 15: Tab "Assumptions"**
4.2 References


Els, F., CHARTS: Iron ore price won't withstand 2015 supply flood, MINING.com


Lassonde, P., 2012. It was the best of times, it was the worst of times, keynote address, Denver Gold Forum, USA, 9–12 September