Resources, Conservation and Recycling 114 (2016) 130–152

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

A system dynamics model for platinum group metal supply, market price, depletion of extractable amounts, ore grade, recycling and stocks-in-use

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ARTICLE INFO

Article history:
Received 2 September 2015
Received in revised form 4 July 2016
Accepted 19 July 2016
Available online 3 August 2016

Keywords:
PGM
Mining
Recycling
Modelling
Market
Scarcity

ABSTRACT

The long term development of world primary extraction, market supply, recycling and extractable amounts of the platinum group metals platinum, palladium and rhodium was assessed. The degree of sustainability was estimated using system dynamics modelling. Compiling estimates from different sources, and considering recent technological advances in deep mining suggests that the Ultimately Recoverable Resource (URR) is about 216,000 ton of platinum group metals down to a mining depth of maximum 5 km, significantly more than earlier published estimates. The world supply and production of platinum group metals was calculated using system dynamics methodology to develop the PGM-model for this study. The model combines mining, ore grade changes, trade markets, price mechanisms, supply, demand, estimates of stock-in-use, waste, dissipative losses and recycling into a whole world system. The model was run for the period of 1900–2400. The model outputs were successfully tested on historic data for mining rate, ore grades and platinum market price during 1900–2014. The model indicates that extraction will reach maximum in the period 2020–2050 and that market supply will peak in 2070–2080. The delay is caused by the effect of recycling. The outputs from the model emphasize the importance of recycling, metal conservation and elimination of dissipative losses in order to secure long term sustainable platinum group metals supply.

1. Introduction

It is a known fact that the platinum group metals (PGM) platinum, palladium and rhodium are scarce natural resources and that these metals are of great importance for modern technologies and modern advanced chemistry. The platinum group metals (PGM) comprise the metals platinum, palladium, rhodium, ruthenium, iridium and osmium. The platinum group metals production is dominated by five major actors; South Africa, Russia, United States, Zimbawe and Canada. South Africa is the dominant producer of platinum (92%). For palladium, Russia (40%) and South Africa (37%) together share and dominate the market (77% of the total). South Africa dominates the rhodium market (80%), where the other big three producers have minor contributions. Several authors have previously expressed concerns about a potential scarcity and a future peak in platinum group metals production from mining and discussed the associated challenges and possibilities for the platinum group metals mining industry and the supply to the market (Jochens, 1980; Allen and Behamanesh, 1994; Cawthorn, 1999, 2010; Wagner and Fettweiss, 2001; Heinberg, 2001; Babakina and Graedel, 2005; Hagelüken et al., 2005; Gordon et al., 2006; Alonso, 2010; Alonso et al., 2007a,b, 2009, 2012; Geoscience Australia, 2009; Thomas, 2009; Yang, 2009; Glaister and Muss, 2010; Graedel et al., 2011; Mudd, 2010, 2012a,b; Schooldermann and Martlehner, 2011; Wäger et al., 2011, 2012; Gordon et al., 2011; Graedel and Erdmann, 2012; Nuss et al., 2014, 2014; Nuss and Eckelmann, 2014; Radetzki, 2012; Elshkaki, 2013; UNEP, 2013b; Bardi, 2013; Eliott et al., 2013, 2014; Nansai et al., 2014; Sverdrup and Ragnarsdottir, 2014). These have addressed different parts of the system, but not really taken a systemic grip and modelled the whole system and how platinum group metals circulate in the system. For that, this study is the first to put it all together and assess it as a dynamic system with feedback.

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http://dx.doi.org/10.1016/j.resconrec.2016.07.011
0921-3449/

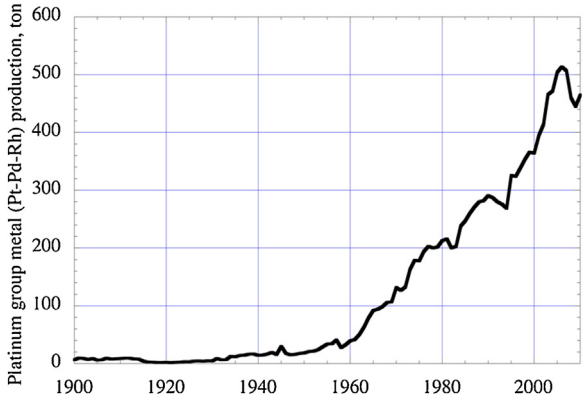

Fig. 1. Global mine production of platinum group metals in ton, for use in society of platinum. Have we reached the maximum production from mines or not? What does the continuation of production look like when we consider remaining reserves? Was the peak in 2005, or will it occur later? Data from USGS (2012–2015).

2. Objectives and scope

Our objective is to model the price of platinum and the physical availability, and to do this based on a systemic mapping of platinum group metals flows in the world platinum group metal trade system. The model we have developed has a wider scope than earlier developed models, and is based on a careful mapping of the whole system of causal feedback links. The wider scope implies that the causal links connect the physical flow dynamics to the market dynamics of supply, demand and market price modelled endogenously from basic principles. We have developed a tool for investigating the dynamics of the platinum market in relationship to what happens in the extraction, supply and consumption system. Our aim is to assess the long term sustainability of the platinum group metals supply to society, and assess the risk for shortage of platinum group metals expressed as decreased production and increased prices. The historic production curve shown in Fig. 1 seems to suggest that platinum group metal mining production reached a peak in 2005–2010. We are asking a number of questions:

1. Production and extraction
   - ○ Will the production go through a peak?
2. Are we at the platinum group metals production peak or not?
3. Was the production peak in 2005 or will it occur later, or never?
4. What would a system dynamics model assessment give?
5. Reserves and resources
   - ○ How large are the total extractable amounts of platinum group metals if we take in the latest resource assessments, consider new technology for mining at great depth, and the resources existing at great depth?
6. How do the known reserves relate over time to the total estimated resources?
7. Can ore grade and extraction prices be included into the extraction dynamics and how does that influence the amount eventually extracted?
8. What is the ratio between the cumulative amounts supplied to society and the cumulative amounts primary extracted?

We assess the supply for the whole globe in a generalized way, and in simulations that cover the past, present and the future (1900–2400). We undertook a renewed survey and assessment of the extractable reserves and resources considering new technologies developed for deep mining as well as all extractable amounts regardless of price. The scope of this paper is to do this for the platinum group metals. We investigate how much the price is determined by supply and demand dynamics in the market. Gold is often found along with platinum, in particular in South Africa. The gold system has it's own intrinsic dynamics, and we have chosen not to include gold in this particular study (Sverdrup et al., 2013a). Ruthenium, iridium and osmium have largely been ignored in this study, their production volumes are relatively small.

3. Background information

Data was taken from a number of sources (von Gruenewaldt 1973; von Gruenewaldt, 1976; Hulbert and von Gruenewaldt, 1982; Sutphin and Page, 1986; Prendergast, 1988; Prendergast and Wilson, 1989; Quiring, 1962; Kunilov, 1994; Cawthorn 1999, 2010; Hilliard, 2001; Williamson, 2003; Wilburn and Bleiwas, 2004; Gauthier et al., 2004; Dalvi et al., 2004; Cailteaux et al., 2005; Gotthelf 2005; Alonso et al., 2007a,b, 2009, 2012; Papp et al., 2008; Geoscience Australia, 2009; Oberthür, 2011; Oberthür et al., 2003a,b, 2013; Gordon et al., 2006 Hagelücken, 2006, 2012; Eckstrand and Hulbert, 2007; Weatherstone, 2008; Ragnarsdottir, 2008; Hagelücken and Meskers, 2009; Ragnarsdottir et al., 2012; Radetzki, 2008, 2012; Saurat and Bringezu, 2009a,b; Levine and Wallace, 2009; Locmelis et al., 2010; Glaister and Muss, 2010; Mudd, 2010, 2012a,b; Butler, 2010, 2011, 2012; Sverdrup et al., 2011; Rasilainen et al., 2010a,b; Eilu, 2011; Oberthür, 2011; Wilburn, 2012; Wilburn and Bleiwas, 2004; Rasilainen et al., 2010a,b, 2012; Elshkaki 2013; Nassar, 2013, 2015; Polinares, 2012a,b; UNEP, 2011a; UNEP, 2013b,c; Williamson, 2003; Wäger et al., 2011; Vermeulen et al., 2013; Royal Bafokeng Platinum, 2013; Zientek et al., 2014; Russian Platinum, 2014; Platinum Group Metals, 2015; Brown et al., 2015). The United States Geological Survey (USGS) database online (USGS, looked up in 2008, 2009, 2012, 2014, 2015; USGS National Mineral Resource Team 1998; British Geological Survey, 2009; Wilburn, 2012; Stillwater Mining Company, 2010, 2011, 2012; Stillwater Mining Company, 2015; Noril'sk Nickel, 2012, 2014) was used for assembling data on extractable platinum group metal amounts and production; general flow and stock data were taken to a large extent from the JM Platinum Review booklets (Butler, 2010, 2011, 2012) and industrial flow and market data from branch organization statistics and unofficial files (Brewster, 2009; Polinares, 2012a,b; Anglo-American Platinum plc, 2012, 2013; Russian Platinum, 2014; Mineweb, 2015; IPA, 2015; Implats, 2015; Stillwater Palladium, 2015; Stillwater Mining Company, 2010, 2011, 2012; Noril'sk Nickel, 2012, 2014, Sverdrup's personal notes).

Fig. 1 shows recorded platinum group metal production to date (adapted from data downloaded from USGS, 2014). Table 1 shows the approximate platinum fluxes in society. It shows the use of platinum in different sectors. Two sectors stand out for the physical size of consumption, the use of platinum, palladium and rhodium in car catalysts and the use of platinum in jewellery. There are further significant inconsistencies in the available published numbers that appear when they are all compiled together and compared against some of the unofficial numbers we have access to. The reasons for these inconsistencies are unknown, but possible explanations are uncertainties in the flux estimates, uncertainty about how large the accumulation in society really is and that some companies may be withholding or distorting numbers for reasons of business secrecy and competition.

In Russia, the platinum group metal reserves have always been regarded as a state secret. In 2013 the platinum budget as shown in Table 1 runs a small net accumulation in society, palladium is possibly running a significant deficit, implying society stocks are decreasing and the rhodium budget seems to balance (Data were largely taken from Johnson Matthey, 2015; Butler, 2010, 2011, 2012). The numbers shown in the table imply that 65% of the mined amount or 46% of the amount supplied to the market is recycled.