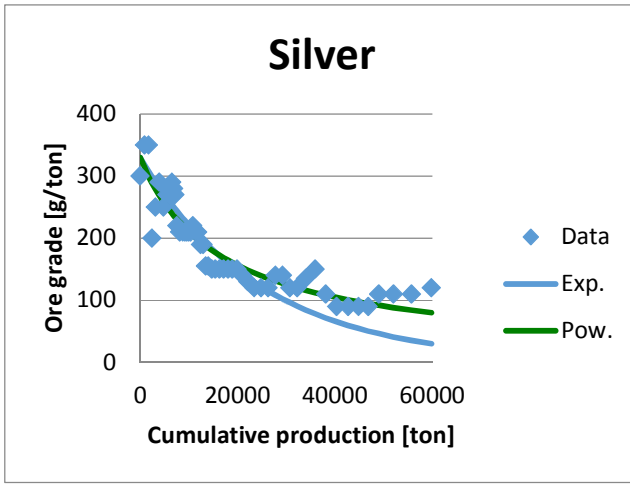
After a long period of stability in the 90's, oil, metal and phosphate prices suddenly went through the roof as the Chinese economy expanded to a world-class player in 2003-2007. The severe economic crisis that followed did not bring prices back to former levels (see box below). The understanding that future prices of resources and restricted access to mining deposits could hurt advanced economies triggered an action of the European Commission towards *resource efficiency* in 2008.

Non-ferrous metal prices relative to 2002[1].

Market prices for metals and minerals fluctuate on a short timescale because mining operations are not always able to respond quickly enough to changes in demand. However, in the long term, prices reflect the costs of production for the *least attractive* (economically most marginal) mines in actual operation. Several authors reported the effect of resource depletion on the development of the cost of mining operations in the last decades. Australian BREE reported an *average* downfall of 33% of mining efficiency (which miners call multifactor productivity: MFP) that was largely due to the depletion of indigenous resources for the period 2000-2010[1]. BREE also concluded that Canadian and US mining operations showed a similar *average* decrease of metal production per unit input of labour and investment in that same period. G. Calvo et al.[2] observed that the *average* ore grade of 25 analysed copper mines, together representing 32% of world copper production, went down by approx. 25% from 2003 to 2013.



Silver ore grade [g/ton] versus cumulative silver metal production [tons since 1900] of Australian mines[3]; fits using exponential (blue) and power law (green) functions.

Ore grade is an important parameter for the cost of metal production. Therefore, future metal prices could be estimated for different scenarios of consumption if the decrease in ore grade c [kg metal/kg ore] could be predicted as a function of the cumulative amount P [tons] of metal produced from the world ore bodies. Studies of Australian mining by Gavin Mudd[3] revealed the development of ore grade in the 20th century. Starting from about 1900, his noisy data can be fit with various model functions, e.g. with exponential or power law models,

$$c(P) = c_{1900}e^{-\alpha P}; c(P) = c_{1900}/(1+\beta P)^{\gamma}$$

Note that for large values of P predictions differ essentially (see box at left).

[1] A. Syed et al., Productivity in the Australian Mining Sector, BREE March 2013.
[2] G. Calvo et al., Decreasing Ore Grades in Global Metallic Mining: A Theoretical Issue or a Global Reality, Resources 2016.
[3] G. Mudd, Research Report 5: The Sustainability of Mining in Australia – Key Production Trends and Their Environmental Implications for the Future, 2009.