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Sustainability in the exploration phase of mining: a Data Envelopment Analysis approach ⋆

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Abstract: Sustainability is a popular topic in many research fields, but sustainability of mining in Finland is even more so after the economic, environmental and social damage caused by case Talvivaara. Here a measure for sustainability of exploration phase of mining is introduced alongside with the mathematics of the method. The method described is called Data Envelopment Analysis (DEA), which is a versatile tool used in many instances to measure eco-efficiency. Here the main emphasis is on combining economic, ecological and social variables with DEA to produce one index for every exploration site studied. This index, between zero (0) and one (1) is called sustainability score of the given exploration site. The paper uses artificial data to introduce the idea of sustainability measurement. However, as shown in the paper, the artificial data is close to the data already collected on the exploration sites. The study at hand is able to discern a useful index called sustainability score, taking into account six variables affecting the sustainability of exploration phase of mining. It should be noted that if more explorations sites are included into evaluation, the utility is two-fold: first, the sustainability scores become more versatile, and second, there can be more variables to be included into the analysis, adding to the detail at which different factors of sustainability can be taken into account.

Keywords: Data Envelopment Analysis, Sustainability, Exploration phase of mining, optimisation, efficiency

1. INTRODUCTION

Mining in Finland has been always a balancing act between different stakeholders. Local population has been mostly positive considering mining activities until recent years. Case Talvivaara has changed that and produced a situation where all the stakeholders suffer from inadequate safety measures.

Mining produces wealth for not only the companies involved but also for the local population in the way of employment possibilities. Other possible beneficiaries of mining activities are the state and county where mining takes place. Possible sufferers are the reindeer herders, tourism industry and tourists, as well as nature conservationists. It is from these instances in recent years where most of the critisism towards mining has risen. It should be noted that for effective mining, all the societal aspects should be taken into account.

Before mining takes place there are many studies to be conducted. This study phase is called the exploration phase of mining. The study at hand introduces methods with which the efficiency of the exploration phase of mining, in economic, social and ecological scales could be risen. The exploration phase of mining includes the activities from drilling the samples until the decision when to establish (if plausible) a mine. The samples studied are usually rock drillcores, gathered by diamond drilling even a half a kilometre below surface.

The exploration phase of mining produces negative economical, social and ecological effects. Diamond drilling is expensive and time-consuming process, having its effect on the surface flora and fauna, as well as social effects as the drilling is usually allowed even in conserved landscape. Howerer, it is possible to diminish the negative effects of exploration and arrive to a more effective exploration phase of mining.

1.1 Sustainability

The sustainability of mining is an area of scientific discussion where there is a high amount of publications available (Hassan et al., 2014). What these publications have in common is that they seek to offer an idea what sustainability is and how it can be developed. The most common scheme for sustainability is to consider economic,

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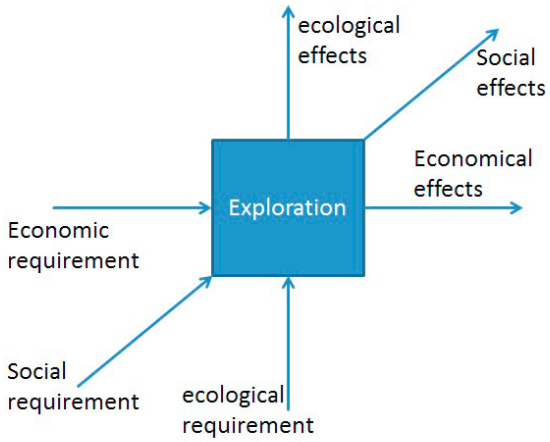

Fig. 1. Sustainability of the exploration phase: thematic diagram.

ecological and social dimensions, as is done in this study as well. In addition, this study is based on the measuring the sustainability in relatively simple and transparent way. It is believed that making the sustainability of exploration phase measureable is also the way forward in order to develop the sustainability of exploration phase.

There are many different sustainability schemes available for mining sector (see e.g. Fonseca et al. (2013)). These schemes usually include a very detailed way of accounting the different environmental, economic and social aspects of mining. These systems of evaluation often are time-consuming and tedious to use. Critique has been raised if these approaches on sustainability have been successful in promoting sustainability in the specific steps of mining (Giurco and Cooper, 2012). There are also critiques on the different types of evaluation programs (see e.g. Fonseca et al. (2012).

Here a new approach for sustainability is introduced, comprising just the exploration phase of mining. The basic idea is introduced in Figure 1, showing the mining product as a system with different inputs and outputs. In this study, the Data Envelopment Analysis (DEA, see below for further discussion) approach is used to evaluate the different dimensions of sustainability, namely economic, ecological and social aspects. It can be said that the DEA is used as a modelling tool for sustainability.

The objective of this research is to establish sustainability scores for the exploration phase of different mining projects. To achieve this end, DEA modelling is used. In DEA, it is of paramount importance to choose the model correctly, but even more important is the question which variables to use.

The type of DEA model used is somewhat dependent on the type of data received. Here only the basic Charnes-Cooper-Rhodes (CCR) or Banker-Charnes-Cooper (BCC) models (input or output oriented) are considered as possible models. While modelling the problem presented by the key variables chosen, the DEA is done in one dimension. The result for each exploration site is called their sustainability score.

1.2 Data Envelopment Analysis

Data Envelopment Analysis (DEA) is non-parametric method for evaluating Decision-Making Units. The first contributions to DEA can be found from the 1950's. Farrell (1957) established the foundations for DEA while solving a linear programming (LP) problem for input-output data set of companies, to find their technical efficiency. Technical efficiency refers to DEA model made from a data set which does not include production costs. On the other hand, economic efficiency refers to a DEA model where the production costs have been included. Here we are interested in technical efficiency.

DEA method has grown in popularity ever since Farrell's discovery. First paper published in the field of operations research was a paper by Charnes et al. (1978). In this and the following paper, Charnes et al. (1979), presented the first basic model for DEA, namely the CCR model. It can be defined as evaluating the efficiency of input-output ratio's weighted sums. In addition, in CCR modelling the efficiency scores of DMU's are given between [0,1], which is basic premise for many DEA models even today. After the CCR model the next important step was by Banker et al. (1984), who introduced the BCC model. In BCC model, the concave surface of DMUs defines the efficiency frontier, in contrast to the constant returns to scale assumption of CCR modelling.

A number of studies based on DEA method is growing in academic publications worldwide. It is now clear that the DEA method has been gradually accepted alongside more traditional regression modelling. Also, the number of different DEA models has grown. For example, Cooper et al. (2006) introduce 20-50 different models, depending on the definition of a model. Of course, this also gives rise to a new problem as a suitable model for a given problem should be found from the high number of possibilities.

Data Envelopment Analysis has many different usages. The classical example is medical facilities, where DEA can be used to compare different facilities to each other, in order to find which of these facilities is the most effective in treating people. DEA can be also used to measure eco-efficiency, as has been done, e.g. for different foodstuffs (Kauppinen, 2008). The instances compared can be of any origin, for example different factories, producing roughly the same product, can be compared. DEA is not limited to these comparisons, but it has been used in developing e.g. rock breakage modelling (Kauppinen et al., 2014), and the work of the geologists in the exploration sites (Kauppinen, 2015).

Basically, to use DEA, one needs input and output data. This is based on efficiency, as efficiency can be defined as unit output per unit input:

$$\text{efficiency} = \frac{\text{output}}{\text{input}} \tag{1}$$

DEA uses linear programming to combine different outputs together and compares them to combined inputs. This comparison is based on Decision-Making Units (DMUs), as DEA produces a comparison of outputs and inputs inside the set of DMUs. The most effective DMU gets a value of