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Analysis

Renewable electricity producing technologies and metal depletion: A sensitivity analysis using the EROI

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ABSTRACT

More and more attention is being paid to renewable technologies because they are seen as a great opportunity to disengage our society from its dependence on fossil fuels. Such flow-based energy resources that rely on solar energy are supposed to lead us toward a sustainable energy future. However, because of their high capital intensity, renewable technologies require large amounts of matter, including both common and rare metals. These metals require energy for their production, and more specifically for their extraction. The energy cost associated with metal extraction is linked to mineral ore grade, meaning that as depletion progresses, energy cost increases. In addition, renewable energy resources deliver less net energy to society compared to fossil fuels, because of their diffuse nature. It is therefore easy to see that a close relationship exists between energy and metal sectors. In this article, we describe more precisely this relationship by investigating how the energy requirement associated with metal extraction could impact the energy-return-on-investment (EROI) of different renewable and nuclear technologies. More precisely, we present a methodology that can be used to calculate the sensitivity of the EROI of a given technology to a specific or to multiple metal ore grade degradation. We found that if considered separately, the qualitative depletion of a given metal has no significant impact on the EROI of renewable and nuclear technologies, unless its concentration approaches very low grade. However, if all metals are considered together, the EROI of these same technologies could be importantly diminished, especially if they tend to very low concentrations.

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1. Introduction

Energy is of primary importance for human societies. Indeed, as for any other physical system, our economic system requires the input of high-quality energy that is used to support physical processes and perform actual work, and is then consequently degraded into low-quality energy (heat) (Georgescu-Roegen, 1971; Odum, 1971; Daly, 1985). Many authors have emphasized the fact that fossil fuels have enabled human organizations to take the path of industrialization and then service-oriented society thanks to their abundance, high concentration and associated low energy cost of extraction (Hall and Klitgaard, 2012; Stern and Kander, 2012; Ayres and Voudouris, 2014). Fossil fuels are by definition non-renewable because they represent finite stocks. They are furthermore a source of pollution, with green house gas emissions monopolizing most of the attention. For these different reasons, the resilience of current complex societies is now questioned and the need to operate a transition from fossil to renewable energies[1] appears obvious and necessary. However, some researchers have already highlighted that renewable technologies rely on various metals like any other infrastructure; and that the requirement of the different sorts of metals needed to produce a unit of renewable energy is more intense when compared to fossil fuels. Furthermore, the extraction of metals from deposits, and their concentration in useable forms require energy. Some studies have shown that the energy cost associated with metal production increases as metal concentration in deposit decreases (Hall et al., 1986). We can see that a complex interdependence exists between energy and metal sectors and it is the purpose of this article to further investigate this relation.

In the present paper, we will first give an estimation of the current amount of global energy consumed by the metal sector. Unfortunately, doing the opposite calculation of the amounts of the different metals cornered by the energy sector is quite impossible. Because the energy cost associated with metal extraction is increasing and that many

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[1] In this article, renewable technologies refer to renewable electricity production from wind and solar energy (wave and tidal could have been incorporated under this denomination, although lack of data prevent us from studying these nascent means of electricity production); biomass is considered out of our scope of study.

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different metals are required in renewable technologies, we will then see that using the energy-return-on-investment (EROI) concept is a useful approach for our topic. We investigate here how the increasing energy cost associated with a specific metal extraction could influence the EROI of different renewable technologies. Then, we have also tested a broader sensitivity of the EROI of these same technologies to all the different metals they require. Finally, we will discuss our methodology, in particular its underlying assumptions, and make some suggestions for further improvements of the kind of analysis we have performed.

2. Empirical Observations

2.1. Interrelation Between Energy and Metal Sectors

Sectors of metal extraction and production represent a significant share of total energy consumption. Rankin (2011) estimated that 10% of global primary energy production is consumed by the metal sector. Data from the International Energy Agency (2014) and from Norgate and Jahanshahi (2011) give a lower value of approximately 7%. We performed our own estimation, using data on mean energy cost of metal production (Valero and Botero, 2002; Rankin, 2011; Tharumarajah and Koltun, 2011; Ashby, 2013) and quantities of production (USGS, 2012) for different metals. As can be seen in Table 1, we found as Rankin that at global level the metal sector requires about 10% of total primary energy consumption. Of course a degree of uncertainty around these data exists for two reasons: unitary energy costs have different years of estimation; and the method of allocation of the joint cost in case of coproduction with other metals may differ from one study to another.

Conversely, the energy sector consumes a large part of the different metals that are produced across the world. Bihouix and De Guillebon (2010) have evaluated that between 5 and 10% of global steel production is absorbed by the energy sector. It is unfortunately really complicated to give more details about the level of consumption of each metal in the energy sector. However, various studies have demonstrated that the intensity of rare metals per unit of delivered energy of renewable technologies (such as wind turbines and PV) is higher than for the infrastructure used in the production of fossil-based electricity (UKERC, 2013a,b; SEI, 2012; Pihl et al., 2012; Yang, 2009; Kleijn and Van der Voet, 2010; Elshkaki and Graedel, 2013; Moss et al., 2013), and that this is also true for base metals and even common minerals

Table 1
Estimations of the energy cost associated with different metal productions and the entire metal sector.
Source: diverse, see Table.

Metal	Energy cost of production (GJ/t)	Source	Production in 2012 (USGS, 2012)	Total energy cost (GJ)	Share of total energy consumption (%)
Aluminum	212	Rankin (2011)	44,400,000	9,391,044,000	1.798%
Antimony	13	Valero and Botero (2002)	180,000	2,412,000	0.000%
Arsenic	28	Valero and Botero (2002)	46,700	1,307,600	0.000%
Beryllium	457.2	Valero and Botero (2002)	230	105,156	0.000%
Bismuth	56.4	Valero and Botero (2002)	7600	428,640	0.000%
Cadmium	110	Valero and Botero (2002)	21,800	2,398,000	0.000%
Cerium	354	Tharumarajah and Koltun (2011)	27,000	9,563,400	0.002%
Chromium	64	Valero and Botero (2002)	24,000,000	1,538,400,000	0.295%
Cobalt	322	Valero and Botero (2002)	110,000	35,420,000	0.007%
Copper (hydro)	64	Rankin (2011)	17,000,000	1,095,820,000	0.210%
Copper (pyro)	33	Rankin (2011)	17,000,000	561,340,000	0.107%
Gadolinium	2162	Tharumarajah and Koltun (2011)	5000	10,812,000	0.002%
Gallium	12,660	Valero and Botero (2002)	200	2,532,000	0.000%
Germanium	2215	Valero and Botero (2002)	118	261,370	0.000%
Gold	68,400	Rankin (2011)	2700	184,680,000	0.035%
Hafnium	633	Valero and Botero (2002)	90	56,970	0.000%
Indium	2875	Valero and Botero (2002)	600	1,725,000	0.000%
Iridium	2100	Ashby (2013)	4	8400	0.000%
Lanthanum	219	Tharumarajah and Koltun (2011)	25,000	5,485,000	0.001%
Lead	20	Rankin (2011)	5,200,000	101,764,000	0.019%
Lead (ISP)	33	Rankin (2011)	5,200,000	169,052,000	0.032%
Lithium	433	Valero and Botero (2002)	37,000	16,002,500	0.003%
Magnesium	437.3	Valero and Botero (2002)	6,350,000	2,776,855,000	0.532%
Manganese	56.9	Valero and Botero (2002)	17,000,000	967,300,000	0.185%
Mercury	409	Valero and Botero (2002)	1810	740,290	0.000%
Molybdenum	148	Valero and Botero (2002)	250,000	37,000,000	0.007%
Neodymium	392	Tharumarajah and Koltun (2011)	21,080	8,263,360	0.002%
Nickel (hydro)	194	Rankin (2011)	2,100,000	406,917,000	0.078%
Nickel (pyro)	114	Rankin (2011)	2,100,000	238,392,000	0.046%
Palladium	5500	Ashby (2013)	200	1,100,000	0.000%
Platinum	270,500	Ashby (2013)	179	48,419,500	0.009%
Praseodymium	220	Tharumarajah and Koltun (2011)	2800	616,280	0.000%
Rhenium	171	Valero and Botero (2002)	5	855	0.000%
Rhodium	14,200	Ashby (2013)	25	355,000	0.000%
Silver	1582	Valero and Botero (2002)	24,000	37,968,000	0.007%
Steel	23	Rankin (2011)	1,500,000,000	34,050,000,000	6.519%
Tantalum	1755	Valero and Botero (2002)	765	1,342,575	0.000%
Tin	207	Valero and Botero (2002)	230,000	47,518,000	0.009%
Titanium	430	Valero and Botero (2002)	190,000	81,662,000	0.016%
Tungsten	357	Valero and Botero (2002)	75,700	27,024,900	0.005%
Vanadium	517	Valero and Botero (2002)	74,000	38,258,000	0.007%
Yttrium	756	Tharumarajah and Koltun (2011)	10,000	7,559,000	0.001%
Zinc (electrolytic)	48	Rankin (2011)	13,000,000	629,720,000	0.121%
Zinc (ISP)	36	Rankin (2011)	13,000,000	466,050,000	0.089%
Zirconium	1371.5	Valero and Botero (2002)	1,440,000	1,974,960,000	0.378%
Metal sector energy consumption in 2012 (GJ)				52,211,442,690	10.525%
Primary energy production in 2012 (GJ)				5.22345E+11	100.000%

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