Annexes

Appendix A: Application of the “strong sustainability” model to the case of iron and steel

This analysis is based on the formula proposed by (Ekins, 2000, Appendix 4):

- \( S_0 \): Stock of unextracted non-renewable resource at beginning of period
- \( R_0 \): Stock of renewable substitutes for the resource
- \( C_0 \): Stock of the non-renewable resource in use
- \( e_i \): Level of economic/environmental service delivered by one unit of the resource
- \( w_0 \): Quantity of resource disposed of as waste during the period
- \( a_i \): Multiplication factor to reflect increase in renewable substitutes during the period

The formula expressing the principle of “strong sustainability” is the following:

\[
 w_0 \leq (1 - e_0/e_1)(S_0 + C_0) + (a_0 - e_0/e_1)R_0.
\]

**S0**: In the case of iron, USGS estimates the concentrated resource at over 800 billion tonnes of ore containing over 230 billion tonnes of iron (USGS, 2009).

**W0**: According to (Chalmin, 2009), around 500 Mt of scrap metal is recycled every year. Since according to other estimations (Grosse, 2010), the efficiency rate for the recycling of ferrous metal waste is around 60 to 70% (Grosse, 2010), the total quantity of scrapped metal would therefore be about 750 Mt, and dispersed metal \( w_0 \) approximately 250 Mt per annum.

**C0**: Finally, based on the evaluations of UNEP’s Resource Panel, we estimate metal stocks in use at 40 billion tonnes (UNEP, 2010).

On the basis of these orders of magnitude, leaving aside the contribution made by renewable resources developed in substitution for iron and steel \( (R = 0) \), we arrive at:

\[
 S_0 + C_0 = 270 \times 10^9 \ t
 R_0 = 0
 w_0 = 250 \times 10^6 \ t/an
\]

The progression threshold of economic and environmental efficiency, which is sufficient for these values to be described as sustainable in terms of this analysis, is therefore for \( R_0 = 0 \):

\[
 w_0 \leq (1 - e_0/e_1)(S_0 + C_0) \iff e_1 \geq (S_0 + C_0) / (S_0 + C_0 - w_0) e_0 = \alpha \cdot e_0
\]

In the case of iron, values are the following:

\[
 \alpha = 270 / (270 – 0.25) = 1.0009
\]
The annual progression of economic and environmental efficiency for use of the iron resource must therefore be greater or equal to 0.09% for the global economy to meet the sustainability criterion defined on the basis of conservation of the economic function of material stocks.

As an example, the material productivity of steel in the British GDP progressed by 1.3% per annum between 1980 and 2000 (Dahlström, Ekins & al., 2004).

Appendix B: A selection of material growth scenarios analysed in the light of the three sustainability criteria

Estimated resources of each material show a cumulative consumption timeframe beyond which the human race enters unknown territory, with increased technical, environmental, economic — and therefore political — difficulties. Even if humankind is able to develop technologies providing access to less and less concentrated resources, way beyond what we now imagine, the economic and environmental cost of the marginal resource will still increase relentlessly. It is therefore in the general interest that use of these more costly resources be postponed as long as possible (Norgate & al. 2006).

It is important to evaluate when this first major shock will occur, and to assess the margin of extra time that each scenario allows compared to “business as usual”.

The US Geological Survey (USGS, 2009), draws a distinction between the concepts of reserves and resources:

- Resource: material deposit in the Earth’s crust in such form and amount that economic extraction of a commodity is currently or potentially feasible.
- Identified resource: that part of the resource whose location, grade, quality, and quantity are known or estimated from specific geological evidence.
- Reserves: identified deposits which could be economically extracted at the time of determination (whether they are being exploited or not).

Data related to reserves are not significant for long-term analyses¹: they represent industrial quantities that fluctuate permanently depending on recent global production on the one hand, and on mining industry investments in prospection and innovation on the other (Kooroshy & al., 2010). For copper for instance, reserves shot up from 90 million tonnes in 1950 to 550 million tonnes in 2008 (ICSG, 2010).

¹ This fact does not prevent some authors, against all the rules of common sense, from referring to reserves for the construction of long term approaches. Take as an example the recent Atlas des Futurs du Monde (Virginie Raisson, Ed. Robert Laffont, Paris, 2011) which presents lifespans of reserves for each material, on the basis of constant annual consumption, based on Mendeleev’s periodic table. Unfortunately, this seductive illustration has no scientific merit in relation to sustainable development and misleads readers into accepting fallacious conclusions. Measuring the lifespan of an ore in terms of reserves is equivalent to evaluating a billionaire’s wealth on the basis of the status of his bank account.
The concept of resource, however, does lend itself to a long-term analysis, since it takes into account both unreliably identified deposits and future economic conditions for their accessibility. Such an evaluation is imprecise but it provides an order of magnitude of the lifespan of mineral resources for various global production dynamics.

Production of a raw material is exponential, meaning that it has a constant annual growth rate, at least in stretches of several decades. Global production of raw steel, for example, increased thirtyfold in the 20th century, i.e. a roughly exponential average annual progression of 3.5%. The production of primary copper (from mining, excluding recycling) has followed a generally exponential progression of 3% a year since 1960, accelerating to 4% over the last 30 years.

Global production of iron ore reached 2.2 billion tonnes in 2008, which initially gives the reassuring impression that humankind can avail itself of several centuries of resource at its present rate of consumption. Yet, if recent global iron consumption dynamics is perpetuated rather than its level, the picture changes radically: if the world economy keeps up the rate of increase in iron ore production experienced from 1998 to 2008, the 800 billion tonnes will be consumed within only 45 years.

An evolutionary production model is therefore what is needed. Figure 1 proposes such an analysis for a few minerals, based on data supplied by USGS (USGS, 2009). It shows that, according to the chosen growth assumptions, resources would run out some time between 2055 and 2130, i.e. within 45 to 120 years. Yet, if only 2008 global production levels were retained using a static approach, it would be wrongly concluded that they would not run out before 250 to 500 years.

Figure 1. Lifespan of estimated resources of a few metals

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2 Remember that global iron ore production doubled between 1998 and 2008.

3 The Club of Rome report (Meadows & al, 1972) already clearly explained this phenomenon of shortening deadlines in its table 4, devoted to non-renewable resources.

In view of the evaluation of the identified resource for each mineral (USGS, 2009), the theoretical date for resource depletion is calculated as of 2008 according to three future annual growth rate assumptions for mineral production. The “business as usual” assumption corresponds to the continuation of the average growth rate observed between 1998 and 2008 (except for lead: 2001-2008). These growth rates apply to mineral extraction, not to total raw material production (primary + secondary). In addition, the figure indicates the ratio between estimated resources and annual production in 2008.

Source: calculations by the author based on USGS data (USGS, 2009) Graph completed from Grosse F., Futuribles, July-August 2010 data.

Based on the example of iron, figure 2 illustrates the effect of various scenarios on depletion of deposits, each scenario being defined according to the three parameters of our analysis:

- the growth rate of total metal consumption (primary + recycled),
- the waste output ratio of this metal (compared to total consumption),
- the recycling efficiency rate.

For each scenario, figure 2 shows cumulative consumption over time of a primary raw material, i.e. cumulative extraction of the resources as a result of these consumption parameters. The various scenarios start conventionally in 2010 and last two centuries. Value 1 on the ordinate is the annual production of the primary raw material in 2010; the two values 250 and 500 therefore correspond to 250 years and 500 years of primary cumulative consumption calculated at the 2010 rate. They give us a representation of the timescale proposed by the current evaluation of global metal resources, as illustrated by figure 1.

All the scenarios begin with growth in total consumption of the raw material (primary + recycled) at a rate of 3.5% per annum until 2050. We are assuming that it is very unlikely that global material growth trends will drop before several decades, both because of population curves and because emerging countries are catching up on their economic lag. The scenarios differ in the assumptions adopted for beyond 2050.

The BAU scenario corresponds to “business as usual”, that is a prolongation of our 20th century for steel: a fairly high recycling rate, but steady growth and a high rate of addition to stocks (moderate waste output), which adds up to a trifling shift in resource use compared to a scenario without recycling (scenario W, which is our worst case scenario in this selection). Beyond a century, production figures become unrealistic. This illustrates the precariousness of the current economic paradigm: willy-nilly, something will happen at some point in this century to our economic and political mechanisms.

The Dw scenario illustrates the limitations of the relative decoupling of growth, i.e. a drop in material growth below 1% in the absence of a recycling effort. In the very long term, the time differential with the two 3.5% scenarios would be considerable; the problem lies in the fact that this very long term will not happen since all the resources will have been consumed long before (250-500 zone of cumulative consumption).

The Z scenario (for zero) illustrates a “zero growth, zero waste” principle, taken at face value: annual global raw material consumption is frozen beyond 2050 at whatever its value at that date and no further waste is ever generated (whether or not it can be recycled). This describes

a society which ceases to grow materially (almost absolute decoupling), which practises waste prevention to the extent that it no longer generates any at all, and therefore accumulates all of the extra raw material it consumes, thereby prolonging indefinitely the life of the goods it uses. As shown in figure 2, the gain compared to scenario BAU is fairly low in the time span under consideration and, above all, estimated depletion of resources (reaching values 250 to 500) only occurs 30 to 50 years later than in the BAU scenario.

The DrW and DRW scenarios illustrate our three criteria for sustainable material development: in this case we have positive, but low material growth (0.5% per annum: relative decoupling of the economy), a middling high to very high recycling rate (60% for DrW and 80% for DRW), and a very high waste output ratio (90% of total quantities of raw material consumed at the same time, i.e. a net addition to stocks of 10% of inputs). Clearly, it is only in such conditions that a substantial flattening of cumulative consumption curves is obtained. In the very long term, the time differential with scenarios BAU or Dw is huge. In the context of the resource time span under consideration, these scenarios and these only among the ones included, delay by a century or almost a century the theoretical date of depletion of the various metals (cumulative primary consumption of 250 to 500). Incidentally, we can guess that each extra decade given over, after 2050, to today’s development dynamics will shorten by considerably more than ten years the final depletion date for the resource in a delayed DrW or DRW scenario.

Figure 2. Cumulative primary material consumption scenarios

![Figure 2. Cumulative primary material consumption scenarios](image)

Caption: The ordinate base 1 represents annual global primary consumption of the raw material considered for the year 2010. The curves represent cumulative raw material consumption, i.e. cumulative extraction of non-renewable resources. For example, a curve
reaches a value of 250 when the material growth scenario under consideration has extracted cumulatively as primary material, in the years since 2010, the equivalent of 250 times the primary annual consumption for 2010. Until 2050, all the scenarios begin with a growth rate of 3.5% per annum, a 50% output ratio and a recycling rate of 60% (for all scenarios except Dw and Gw) or 0% (Dw and Gw).

Beyond 2050, the parameters of the various scenarios are shown in table 1.

Table 1. The parameters of the various scenarios are given

<table>
<thead>
<tr>
<th>Description</th>
<th>Growth (annual rate, total consumption)</th>
<th>Recycling (efficiency)</th>
<th>Waste (output ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>3.5%</td>
<td>60%</td>
<td>50%</td>
</tr>
<tr>
<td>W</td>
<td>3.5%</td>
<td>0%</td>
<td>50%</td>
</tr>
<tr>
<td>Z</td>
<td>0%</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>Dw</td>
<td>0.5%</td>
<td>0%</td>
<td>50%</td>
</tr>
<tr>
<td>DrW</td>
<td>0.5%</td>
<td>60%</td>
<td>90%</td>
</tr>
<tr>
<td>DRW</td>
<td>0.5%</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td>DRw</td>
<td>0.5%</td>
<td>80%</td>
<td>50%</td>
</tr>
<tr>
<td>UK ‘Iron &amp; steel in the UK’ type parameters after 2050</td>
<td>1.1%</td>
<td>71%</td>
<td>69%</td>
</tr>
</tbody>
</table>

Scenario DRw illustrates the perverse effect of low waste generation: by reducing from 90% to 50% the waste output ratio of the economy, i.e. by almost halving waste generation, with identical growth and recycling rates, there is a considerable deterioration of the sustainable nature of the DRW scenario. As less waste is generated, less waste is recycled and there is an acceleration of the drawdown of the natural resource. Production of the raw material is, in this case, devoted to accumulation rather than activation of the circular economy cycle.

Finally, the UK scenario shows the result that the current iron and steel parameters of the British economy would have if they applied to the whole world from 2050 onwards. Depletion of the main deposits is delayed by 30 to 50 years compared to scenario BAU, “business as usual”. We can see the appeal of the UK system, but also the extent to which it is still off the mark for truly sustainable management, in other words, providing enough respite for several human generations in line with the resource time spans under consideration (scenario DRW, or even DrW).
Scenario DRW, the most virtuous as regards conserving material resources and avoiding environmental impacts, does not include any reduction of waste flows; on the contrary. Just like DrW, for it to be efficient it must include, among other things, a vigorous effort to curb stock development, and therefore sudden extra waste generation, when it is theoretically implemented in 2050 (see figure 3). With identical production and recycling dynamics, relative stagnation of waste flows would perpetuate the annual accumulation rate and lead to DRw, which is a much less efficient scenario for resource conservation.