sustainability

MDPI

Review

Material Services with Both Eyes Wide Open

Luis Gabriel Carmona [1,2,*], Kai Whiting [1,3], Angeles Carrasco [3], Tânia Sousa [1] and Tiago Domingos [1]

1 MARETEC, Department of Mechanical Engineering, Instituto Superior Técnico, Universidade de Lisboa, Avenida Rovisco Pais 1, 1049-001 Lisboa, Portugal; whitingke@yahoo.co.uk (K.W.); taniasousa@tecnico.ulisboa.pt (T.S.); tdomingos@tecnico.ulisboa.pt (T.D.)

2 Faculty of Environmental Sciences, Universidad Piloto de Colombia, Carrera 9 No. 45A-44, 110231 Bogotá, Colombia

3 Mining and Industrial Engineering School of Almadén, Universidad de Castilla–La Mancha, Plaza Manuel Meca 1, 13400 Almadén, Spain; angeles.carrasco@uclm.es

* Correspondence: lugacapa@gmail.com; Tel.: +351-21-841-73-66 (ext. 1366)

Received: 1 August 2017; Accepted: 23 August 2017; Published: 24 August 2017

Abstract: Energy has been at the forefront of the sustainable development discourse for quite some time as policymakers, industry heads and society at large have taken progressive steps to cut carbon via renewable energy technologies and energy efficiency measures. Unfortunately, some of these methods have given rise to perverse socio-environmental effects; as materials have been unnecessarily sacrificed, mines and wells have opened and plantations grown, in the name of energy saving. This paper contributes to clean energy-orientated policies and practices by exploring the discipline of sustainable materials. We first review two strategies: energy efficiency linked to materials; and material efficiency, meaning "doing more with less." We find that, although both contribute significantly, they are hampered by the rebound effect and their focus on "doing less bad" rather than "good". Furthermore, they do not in themselves evaluate the services and societal wellbeing that materials provide. We then define "material services" and propose a wider strategy that encompasses and enhances the previous two. Under the new strategy, we argue that sustainable materials should be considered as those that do no harm and which optimally, through the services provided, contribute to better sustainable development policies and practices.

Keywords: sustainable materials; service efficiency; sustainable development goals; material efficiency; material consumption; material stock; material footprint

1. Introduction

Throughout time, humankind has required materials and energy to thrive. In fact, the only way, so far, for countries to advance and develop entails their mass consumption [1,2]. In this respect, an economy takes shape according to the relative value given to those services required to meet needs, create prosperity, and stimulate growth [3].

There is a growing realisation that the current trajectory of resource consumption is unsustainable and accordingly, there is significant interest in reducing greenhouse gas emissions whilst encouraging a more efficient and sustainable use of materials, water and energy [4]. Haefele [5] and Nakicenovic et al. [6] were among the first to note society's dependence on energy to support the functioning of complex systems that, in turn, convert energy and mass flows into desirable end uses (services). Since then, the importance of materials, specifically, has become increasingly recognised [7]. They were categorised into "biomass", "fossil fuels", "industrial minerals and metal ores" and "bulk materials for construction" by Fischer-Kowalski et al. [8].

Allwood et al. [9] comprehensively evaluate the role of materials in their book *Sustainable Materials: With Both Eyes Open*. They focus on material and energy efficiency and frequently use carbon emissions, as an environmental indicator, to measure the performance of the industrial sector. The book, as recognised by Bill Gates, offers important insights into the sustainability problem through the re-design of production processes, which reduce material use, improve product function and increase corporate profitability [10]. A particular emphasis is given to innovative designs and practices which provide the same level of final service with less material and lower carbon emissions per unit of production. Allwood et al. call for a transition from a carbon cutting strategy based on conventional approaches, to one that emphasises the potential benefits of reducing material consumption in the production phase. The former strategy is referred to as "one eye open" and the latter as "both eyes open." In this paper, a comprehensive literature review is performed to identify the strengths and weaknesses of both strategies. Based on the insights from the literature review, we develop our own strategy, which we coin "eyes wide open" (Table 1). Under the latter, we explore and define the concepts of stock optimisation, stock efficiency and material service efficiency.

Table 1. A summary of sustainable material strategies: from one eye open to eyes wide open.

Strategy	Strategy Focus			
	Production Stage	**Final Product (Use)**	**Waste/End-Of-Life**	**Potential Benefits**
One eye open Energy efficiency of materials	Less utilities (energy, water)	Same product with improvements in energy efficiency	Conventional recycling and end-of-pipe technologies (e.g., carbon storage, urban mining)	Carbon savings and monetary cost reduction
Both eyes open Material efficiency	Less raw material (biomass, mineral ore)	Better products (durable, resistance, fixable, recyclable)	Direct re-use and non-destructive recycling	Innovation leading to further carbon reductions, a higher market price and better-quality products for the consumer
Eyes wide open Material service optimisation	Better materials (renewable, non-toxic, conflict free, etc.)	Stock optimisation via smarter demand and material service efficiency	Upcycling	Greater fulfilment of sustainable development goals due to an emphasis on socio-environmental aspects

Our strategy is complementary and works like a Russian doll, encasing the others (Figure 1); it neither replaces nor makes the previous two strategies obsolete. The added value of the "eyes wide open" strategy is that it breaks a production-centric paradigm by extending the scope to consumption and the wider effect that material services have on societal and environmental wellbeing. This is in line with the United Nations Environment Programme's broader and more inclusive definition of resource efficiency: producing more wellbeing with less material consumption to meet human needs, whilst respecting the ecological carrying capacity of the Earth [4,11].

Neither material consumption nor material efficiency tell us what materials are destined for nor whether their production is beneficial. For these kinds of decisions, society must look beyond material accounting and unit savings, into services, something which has already been done with energy [12]. In our opinion, material services offer the next big step in the sustainability debate. Comparing alternative pathways for providing the same service with lower resource needs will create space for societal transformation triggered by a more holistic view of sustainable development [13].

The biggest problem is that the sub-disciplines of material flows, efficiency and services are still novel [14]. As a result, "material services" have no consensus as to their definition and scope [15], hence the need for this paper, which defines the term and expands the aforementioned concepts.

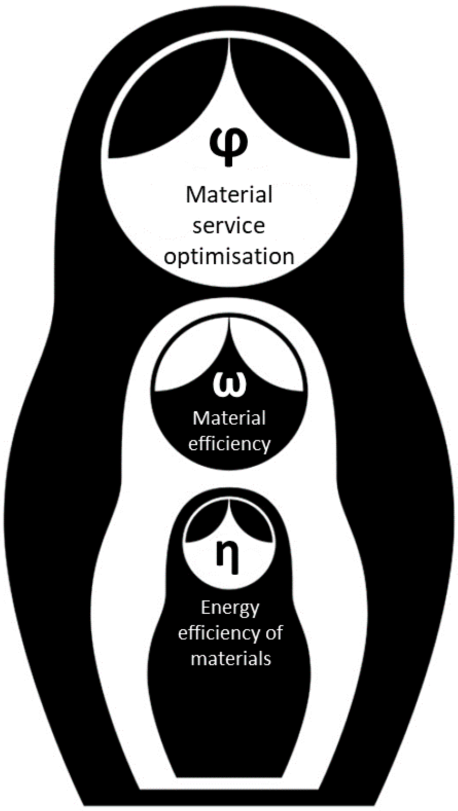

Figure 1. The Russian doll of sustainable material strategies.

2. The "Problem" with Materials

Ever-increasing material flows are required to support material and energy services [16–18]. The global total of material extraction has multiplied tenfold since the beginning of the 20th century, beginning at 7 Gt/year in 1900 and reaching 78 Gt/year in 2010 [19]. In 2008, the average amount of global raw material consumption reached 10.5 tonnes per capita, although this was not shared equally among countries. Those with a medium level of human development registered five tonnes per capita whilst those in less developed nations had 2.5 tonnes per capita, a figure which has not grown for the past two decades [18,20]. Under business as usual models nine billion people would require about 180 Gt/year of materials, by 2050, for the provision of major services such as housing, mobility, food, energy and water supplies [21,22]. This is approximately two and half times the amount consumed in 2010. Other estimates are similar at 140 Gt/year [23].

Half of all extracted materials are used to supply endo-somatic (in the way of food) and exo-somatic energy (associated with industrial energy conversions and other direct energy needs). The other half is used for bulk construction materials, industrial processes and product manufacture [20]. The latter are those that tend to accumulate as stock and provide the material basis for wealth [24–26]. Material stocks transform material and energy flows into services. On a macro level, material stock increased 23-fold from 1900 to 2010, in line with GDP (27-fold) over the same period. The amount of primary material input used to build up or renew stocks rose from 1 Gt/year to 36 Gt/year [19].

In some cases, it may take many years for a given material to return to the environment, normally in the form of waste, and it is in-use and lucrative stock that is driving the demand for materials and energy at all levels of their life cycle [19,27,28]. This behaviour manifests on both an individual and collective level in the way that society expends effort and resources to build, enlarge and maintain what they already have. Arguably, this phenomenon has its roots in wealth accumulation and social status.

Kahneman et al. [29] describe a similar microeconomic behaviour in their study on endowment effect and loss aversion. In other words, this behaviour is inherent in humanity, regardless of scale.

There is a correlation between GDP and material consumption [30]. In fact, Wiedmann et al. [20] show that with every ten per cent increase in GDP the average national material footprint, which is indicative of material consumption, increases by six per cent. The same can be said for carbon, with a one per cent growth in GDP leading to a 0.5–0.7 per cent rise in carbon emissions [31].

Such figures may, at first glance, seem important only from a resource depletion perspective, which may not be significant if mineral conservation and geological patrimony is not a priority for sustainable development [32]. There are, however, other social and environmental concerns at play. For example, on the one hand, mineral resources can foster economic and social development through their exploitation; and on the other, mining operations can result in significant environmental degradation and social fragmentation, community displacement and conflict, if there is an "overemphasis of economic issues at the expense of environmental and social integrity" [33] (p. 262). Such conflicts of interest occur further along the lifecycle too. As Weidmann et al. [20] points out, internationally traded commodities alone (which also bring wealth to nations) are responsible for 26 per cent of global CO_2 emissions, 30 per cent of the world's threatened species and 32 per cent of the world's freshwater consumption [34–36].

3. Zero Eyes Open: Turning a Blind Eye to Materials

Current material dependency can be easily identified with the quick comparison between a 21st century and mid-20th century office. The material (and energy) required to provide the same service, albeit not at the same level/quality, has multiplied over the last 67 years. In the 21st century office, in addition to the landline (though without the operator's switchboard), which a 1950s office worker would recognise, there is also a modem and a fax machine. The typewriter and the shared radio have given way to the laptop, printer and headphones. The light bulb, whilst less energy efficient than today's LED, was more material efficient. The old Ford of 15 leaded petrol miles per gallon has given way to the Toyota Prius, which, although less polluting at source, is not necessarily more energy efficient and is certainly less material efficient given that it uses the same materials as an old Ford, plus a host of rare earth elements (Table 2).

Table 2. Comparison of some material services and the chemical elements involved to support them in 1950 and 2017.

Material Service	1950			2017		
	Product	**Mass and Main Chemical Elements**	**Energy Efficiency**	**Product**	**Mass and Main Chemical Elements**	**Energy Efficiency**
Transportation	1950s car	1440 kg—C, Co, Cr, Cu, Fe, N, O, Pb, Pt, S, Sn, Zn [37–39]	15 Miles per Gallon [40]	Hybrid car	1325 kg—Al, Ar, Au, Br, C, Cd, Ce, Cr, Co, Cu, Dy, Eu, F, Gd, Ga, In, I, Fe, Kr, La, Li, Mn, Mo, Nd, Ni, N, O, Pd, P, Pt, Pb, K, Cl, Pr, Re, Rh, Sm, Ag, Na, Sr, S, Ta, Te, Sn, U, Xe, Zn, Zr [41–44]	50 Miles per Gallon [45]
Information storage and processing	Remington Typewriting	3.6 kg—C, Cr, Fe, N, O, Zn [46]	No automatic performance	Laptop and printer	2–3 kg (laptop) and 2–3 kg (printer)/ Around 45, including: Al, Ar, Au, Br, Cd, C, Ce, Cr, Co, Cu, Eu, F, Ga, H, In, I, Fe, La, Li, Mn, Mo, Nd, Ni, N, O, Pb, Pd, P, Pt, Pr, Rh, Sm, Ag, Sr, S, Ta, Te, Sn, Ti, Xe, Zn, Zr [47] Still telephones (1.6 kg) and mobile phones (150 g) are used [48]. In addition, headphones are added to laptop	Peak output efficiency = 1.5×10^{15} computations per kWh [49]
Tele-communication	Telephone	4 kg [50]	No automatic performance			
Entertainment	Radio	15 kg [51]	No automatic performance			
Lighting	Light bulb	34 g—Ar, Al, B, C, Fe, N, Ni, O, Si [52]	60 W/800 lumen [53]	LED	56.6 g—Ag, Al, As, Au, C, Ga, H, In, N, O, P, Zn [54–56]	11 W/815 lumen [57]

The electric car epitomises the problem with the 21st century sustainability discourse. In David MacKay's [58] *Sustainable Energy without the Hot Air*, the energy efficiency of an electric car is touted to be higher than that of a conventional one, when using the UK electricity grid as a reference. This may be true but it overlooks the inter-dependency between materials and energy and the impact of their extraction on the environment and society. To take a holistic look at the issue we must juxtapose the opening of mines and the sacrifice of materials with the potential for carbon/energy savings.

In terms of materials, a hybrid electric car needs two forms of storage—a lithium battery and a fuel tank. Lithium resource availability is debatable, dependent on whether a techno-optimist stance is taken. The optimist ignores the limited availability of terrestrial lithium, which will run out by the end of the century under mass electric car adoption scenarios, and points to oceanic lithium. The latter is an attractive solution as extracting lithium from seawater requires only a trivial amount of energy in theory—1.2 kWh/kg—to go from an ocean concentration to a two per cent solution [59]. Less questionable is the impact of lithium extraction on Bolivia's Salar de Uyuni, which constitutes half of the global lithium reserves on Earth [60,61]. The lithium mines compete with quinoa farmers for scarce freshwater supplies as the current water use at 10 kt/year production is larger than the recharge rate of the basin [62]. There is also the issue of the chemicals used to obtain lithium, which have already caused environmental degradation in the Salar de Atacama in Chile [59,63]. Water scarcity, and the subsequent displacement of indigenous people, is also a major socio-environmental concern in the Atacama Desert where mining for copper, gold, silver, molybdenum, and lithium competes with basic potable water needs and ecosystem services, at the detriment of biodiversity and communal lands [64]. Furthermore, and according to Grosjean et al. [65], water resources in this region should be considered a fossil or non-renewable resource.

However, mining is not the only problem, as hybrid car production also requires all the component parts that feed the combustion engine and the battery system to be processed, transported and disposed of eventually. Disposal issues are particularly neglected, if one considers the growing accumulation of waste plastic in the oceans or the electronic waste dumps in Agbogbloshie, Ghana [66–68].

4. One Eye Open: Glancing at Materials but Fixed on Energy

Energy inputs, and by extension carbon emissions, linked to material manufacture have received a great deal of attention compared to material inputs. This is because a considerable amount of energy is used in Industry to make a few key materials [69]. Steel, cement, paper, plastic and aluminium dominate industrial sector greenhouse gas emissions, whilst biomass is a source of those emissions associated with agriculture and deforestation [70,71]. The "one eye open" approach focuses on improving the sustainability of materials through a reduction in energy intensity and flow, often using carbon emissions as a proxy. Carbon emissions are a useful and simple metric that governments, the private sector and, increasingly, the general public understand [72], which is why this strategy dominates the sustainable material debate.

Various options fall under the umbrella of one eye. These include carbon sequestration, energy efficiency, heat capture, novel process routes and recycling [72]. Most examples are production processes or end of pipe based, with limited exploration into final product improvements. They represent resource efficient manufacturing and cost cutting, through improvements in technology and working practice [73].

The Weaknesses of a One Eye Strategy

This strategy is heavily focused on cutting energy costs but, as such costs reduce, there is often an accompanying "rebound effect" [74]. Such effects can occur at varying scales and may modify the demand of a given material product (or energy service) directly. They can also have an economy wide impact on the price of goods, consumer preferences and consumption patterns [75]. In terms of a direct rebound example, Stapleton et al. [76] estimated that fuel consumption in UK private vehicles increased between 9 and 36 per cent from 1970 to 2011.

Carbon sequestration may contribute, in theory, to a reduction in carbon emissions and is included under Allwood and Cullen's [72] one eye open strategy because it could be a solution if no further energy efficiency can be gained. However, this approach, as stated by Allwood et al. [77], is inherently uncertain. Firstly, the UK Government, a key supporter of such technologies, has withdrawn funding for carbon capture and storage projects; secondly, even the most optimistic estimations for reduction of atmospheric carbon, via this route, are negligible (28 Mt) compared to global anthropogenic emissions (51,000 Mt) [78,79].

A far more acceptable solution is the conventional recycling of post-consumer or production scrap, meaning the breaking down, re-melting and re-forming of old scrap, or the re-pulping of paperboard. Despite being destructive in nature, this form of recycling is seen by many as the most important mechanism for sustainability. Gutowski et al. [69] provide a comprehensive review of recycling opportunities as a means to improve energy efficiency and reduce the environmental impacts associated with mining and extraction, smelting, material refining, incineration and landfill. They question the fact that recycling is seen as the cornerstone of a closed-loop economy. Firstly, non-biological material recycling is not 100 per cent efficient, as there will always be material and exergy losses. Secondly, reverting to recycling as the default option has created an attitude and over-reliance that can, at times, lead to energy efficiency at the expense of materials and other more innovative solutions.

5. Both Eyes Open: Looking but Not Really Seeing

A material reduction approach falls under the "both eyes open" strategy because of its focus on "material efficiency" which promotes "doing more with less". This concept minimises the unnecessary consumption of rare and non-renewable resources in the present for the benefit of future generations [80]. In this way, it encourages reuse and stimulates "greener" procurement [81].

In engineering one asks, "How much material is required to deliver a unit of standardised product?" In these terms, efficiency improves if the same unit of product is manufactured with less material, without jeopardising quality/functionality. The latter is measured in terms of technical characteristics e.g., thermal or electrical conductivity, or strength-to-weight. As an example of how this can play out Milford et al. [82] provide a case study on how steel production could be enhanced by reducing materials, whilst maintaining (or improving) the technical capabilities of steel as an intermediate product. In their case study, there are six ways, which we group into three categories, to reduce material consumption (Table 3). We also include a scheme of a production system operating in accordance with the both eyes strategy, as shown by Figure 2.

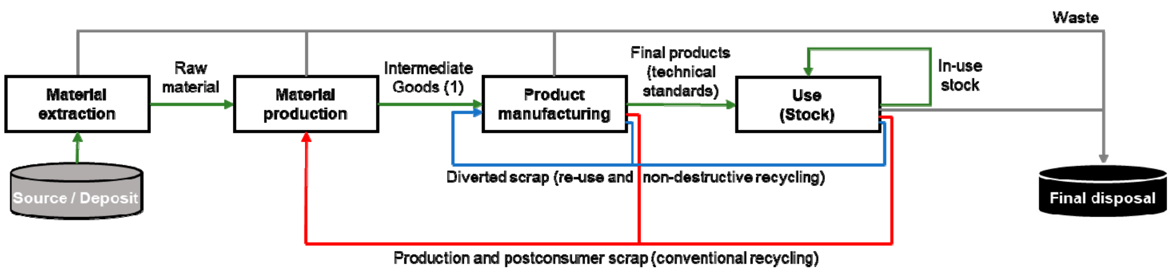

Figure 2. A generic production system for the both eyes open strategy. Note: Raw materials may also be fed directly into the product manufacturing stage, bypassing material production.

Table 3. Material efficiency solutions proposed by Allwood and Cullen [72].

Stage	Action	Measurement of Savings
Production stage	Less metal, same service	ML = 1 − (New product mass/Original product mass)
	Fabrication yield improvement	MY = 1 − (New fabrication actual mass yield/Original fabrication actual mass yield)
Final Product (Use)	More intense use	MI = 1 − (New mass of products required to provide service/Original mass of products required to provide service)
	Life extension	MX = 1 − [(New product mass/new mean product life)/(Original product mass/original mean product life)]
Waste/End-of-life	Re-use	MR = Mass of scrap diverted for re-use/Original mass of end-of-life scrap sent for conventional recycling
	Production scrap diversion	MD = Mass of scrap sent for non-destructive recycling/Original mass of production scrap sent for conventional recycling

5.1. Production Stage

The possibility of using less material to provide the same, or a better, service has been proposed in the car industry where material substitution and dematerialisation, in terms of metal quantities, is thought to lead to fuel efficiency improvement—courtesy of light-weighting and best available technology. As Mackenzie et al. [83] note, whilst the share of conventional steel and iron have shrunk by a third, these metals have been replaced with increasing quantities of high-strength steel (fivefold), magnesium (tenfold), aluminium (fourfold), plastics and composites (twofold), rubber and glass (modest growth). Likewise, Serrenho and Allwood [84] state that whilst the steel and iron component has decreased percentage wise, the overall weight of a UK car has gone from 995 kg in 1975 to 1321 kg in 2012. The national car stock has also risen. These examples indicate that whilst less material is being used in terms of mass, for certain cases (conventional iron and steel), it is not that cars (or vehicles generally) are built using *fewer materials*.

Mixtures lead to increased difficulties in recycling and disposal at the end of life [43]. Such challenges become more complex in light of the rebound effect, which is not restricted to energy. In fact, as Kallis [30] points out, any form of efficiency gain stimulates growth and surplus. Thus, any improvements in efficiency are often overcompensated by economic growth and rebound effects [85]. This observation is confirmed by Pfaff and Sartorious [86] who show that the direct material rebound is between 2.5 per cent and 10.5 per cent, which is admittedly lower than the rebounds observed for energy, as discussed in Section 4. Likewise, Magee and Devezas' [87] studied 69 material uses from the 1940s to 2007 and found that there was no dematerialisation, in absolute terms, for 57 of them. The six materials that did show a decoupling were asbestos, beryllium, mercury, thallium, tellurium, and wool. The first four clearly fell out of favour due to legal restrictions that resulted from their toxicity, whereas for tellurium and wool substitution is likely the cause. Therefore, it does not appear that technological improvements, including efficiency, result in a reduction in material use. Even if material efficiency is increasing it is not enough on its own to stabilise material consumption and reduce environmental deterioration [2], especially given that more material is required in 2017, compared to 2000, to create one unit of GDP [18]. Arguably, the issues discussed in this section could be addressed under a more complete form of sustainable material policy and practice (Figure 1).

5.2. Final Product and Consumer Side

A different approach to manufacturer-driven dematerialisation and yield improvement is on the consumer side. It calls for individuals to select products they can use more intensely or for longer [88]. "Modularity" supports such thinking because only the failed component needs to be replaced and disposed of. This, in many instances, although maybe not all, supports a cheaper and more material efficient form of providing value to the consumer, through the extension of product life. Greater durability and product standardisation also encourages efficient material use through sharing or multiple function items [89]. Such concerns come under what Prabhu [90] terms "frugal innovation". This concept represents the ratio of value that a given product provides to a consumer. It also asks how resources can and should be used to bring better services to more people.

One of the most difficult things to ascertain is how exactly consumer psychology, corporate marketing and advertisement play out in a capitalist system. Durable and resilient materials go hand in hand with sustainability, and, in theory but perhaps not in practice, provide a user with more utility. Fashion provides an example of where aesthetics, social pressure and preferences, along with changing waistlines, are the main determinants of a product's lifespan rather than the robustness of the fabrics and stitching [91,92]. In which case, consumers may not want longer lasting clothes at the expense of "feeling chic". In the UK alone, for example, an estimated £140 million worth (350,000 tonnes) of used clothing goes to landfill annually [93]. In addition, whilst Chapman [94] suggests that cultivating an emotional and experiential connection with a product may prevent a throwaway culture, and thus consumerism, as Krausmann et al. [19] indicate, such a connection may not reduce the desire to buy more. In fact, the average UK household owns £4000 worth of clothes, 30 per cent of which has not been used for over a year [93]. In practice, from a sustainability perspective, there is little point expending resources so that a product lasts longer, either because it is personalised, or made with better quality materials (or by highly skilled workers), if consumers continue to buy new.

5.3. End of Life

In the "both eyes open" strategy there are two potential opportunities for material efficiency at the disposal stage: direct re-use and non-destructive recycling of scrap. As aforementioned, conventional recycling is destructive in nature as it requires the breakdown of material in order to be reincorporated. This is neither energy nor material efficient and creates a lower quality product. Allwood et al. [95] state that the best available techniques for non-destructive recycling include superficial, deformative, subtractive and additive, or direct re-use. This kind creates a diversion of scrap and is, according to Serrenho et al. [96], the best way to achieve a substantial reduction of carbon emissions within the UK steel industry.

5.4. Material Efficiency: How to Go Beyond It?

Measuring material efficiency has added complications that energy does not. Energy flows are easier to trace and savings easier to calculate because these kinds of stocks have shorter life cycles. The number of available energy sources is also much reduced compared to materials, which can be combined to produce alloys and other types of composites. Thus, the knock-on effects of new technologies are much more difficult to predict, and consequently "solve". To use the electric car as an example once more, whilst one can relatively easily identify the fuel efficiency gains per passenger-km using an energy services Sankey diagram from primary energy to final services, it is much more difficult to calculate the material efficiency of that same passenger-km from mineral deposit to final service. As of 2017 (and to our knowledge), there is no such diagram following the flow of a single material contained within an electric car, though there are many materials within them. Tukker et al. [97] developed a Sankey diagram that links 65 Gt of material extraction to global consumption but the final mass flows were allocated to only one final consumption category and not final material services. Stocks were not considered either.

One way to fix some of the issues linked to material efficiency is through State-led regulation of production or consumption. An example of such legislation is through restricting the quantity of steel permitted in modern builds (typically more steel is placed inside a building than necessary, as this reduces labour costs). Ekvall et al. [17] propose four policy instruments to encourage better resource use. These are the introduction of a new material tax, an extension of environmental taxes, extended producer responsibility, and State-led technical requirements that declare the type and quantity of material permitted in certain products. Likewise, Söderholm and Tilton [98] argue that material efficiency policy needs to address environmental impacts and information failures, rather than issues linked to resource scarcity.

Such initiatives are very welcome but do not answer the harder and more important questions of; "How can materials provide individuals with what they really (or think they) want?" "How should materials be used to support societal goals and aspirations?" and "How can a 21st century knowledge-based economy operate so that services, and not products, are at the forefront of development?" To answer these kinds of questions it is not sufficient to have "both eyes open", because we are looking but not really seeing. For this reason, we add the last and biggest Russian doll to these approaches: eyes wide open.

6. Eyes Wide Open: Looking Forward to the Sustainable Development Horizon

Design and engineering applications, typically seen by the general public through final products or objects, can define the social meaning and status of a particular element or a composite. This is because the application and the story behind it (which both producers and consumers tell) alter how people interact with it, its level of desirability and function [99]. Ivory, for example, has not changed but due to an increased awareness regarding animal cruelty and extinction, its use, and the social status earned by owners, outside of very select circles, has diminished [100]. The same is true for mercury. Once a prized commodity supporting the gold rush of the Spanish conquests in America, its toxicity levels have significantly curbed demand to the point that Spain's most important mercury mine, although still full of the metal, has since been converted into a museum [101,102]. Even if no environmental issue or other external factor is identified, relationships with materials can fluctuate in line with consumer experiences. When plastic was marketed and consumed in the 1950s it was compared favourably to ceramic crockery—as a far more silent, hygienic and soft alternative. The same plastics used in the 21st century for the same functions are now seen as tacky, unbreathable and unhygienic [100]. Such examples demonstrate that societal relations with materials matter and that, through meaning, society can determine markets. Additionally, if society's relationship with one material can be modified, so can their relationship to materials generally.

The "eyes wide open" approach requires a strategic re-think of how materials are thought of, valued and used. It breaks the paradigm of seeing materials as products and emphasises the services behind them.

6.1. Material Services: How Best to Unify the Concept?

There are no clear definitions as to what material services are, or could be, which is one of the biggest barriers to exploring the subject. Another issue when it comes to environmental concerns linked to materials is that Google Scholar sub-categorises sustainable energy but not sustainable materials, as part of the wider environmental field. There are also many high impact journals dedicated to sustainable energy. The same cannot be said for sustainable materials. This may be because the sub-discipline of sustainable materials is newer than its sustainable energy counterpart and awareness of the issue is limited.

Table 4 is a comprehensive analysis of key search terms related to sustainable energy, materials and services. The raw data are taken from the "Web of Science -ISI" database. The words we selected are arguably the most readily associated with each of the three sustainable material strategies. The results are indicative of the limited attention paid to materials within the sustainability discourse when compared to energy, a fact which holds consequences linked to resource depletion, social issues and environmental deterioration, for future generations. Given the data available, an evaluation of Google web searches between 2000 and 2008, using the NGramar tool, and searches between 2004 and June 2017, using Trends, were carried out.

Various papers within the sustainability discourse define "material services" relative to mass terms and the final product stage [9,82,88,103]. As far as we are aware, no one has ventured into "end user service" which would require functional units of, say passenger-km in transport, m^3 of hot water at 60 °C for heating and hygiene, and GBs of data storage for IT and communications. However, this is an altogether more useful scope because one can ascertain the purpose behind, and the effectiveness of, material use. It also means that material services could be compared to energy services in order to analyse the environmental trade-off between energy and materials. For example, we can provide the same thermal comfort with more material and less energy, if we have better insulation or vice versa. Such developments mean that one could also ask whether we should deliver material services in a different form or according to a consensus-driven set of societal goals, which has been hinted at by Allwood et al. [77] (p.4) in terms of *potential for energy savings*.

Table 4. Incidence and first appearance of key terms linked to the three sustainable material strategies.

Strategy	Key Concept	Year Term Is Introduced	No. Papers	Relevant Authors (with More than 5 Publications)	Publications Impact (h-Index)	Ngramar Viewer—Books in 2008 ($\times 10^{-8}$)	Trend Average Interest on Search (Index)
One eye	Energy efficiency	1907	48766	>500	78–122	90.26	63
	Energy service	1977	1371	25	56	2.53	77
Both eyes	Material consumption	1910 (jump until 1951)	1031	15	42	6.46	1
	Material efficiency	1969	443	10	31	1.05	1
Eyes wide open	Material service	1977 (jump until 1994)	74	4 *	11	1.39	5

* Just 3 publications were considered.

The sub-discipline of "energy services" evaluates those services provided by energy and not just the energy carriers themselves. Various authors have discussed energy flows. Sousa et al. [104] undertook a comprehensive literature review on the scope of energy flows from primary to useful energy or exergy. Other authors have gone further and explored primary energy flows through to final services, including Haefele [5], Nakicenovic [6,105,106], Schaeffer and Wirtshafter [107], and Cullen and Allwood [12]. However, only Cullen and Allwood [12] measure the energy services with units, the other papers are more conceptual in nature. Table 5 shows the energy service categories which also apply to material services.

Table 5. Comparison of energy service categories.

Final Service Categories *	Schaeffer and Wirtshafter [107]	IEA [108]	Cullen and Allwood [12]
Transport	Transport by mode (Bus and truck, Automobile and truck, Airplanes, Ship, Train)	Passenger transport by mode (sea, heavy road, light road, air, rail)	Passenger transport (passenger-km)
		Freight transport by mode (sea, heavy road, light road, air, rail)	Freight transport (tonne-km)
Shelter (Housing and Buildings)	-	-	Structure ($MPa^{2/3}m^3$)
Thermal comfort	-	Space heating	Thermal comfort (m^3 K air)
	Refrigeration	Space cooling	
Hygiene	Water heating	Water heating	Hygiene (m^3 K hot water)
	-	-	Hygiene (Nm work)
Food	Cooking	Cooking	Sustenance (J food)
Communication and information storage	-	-	Communications (bytes)
Illumination	Lighting	Lighting	Illumination (lm-s)
Intermediate goods production (see Figure 2)	Industrial sector	Intermediate goods production by sectors (paper, iron and steel, aluminium, steel, cement)	Intermediate goods production by sectors (paper, iron and steel, aluminium, steel, cement), and later allocated to the final service as embodied energy

* Energy (or material) services may support other services required by society e.g., education. However, in terms of energy or materials, they are covered by the other categories. We consider that clothing, culture and entertainment (chess, internationally recognised monuments, etc.) and health (medicine and medical equipment) form material services. They have not yet been evaluated as energy services.

There is also a conceptual and physical bridge between energy, materials and ecosystem services. The latter refer to those benefits that people obtain from ecosystems [109,110]. These include provisioning (e.g., food and water), regulating (e.g., flood and disease control), cultural and habitat/supporting services (e.g., nutrient cycling and shelter) [111,112]. In short, the biosphere and geosphere (amongst others) provide all organisms with the essential components that make life here on Earth possible. The technosphere, and those services which constitute it, are in turn dependent on the resources, including energy, materials and other services taken from Nature.

Figure 3 integrates the material services found in the technosphere with the ecosystem services categories found in the Earth system [111,112]. Thus, the concept of "material services" is fundamentally concerned with the fulfilment of societal needs and the provision of a higher quality of life within the technosphere.

In line with both the ecosystem services and the United Nation's energy services definition for the Millennium Development Goals [113], we define material services as:

> *"Those benefits that materials contribute to societal wellbeing, through fuels and products (regardless of whether or not they are supplied by the market) when they are put to proper use."*

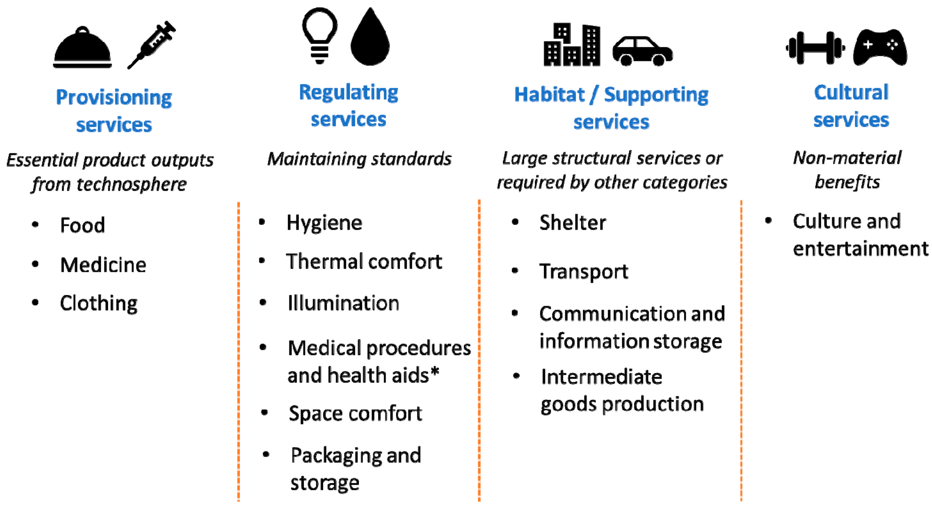

Figure 3. Material services at a glance. Note: Some services can be placed in more than one category depending on the exact nature of the service provided; however, this paper only aims to identify services and the conceptual links between the technosphere and Earth system services. * Health aids include glasses, wheel chairs, etc.

6.2. What Should an Eyes Wide Open Strategy Consider?

As the eyes wide open strategy incorporates "material services" it requires more than just a technical or engineering based solution. This is because it goes beyond material properties and making materials more efficiently, to ask why society produces a given material in the first place. It also extends the previous strategies, which are predominantly focused on efficiency and material quality, by considering how one ensures that the technosphere contributes to the fulfilment of societal needs, whilst enhancing (not degrading) the Earth and societal living standards.

The philosophical underpinnings of eyes wide open prioritise a positive net impact on society and the environment. This provides the guiding structure for "eyes wide open" to operate, wherein sustainable technical and technological decisions can be made. It also gives legitimacy to the socio-environmental concerns raised by those communities living in close proximity to important mineral reserves, such as the aforementioned Bolivian farmers, and those affected by poor end of life practices, such as in Agbogbloshie (see Section 3). Consequently, more stakeholders can be involved in the discussions surrounding the attainment of the sustainable development goals.

6.2.1. Establishing Criteria for Better Materials

For our theory to be practiced, society must begin to demand not just more materials or different materials, but better ones. Companies, kept in check by consumers and independent regulators, should ask the more important, and altogether more difficult, questions of, "Besides profit, why should we make this product?" and "How can we improve our production process to contribute to social and environmental improvements, rather than just cutting carbon emissions?"

Such questions, although poignant to society and discussed in Sections 1 and 2, are not raised in the one eye or both eyes open strategies because of their emphasis on energy, material performance and unit savings. There are various opportunities to integrate key developments occurring elsewhere in the academic community into a more complete sustainable material framework. Such developments lend themselves to proactive engineering solutions that promote better materials, as shown in Table 6. Accordingly, Industry leaders charged with evaluating the sustainability of materials should also explore resource depletion, toxicity, geographical location and resource renewability, and not just the physical characteristics of materials, i.e. resistance, tensile strength and pliability [114].

Table 6. Proposed criteria for evaluating better materials.

Better Material Criteria	Description	Measurement	Key References Supportive of the Concept
Resource depletion	Criticality of the raw material used in a product relative to natural reserve and market demand.	Mass of current product that can be easily substituted within a determined economy.	[115,116]
Toxicity	The number and concentration of hazardous chemicals in products along with the aggregated risk to the end user	Mass of toxic elements below acceptable level according to national legislation or corporate guidelines (CAS#)	[117,118] REACH 1907/2006
Geographical location	Confirmed ethical sourcing from social perspectives Confirmed ethical sourcing from an environmental/ecological perspective	Independently certified as a conflict zone and slave/child labour free products e.g., Kimberley Process, Fair Trade Independently certified as sensitive to the environment e.g., Rainforest Alliance	[119,120] Dodd-Frank Act 2010; Conflict Mineral Directive 2017/821
Resource renewability	The degree of renewable material utilised in the manufacture of a product or service.	Mass from renewable resources	[121,122]

6.2.2. Stock Optimisation

Stock optimisation, by definition, refers to the most appropriate selection of materials, and their use, relative to an agreed set of criteria. Under the "eyes wide open" strategy, the most obvious set of criteria are the sustainable development goals. Consequently, material allocation, supported by smarter demand and stock efficiency, should not be purely market based. For example, those in charge of stock efficiency must assess current stock levels, how stocks are being employed (or not) and whether (and to what degree) they support societal needs through their use of energy, labour and materials.

In the private sector, smarter demand drives efficiency as computer algorithms collect data to identify customer preferences and business teams evaluate how a service is being used. This improves resource allocation, user experience and leads to higher profit margins. All aspects are commonly achieved via a product service system (PSS). The latter increasingly supports a sharing and membership-based economy [123–125].

Car pools, such as BlaBlaCar [126], and various taxi apps, provide an example of where PSS is becoming the norm as customers are gaining convenient access to on demand, door to door transport services. Hence, many now question whether they actually need a car or just a convenient private service that simply takes them from A to B. Another example includes accommodation via the renting of empty rooms by private individuals as consumer preferences change from the hotel model to a more local and authentic feel [127].

Uber, Airbnb and Netflix are all examples of disruptive innovations that created paradigm shifts away from conventional ways to travel from one place to another, stay in accommodation and watch TV series, respectively [128,129]. They also happen to reduce, under the right regulations and monitoring, the need for stock accumulation. These services exemplify the membership economy of user based experiences built on continual relations and service renewals, instead of one-time buyers, owners and hoarders.

Decisions linked to resource allocation and PSS have a direct effect on what material is produced and how the resulting product is used. In this respect, perhaps Industry should not be encouraged by society to invest resources into improving a private vehicle service, when doing so diverts them from mass transport options. Trams and fast-speed trains have a higher carrying capacity and thus save more energy and resources per passenger-km.

Stock efficiency, although a scant amount of literature exists on it (see Section 2), builds on the aforementioned concept of material efficiency and its production focus of delivering the same number of unit product with less material. Stock efficiency considers accumulated stock, whether in use or obsolete. It is defined by the following formula:

$$stock\ efficiency = \frac{material\ service}{\frac{material\ stock}{life\ time}} \tag{1}$$

where the stock efficiency is the ratio between a given material service in a given year divided by material stock (inputs stock + in-use stock − obsolete stock and stock outputs as waste).

One should calculate material stock in terms of mass over its expected (or actual) lifetime. This is because, as Müller et al. [130] observe, it is not necessarily the direct annual consumption of a material that provides a service. Where lifetime is unknown, one can estimate it based on physical properties and cultural norms, as discussed in Skelton and Allwood [131]. Where stock provides more than one service, say the rare earth metals contained in a smartphone, one would need to allocate based on the frequency of use per service.

To compare and contrast material efficiency with stock efficiency, one should map material flows from the ore to the end use product to obtain the former, and then map from the end-use product on incorporation into stock. One can then evaluate how that stock is used to fulfil a service and its efficiency. Figure 4, in way of example, begins with iron ore extraction and follows the iron through to its implementation, within either the fleet (vehicle stock) of a public or private transport system used to provide mobility for a given year.

Stock efficiency does not provide the complete picture when it comes to societal material dependency as material services often require stock *and* consumables. The latter refer to those products that are typically only used once, unless subjected to recollection and further processing (e.g., paper, fuels and disposable sanitary products). On calculating the efficiency of both stock and consumables one obtains material service efficiency (φ) for a given year, as shown in Equation (2):

$$\varphi = \frac{material\ service}{\frac{material\ stock}{life\ time} + consumables} \tag{2}$$

The ability to differentiate between material efficiency and material service efficiency, and then to map their collective contribution to sustainable development, allows politicians and heads of industry to provide a better service by asking, to what extent do cars (as opposed to buses, trams and trains), or the lithium in the electric vehicle (as opposed to the fossil fuel in the diesel car), contribute to the quality of transport as a material service (which is considered, partly, in Figure 4). This is an important question when seven of the 17 Sustainable Development Goals include one or more targets that address both rural and urban transport [132]. This should lead to discussions on whether, or not, a material unit could be better employed elsewhere to bring about, for instance, sustainable water security, gender equality or poverty reduction.

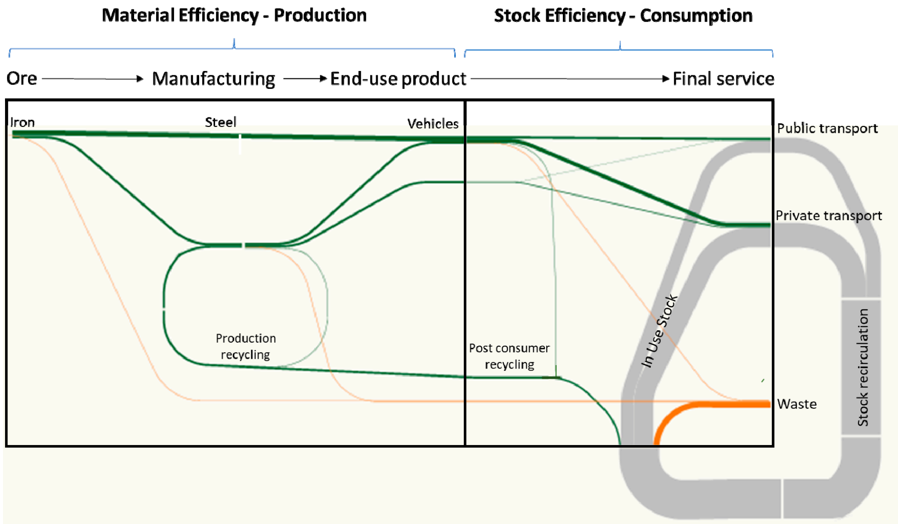

Figure 4. A proposed Sankey diagram tracing steel used to support transport as a material service.

6.2.3. Redefining Waste as a Concept

For waste issues, the "eyes wide open" strategy promotes principle 6 of the Hanover principles and the subsequent upcycling framework established by Braungart and McDonough [133,134] who argue that society does not have a waste issue, but a design one. This issue can disappear, or at least be very much reduced, via repurposing, which means that waste is not inevitable. Products and services can be designed to maximise "goods" instead of minimising "bads". Thus, a tier can be added to the top of the waste hierarchy, wherein the idea of producing less waste or "doing the wrong things better" is superseded by a society which does not believe in the end of life stage, but rather the reincarnation of products, once their first "life" has ended. In this respect, our strategy borrows heavily from the circular economy and the idea that we must look *beyond the current "take, make and dispose" extractive industrial model, to one that is restorative and regenerative by design* [135].

Designing for multiple uses where quality material resources rather than toxic, or difficult to recycle, residual is passed onto the next generation for their own use, is the true embodiment of sustainable development. This is because it adds to future possibilities rather than taking them away. Therefore, practitioners of the "eyes wide open" strategy ask how a product can be designed and manufactured with its next use in mind, either as a feedstock for the biosphere, or the technosphere, so cycles can continue (almost) indefinitely. The closing of cycles is made necessary by upgrading the quality of a given material upon its upcycling. This is contrary to the conventional recycling processes that degrade a material on each successive use. Upcycling can ensure that only one material is used in the construction of a product so that recycling is simplified. Where previous lives have added toxic components to a material, upcycling removes the toxins and makes it safer for use and re-use. An example of this is the removal of antimony in PET bottles before they are converted into polyester fleeces, which also reduces the likelihood of human and environmental health issues linked to the element's toxicity [134,136]. Under upscaling principles, fleece material should be kept at a higher-grade state by ensuring that no further additions, such as nylon zips, occur at the detriment of closing the material cycle. Where full closure of cycles is not possible, innovation is actively encouraged, particularly that which is linked to biomimicry [137,138].

6.3. What an Eyes Wide Open World Might Look Like

To understand how the "eyes wide open" strategy could work in the real world let's propose a new way of thinking about providing clothing to children. To create our "eyes wide open" business model and *modus operandi*, we must make a few assumptions. Firstly, few consumers, if they can afford not to, will knowingly buy clothes containing toxic compounds such as pesticides or antimony to clothe their children. Thus, the fashion industry should not place such elements in the cloth, and antimony-free PET should be used. Secondly, few, if any, members of society agree with slave or child labour. Consequently, fibres and finished garments should be sourced from fair trade cooperatives or at least in factories that do not employ children and where workers get a "living wage". The crop, from which the fibres are obtained, should require limited, if any pesticides and artificial fertiliser, as is the case for hemp, bamboo or organic cotton. This reduces the occupational illnesses, accidents and environmental issues associated with pesticide and fertiliser spraying. It also stops the chemical leaching that occurs if clothing happens to be disposed into landfill.

Under this system one can also go further than "doing less bad", by producing a fibre that cleans the process water used so that water that leaves the factory is purer than when it entered. The same concept could be employed for atmospheric carbon emissions, so that the company goes beyond carbon zero and waste. Zero waste would lead to clothes made of one material. Unsold clothes could be donated to homeless shelters or re-spun into different products. A British company known as The Hemp Trading Company (THTC) has pioneered this ethical approach to fashion by making men and ladies wear with environmental and social activist statements in their designs [139].

For the use stage, a membership relationship could be developed, either formally or informally. Formal options could be a yearly membership whereby parents "rent" their child's wardrobe and exchange the clothes that no longer fit for newer ones that accommodate the latest growth spurt. In this case, the user is provided with options from a catalogue and is not stuck with the problem of having excess clothes that serve no purpose. For the producer, there is a guaranteed (re-occurring) stable income over a determined period, which supports growth and makes investment decisions easier [140]. Furthermore, the returned material, whilst useless to the consumer, is a prime input for the producer, who having originally designed it for recycling, would potentially have a cheaper raw material option. The more complex reverse logistics could be financed in part by the yearly memberships.

An informal "membership" option, which has been tested by the clothing company C&A, provides vouchers to be used in store for those customers who return their old and unwanted item(s) [141]. These membership-based options remove the concept of waste, at least in theory, whilst also encouraging sales.

6.4. Challenges to an Eyes Wide Open World

Perhaps the hardest barrier to overcome is that this strategy is still in an embryonic stage. As one might expect with the establishment of a new approach, some of the ideas discussed in this paper have yet to be explored in detail or worked on by others in the scientific or business community. This paper, which could be interpreted by some as a manifesto, needs to receive interest from others for the ideas to grow into a body of knowledge that will be rigorous enough to cross the science-policy interface and trickle into the public domain.

There are also some issues within the solutions proposed which may hinder mass implementation. Products re-incorporated back into stock via upcycling, for example, may be more expensive because of the specialised knowledge and labour intensive practices required to reclaim material, as is the case for products as diverse as clothes to concrete [89,142,143]. Furthermore, upcycling a product which was not originally intended for re-use carries expensive costs thermodynamically [28]. This issue can be rectified at the design and production stage should one take into consideration the ease of upcycling as a product's end of life approaches.

The rebound effect is particularly difficult to estimate and predict. Optimising material use in line with societal needs, as opposed to pure market demand, may reduce its likelihood. This is because, in theory, one is effectively legislating, or at least reducing, the incentive to manufacture products that go against the sustainable development goals. That said, it is impossible, at this stage, to say how successfully the "eyes wide open" strategy could tackle the rebound effect; as such, further research and modelling is required.

Another point to consider is service quality, which would have to increase if one were to maximise use and customer experience in a shared/membership economy. There is, of course, a trade-off between quality and product longevity as materials may last longer than the usefulness of a product or service, which would inhibit sustainability gains. Evidence of this is the evolution of the record to cassette, then CDs to MP3s, in a period of only 30 years.

7. Discussion

There are some possible political implications to following a sustainable material policy that are briefly worth discussing. Foremost, there will certainly be tension points as one defines what a societal need is and where conflicts exist (one person's need could infringe upon another's). Linked to this idea, is that, under the "eyes wide open" strategy, the issue of ownership is important, despite its emphasis on user based transactions. Consequently, society must actively encourage transparent big data collection, open source software and design.

Collectively, and in way of an example, we must ensure that solar panels are not only leased by big corporations but also partly (or fully) owned by those that rely on the energy produced by them. Such thinking provides assurances to vulnerable communities, who are often relegated down the list of stakeholder priorities, because they become shareholders that can negate certain risks and enjoy a greater share of the profit [144]. However, this is a difficult balancing act, as neither should the "eyes wide open" approach stifle innovation and economic growth, where such growth contributes to the SDGs, nor should growth occur for its own sake.

An important question is whether, or perhaps to what extent, or how quickly, can those citizens of lesser developed nations join the membership economy, thus allowing their country to bypass some of the more detrimental effects of industrialisation and the environmental damage depicted on the environmental Kuznets curve. The difficulty in creating such a path, especially when it comes to materials, is that there are no examples of low industrialisation and high GDP per capita and there is no country with an Human Development Index (HDI) equal to or greater than 0.9, with a material footprint of less than 20 tonnes per capita [1]. Thus, there is, unfortunately, no road map depicting how one emerges out of poverty by leapfrogging the destructive processes that got other countries to where they are today. Likewise, no nation has achieved economic wealth without growth and no country has protected the environment with it [145].

Certainly, one way of providing a material service should be favoured over another if it effectively supports the United Nation's sustainable development goals [146]. Before this can be achieved, however, a consensus must be reached on what a "material service" is, what exactly it encompasses and how the term should be defined under the umbrella of sustainability. Does our definition of, "*Those benefits that materials contribute to societal wellbeing, through fuels and products (regardless of whether or not they are supplied by the market) when they are put to proper use*" suffice? Furthermore, given the multi-faceted nature of materials, which elements in each of the three identified strategies should we prioritise, and how do we tackle those issues we see as the most important?

Acknowledgments: We acknowledge the financial support of Fundação para a Ciência e a Tecnologia (FCT) and MIT Portugal Program through the grants PD/BP/113742/2015 and PD/BD/128038/2016; MARETEC by FCT/MCTES (PIDDAC) through project UID/EEA/50009/2013; and the support of Universidad Castilla-La Mancha (UCLM) in making this research possible. We thank LE and Hanna Murray-Carlsson for their advice, and Hanife Moumin for her editorial skills.

Author Contributions: Luis Gabriel Carmona and Kai Whiting conceived this study, led the narrative framing for the paper and coordinated its writing. All co-authors provided substantial inputs to writing and significant feedback on numerous drafts.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gutowski, T.; Cooper, D.; Sahni, S. Why we use more materials. *Phil. Trans. R. Soc. A* **2017**. [CrossRef] [PubMed]
2. Schandl, H.; Fischer-Kowalski, M.; West, J.; Giljum, S.; Dittrich, M.; Eisenmenger, N.; Geschke, A.; Lieber, M.; Wieland, H.; Schaffartzik, A. Global Material Flows and Resource Productivity: Forty Years of Evidence. *J. Ind. Ecol.* **2017**. [CrossRef]
3. Jackson, T. *Prosperity without Growth. Economics for a Finite Planet London*, 1st ed.; Earthscan: London, UK, 2009, ISBN 978-1-84971-323-8.
4. Milios, L. *Policies for Resource Efficient and Effective Solutions: A Review of Concepts, Current Policy Landscape and Future Policy Considerations for the Transition to a Circular Economy*; International Institute for Industrial Environmental Economics at Lund University—Mistra: Lund, Sweden, 2016.
5. Haefele, W. On energy demand. *IAEA Bull.* **1977**, *19*, 21–37.
6. Nakićenović, N.; Grübler, A.; Inaba, A.; Messner, S.; Nilsson, S.; Nishimura, Y.; Rogner, H.-H.; Schäfer, A.; Schrattenholzer, L.; Strubegger, M. Long-term strategies for mitigating global warming. *Energy* **1993**, *18*, 401. [CrossRef]
7. Gould, O.; Simeone, A.; Colwill, J.; Willey, R.; Rahimifard, S. A material flow modelling tool for resource efficient production planning in multi-product manufacturing systems. *Proc. CIRP* **2016**, *41*, 21–26. [CrossRef]
8. Fischer-Kowalski, M.; Krausmann, F.; Giljum, S.; Lutter, S.; Mayer, A.; Bringezu, S.; Moriguchi, Y.; Schütz, H.; Schandl, H.; Weisz, H. Methodology and indicators of economy-wide material flow accounting. *J. Ind. Ecol.* **2011**, *15*, 855–876. [CrossRef]
9. Allwood, J.M.; Cullen, J.M.; Carruth, M.A.; Cooper, D.R.; McBrien, M.; Milford, R.L.; Patel, A.C. *Sustainable Materials: With Both Eyes Open*, 1st ed.; UIT Cambridge: Cambridge, UK, 2012, ISBN 1-906860-07-6.
10. Gates, B. Reduce, Reuse, Retool. Available online: https://www.gatesnotes.com/Books/Sustainable-Materials-With-Both-Eyes-Open (accessed on 5 May 2017).
11. *ABC of SCP: Clarifying Concepts on Sustainable Consumption and Production*; United Nations Environment: Nairobi, Kenya, 2010.
12. Cullen, J.M.; Allwood, J.M. The efficient use of energy: Tracing the global flow of energy from fuel to service. *Energy Policy* **2010**, *38*, 75–81. [CrossRef]
13. Haberl, H.; Wiedenhofer, D.; Erb, K.H.; Görg, C.; Krausmann, F. The Material Stock–Flow–Service Nexus: A New Approach for Tackling the Decoupling Conundrum. *Sustainability* **2017**. [CrossRef]
14. Lane, R. Understanding the dynamic character of value in recycling metals from Australia. *Resources* **2014**, *3*, 416–431. [CrossRef]
15. Baptist, S.; Hepburn, C. Intermediate inputs and economic productivity. *Philos. Trans. R. Soc. A* **2013**, *371*, 1–21. [CrossRef] [PubMed]
16. Kooroshy, J.; Meindersma, C.; Rademaker, M.; Sweijs, T.; Diederen, A.M.; Beerthuijzen, M.; De Goede, S. *Scarcity of Minerals. A Strategic Security Issue*; The Hague Centre for Strategic Studies: The Hague, The Netherlands, 2009.
17. Ekvall, T.; Hirschnitz-Garbers, M.; Eboli, F.; Śniegocki, A. A systemic and systematic approach to the development of a policy mix for material resource efficiency. *Sustainability* **2016**, *8*, 373. [CrossRef]
18. Schandl, H.; Fischer-Kowalski, M.; West, J.; Giljum, S.; Dittrich, M.; Eisenmenger, N.; Geschke, A.; Lieber, M.; Wieland, H.P.; Schaffartzik, A. *Global Material Flows and Resource Productivity: Assessment Report for the UNEP International Resource Panel*; United Nations Environment Programme: Paris, France, 2016.
19. Krausmann, F.; Wiedenhofer, D.; Lauk, C.; Haas, W.; Tanikawa, H.; Fishman, T.; Miatto, A.; Schandl, H.; Haberl, H. Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 1880–1885. [CrossRef] [PubMed]
20. Wiedmann, T.O.; Schandl, H.; Lenzen, M.; Moran, D.; Suh, S.; West, J.; Kanemoto, K. The material footprint of nations. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 6271–6276. [CrossRef] [PubMed]
21. Dittrich, M.; Giljum, S.; Lutter, S.; Polzin, C. Green economies around the World? In *Implications of Resource Use for Development and the Environment*; Sustainable Europe Research Institute (SERI): Vienna, Austria, 2012; p. 43.

22. Schandl, H.; Hatfield-Dodds, S.; Wiedmann, T.; Geschke, A.; Cai, Y.; West, J.; Newth, D.; Baynes, T.; Lenzen, M.; Owen, A. Decoupling global environmental pressure and economic growth: Scenarios for energy use, materials use and carbon emissions. *J. Clean. Prod.* **2016**, *132*, 45–56. [CrossRef]
23. Fischer-Kowalski, M.; Swilling, M.; Von Weizsacker, E.U.; Ren, Y.; Moriguchi, Y.; Crane, W.; Krausmann, F.K.; Eisenmenger, N.; Giljum, S.; Hennicke, P. *Decoupling: Natural Resource Use and Environmental Impacts from Economic Growth*; United Nations Environment Programme: Paris, France, 2011, ISBN 92-807-3167-X.
24. Chen, W.-Q.; Graedel, T.E. In-use product stocks link manufactured capital to natural capital. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 6265–6270. [CrossRef] [PubMed]
25. Rogich, D.; Cassara, A.; Wernick, I.; Miranda, M. *Material Flows in the United States: A Physical Accounting of the US Industrial Economy*; World Resources Institute (WRI): Washington, DC, USA, 2008; p. 10.
26. Weisz, H.; Suh, S.; Graedel, T.E. Industrial Ecology: The role of manufactured capital in sustainability. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 6260–6264. [CrossRef] [PubMed]
27. Schnaiberg, A. *Environment: From Surplus to Scarcity*; Oxford University Press: Oxford, UK, 1980.
28. Cullen, J.M. Circular Economy: Theoretical Benchmark or Perpetual Motion Machine? *J. Ind. Ecol.* **2017**, *21*, 483–486. [CrossRef]
29. Kahneman, D.; Knetsch, J.L.; Thaler, R.H. Anomalies: The endowment effect, loss aversion, and status quo bias. *J. Econ. Perspect.* **1991**, *5*, 193–206. [CrossRef]
30. Kallis, G. Radical dematerialization and degrowth. *Philos. Trans. R. Soc. A* **2017**. [CrossRef] [PubMed]
31. Burke, P.J.; Shahiduzzaman, M.; Stern, D.I. Carbon dioxide emissions in the short run: The rate and sources of economic growth matter. *Glob. Environ. Chang.* **2015**, *33*, 109–121. [CrossRef]
32. Whiting, K.; Carmona, L.G.; Carrasco, A.; Sousa, T. Exergy Replacement Cost of Fossil Fuels: Closing the Carbon Cycle. *Energies* **2017**, *10*, 979. [CrossRef]
33. Phillips, J.; Whiting, K. A geocybernetic analysis of the principles of the Extractive Industries Transparency Initiative (EITI). *Resour. Policy* **2016**, *49*, 248–265. [CrossRef]
34. Peters, G.P.; Minx, J.C.; Weber, C.L.; Edenhofer, O. Growth in emission transfers via international trade from 1990 to 2008. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 8903–8908. [CrossRef] [PubMed]
35. Lenzen, M.; Moran, D.; Kanemoto, K.; Foran, B.; Lobefaro, L.; Geschke, A. International trade drives biodiversity threats in developing nations. *Nature* **2012**, *486*, 109–112. [CrossRef] [PubMed]
36. Lenzen, M.; Moran, D.; Bhaduri, A.; Kanemoto, K.; Bekchanov, M.; Geschke, A.; Foran, B. International trade of scarce water. *Ecol. Econ.* **2013**, *94*, 78–85. [CrossRef]
37. Automobile Catalog: 1950 Ford (USA) Custom Tudor Sedan All Versions Specifications and Performance Data. Available online: http://www.automobile-catalog.com/make/ford_usa/full-size_ford_2gen/full-size_ford_2gen_custom_2-door_sedan/1950.html (accessed on 1 May 2017).
38. The Pneumatic Tire. Available online: https://www.fueleconomy.gov/feg/pdfs/PneumaticTire_HS-810-561.pdf (accessed on 5 May 2017).
39. Schirber, M. The Chemistry of Life: The Plastic in Cars. Available online: https://www.livescience.com/5449-chemistry-life-plastic-cars.html (accessed on 5 May 2017).
40. *Annual Energy Review 2011*; Energy Information Administration: Washington, DC, USA, 2012.
41. Habermacher, F. *Modeling Material Inventories and Environmental Impacts of Electric Passenger Cars*; Department of Environmental Science ETH: Zürich, Switzerland, 2011.
42. Graedel, T. Rare Earths and Other Scarce Metals: Technologically Vital but Usually Thrown Away. Available online: http://www.rsc.org/images/Thomas-Graedel_tcm18-230232.pdf (accessed on 5 May 2017).
43. Valero Capilla, A.; Valero Delgado, A. *Thanatia: The Destiny of the Earth's Mineral Resources: A Thermodynamic Cradle-to-cradle Assessment*; World Scientific: Singapore, 2014, ISBN 981-4602-49-3.
44. Del Duce, A.; Gauch, M.; Althaus, H.-J. Electric passenger car transport and passenger car life cycle inventories in ecoinvent version 3. *Int. J. Life Cycle Assess.* **2016**, *21*, 1314–1326. [CrossRef]
45. Fuelly Toyota Prius MPG. Available online: http://www.fuelly.com/car/toyota/prius (accessed on 18 August 2017).
46. MadeHow Typewriter. Available online: http://www.madehow.com/Volume-7/Typewriter.html (accessed on 5 May 2017).
47. Hischier, R.; Classen, M.; Lehmann, M.; Scharnhorst, W. Life Cycle Inventories of Electric and Electronic Equipment: Production, Use and Disposal. Available online: http://www.ecoinvent.org/database/

older-versions/ecoinvent-version-2/reports-on-ecoinvent-2/reports-on-ecoinvent-2.html#1662 (accessed on 24 August 2017).
48. Technical Specifications of the Cisco Phone IP 7960G/7940G. Available online: http://www.cisco.com/c/en/us/td/docs/voice_ip_comm/cuipph/7960g_7940g/sip/7_5/english/administration/guide/ver7_5/sipaxc75.pdf (accessed on 1 May 2017).
49. Koomey, J.G. A primer on the energy efficiency of computing. *AIP Conf. Proc.* **2015**, *1652*, 82–89.
50. OldPhone 1957 Western Electric Telephone Model 500 Fully. Available online: http://www.oldphoneshop.com/products/1957-western-electric-telephone-model-500-fully-restored.html (accessed on 5 May 2017).
51. The Henry Ford Zenith Saratoga Radio-Phonograph Combination, Model H664. 1950–1952. Available online: https://www.thehenryford.org/collections-and-research/digital-collections/artifact/295506 (accessed on 5 May 2017).
52. How Light Bulb Is Made. Available online: http://www.madehow.com/Volume-1/Light-Bulb.html (accessed on 5 May 2017).
53. How Heavy Is 15 Grams? Available online: http://www.bluebulbprojects.com/measureofthings/results.php?comp=weight&unit=gms&amt=15&sort=pr&p=1 (accessed on 1 May 2017).
54. A Basic Guide to How LED Lights Work. Available online: http://www.compoundchem.com/2016/12/14/leds/ (accessed on 1 August 2017).
55. Funk, J. New Light-Weight LED Bulb from Cree Costs Less, Is Brighter and Last 22 Years. Available online: http://www.cleveland.com/business/index.ssf/2014/10/new_light-weight_led_bulb_from.html (accessed on 5 May 2017).
56. Light-Emitting Diode (LED). Available online: http://www.madehow.com/Volume-1/Light-Emitting-Diode-LED.html (accessed on 5 May 2017).
57. How Energy-Efficient Light Bulbs Compare with Traditional Incandescents. Available online: https://energy.gov/energysaver/how-energy-efficient-light-bulbs-compare-traditional-incandescents (accessed on 5 May 2017).
58. MacKay, D. *Sustainable Energy-without the Hot Air*; UIT Cambridge: Cambridge, UK, 2008, ISBN 0-9544529-3-3.
59. Kushnir, D.; Sandén, B.A. The time dimension and lithium resource constraints for electric vehicles. *Resour. Policy* **2012**, *37*, 93–103. [CrossRef]
60. Ericksen, G.E.; Vine, J.D.; Ballón, A.R. Chemical composition and distribution of lithium-rich brines in Salar de Uyuni and nearby salars in southwestern Bolivia. *Energy* **1978**, *3*, 355–363. [CrossRef]
61. Garrett, D.E. *Handbook of Lithium and Natural Calcium Chloride*; Elsevier Academic Press: Oxford, UK, 2004, ISBN 0-08-047290-7.
62. Aguilar-Fernández, R. Estimating the Opportunity Cost of Lithium Extraction in the Salar de Uyuni, Bolivia. Available online: https://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/1554/Aguilar,%20Rodrigo_MP_2009.pdf (accessed on 18 August 2017).
63. Hindery, D. *From Enron to Evo: Pipeline Politics, Global Environmentalism, and Indigenous Rights in Bolivia*; University of Arizona Press: Tucson, AZ, USA, 2013, ISBN 0-8165-0237-4.
64. Romero, H.; Méndez, M.; Smith, P. Mining development and environmental injustice in the Atacama Desert of Northern Chile. *Environ. Justice* **2012**, *5*, 70–76. [CrossRef]
65. Grosjean, M.; Geyh, M.A.; Messerli, B.; Schotterer, U. Late-glacial and early Holocene lake sediments, ground-water formation and climate in the Atacama Altiplano 22–24°S. *J. Paleolimnol.* **1995**, *14*, 241–252. [CrossRef]
66. Derraik, J.G. The pollution of the marine environment by plastic debris: A review. *Mar. Pollut. Bull.* **2002**, *44*, 842–852. [CrossRef]
67. Law, K.L.; Morét-Ferguson, S.; Maximenko, N.A.; Proskurowski, G.; Peacock, E.E.; Hafner, J.; Reddy, C.M. Plastic accumulation in the North Atlantic subtropical gyre. *Science* **2010**, *329*, 1185–1188. [CrossRef] [PubMed]
68. Minter, A. The Burning Truth behind an E-Waste Dump in Africa. Available online: http://www.smithsonianmag.com/science-nature/burning-truth-behind-e-waste-dump-africa-180957597/ (accessed on 5 June 2017).
69. Gutowski, T.G.; Allwood, J.M.; Herrmann, C.; Sahni, S. A global assessment of manufacturing: economic development, energy use, carbon emissions, and the potential for energy efficiency and materials recycling. *Annu. Rev. Environ. Resour.* **2013**, *38*, 81–106. [CrossRef]

70. Allwood, J.M.; Cullen, J.M.; Milford, R.L. Options for achieving a 50% cut in industrial carbon emissions by 2050. *Environ. Sci. Technol.* **2010**, *44*, 1888–1894. [CrossRef] [PubMed]
71. Gutowski, T.G.; Sahni, S.; Allwood, J.M.; Ashby, M.F.; Worrell, E. The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. *Philos. Trans. R. Soc. A* **2013**. [CrossRef] [PubMed]
72. Allwood, J.M.; Cullen, J.M. *Sustainable Materials without the Hot Air: Making Buildings, Vehicles and Products Efficiently and with Less New Material*, 2nd ed.; UIT Cambridge: Cambridge, UK, 2015, ISBN 978-1-906860-30-1.
73. Gould, O.; Colwill, J. A framework for material flow assessment in manufacturing systems. *J. Ind. Prod. Eng.* **2015**, *32*, 55–66. [CrossRef]
74. Jevons, W.S. The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of the Coal-Mines. Available online: https://archive.org/details/coalquestionani00jevogoog (accessed on 24 August 2017).
75. Zink, T.; Geyer, R. Circular Economy Rebound. *J. Ind. Ecol.* **2017**, *21*, 593–602. [CrossRef]
76. Stapleton, L.; Sorrell, S.; Schwanen, T. Estimating direct rebound effects for personal automotive travel in Great Britain. *Energy Econ.* **2016**, *54*, 313–325. [CrossRef]
77. Allwood, J.M.; Gutowski, T.G.; Serrenho, A.C.; Skelton, A.C.; Worrell, E. Industry 1.61803: the transition to an industry with reduced material demand fit for a low carbon future. *Philos. Transact. A Math. Phys. Eng. Sci.* **2017**. [CrossRef] [PubMed]
78. House of Commons—Energy and Climate Change Committee. *Future of Carbon Capture and Storage in the UK*; HM Stationery Office: London, UK, 2016.
79. Global CCS Institute The Global Status of CCS 2015: Summary Report. Available online: https://www.globalccsinstitute.com (accessed on 1 February 2017).
80. Ayres, R.U.; Peiró, L.T. Material efficiency: rare and critical metals. *Philos. Trans. R. Soc. A* 2013. [CrossRef] [PubMed]
81. Park, J.; Yoon, J.; Kim, K.-H. Critical Review of the Material Criteria of Building Sustainability Assessment Tools. *Sustainability* **2017**, *9*, 186. [CrossRef]
82. Milford, R.L.; Pauliuk, S.; Allwood, J.M.; Müller, D.B. The roles of energy and material efficiency in meeting steel industry CO_2 targets. *Environ. Sci. Technol.* **2013**, *47*, 3455–3462. [CrossRef] [PubMed]
83. MacKenzie, D.; Zoepf, S.; Heywood, J. Determinants of US passenger car weight. *Int. J. Veh. Des.* **2014**, *65*, 73–93. [CrossRef]
84. Cabrera Serrenho, A.; Allwood, J.M. Material stock demographics: Cars in Great Britain. *Environ. Sci. Technol.* **2016**, *50*, 3002–3009. [CrossRef] [PubMed]
85. Steinberger, J.K.; Krausmann, F.; Getzner, M.; Schandl, H.; West, J. Development and dematerialization: An international study. *PLOS ONE* **2013**. [CrossRef] [PubMed]
86. Pfaff, M.; Sartorius, C. Economy-wide rebound effects for non-energetic raw materials. *Ecol. Econ.* **2015**, *118*, 132–139. [CrossRef]
87. Magee, C.L.; Devezas, T.C. A simple extension of dematerialization theory: Incorporation of technical progress and the rebound effect. *Technol. Forecast. Soc. Chang.* **2017**, *117*, 196–205. [CrossRef]
88. Pauliuk, S.; Müller, D.B. The role of in-use stocks in the social metabolism and in climate change mitigation. *Glob. Environ. Chang.* **2014**, *24*, 132–142. [CrossRef]
89. Cooper, D.R.; Gutowski, T.G. The environmental impacts of reuse: A review. *J. Ind. Ecol.* **2017**, *21*, 38–56. [CrossRef]
90. Prabhu, J. Frugal innovation: doing more with less for more. *Philos. Trans. R. Soc. A* **2017**. [CrossRef] [PubMed]
91. Fletcher, K. *Craft of Use: Post-Growth Fashion*; Routledge: London, UK, 2016, ISBN 1-317-29782-2.
92. Fletcher, K. Exploring demand reduction through design, durability and 'usership' of fashion clothes. *Philos. Trans. R. Soc. A* **2017**. [CrossRef] [PubMed]
93. Gracey, F.; Moon, D. Valuing our clothes: the evidence base; Waste & Resources Action Programme (WRAP). Available online: http://www.wrap.org.uk/sites/files/wrap/VoC%20FINAL%20online%202012%2007%2011.pdf (accessed on 1 August 2017).
94. Chapman, J. *Emotionally Durable Design: Objects, Experiences, and Empathy*, 1st ed.; Earthscan: London, UK, 2005, ISBN 978-1-84407-181-4.

95. Allwood, J.M.; Ashby, M.F.; Gutowski, T.G.; Worrell, E. Material efficiency: A white paper. *Resour. Conserv. Recycl.* **2011**, *55*, 362–381. [CrossRef]
96. Serrenho, A.C.; Mourão, Z.S.; Norman, J.; Cullen, J.M.; Allwood, J.M. The influence of UK emissions reduction targets on the emissions of the global steel industry. *Resour. Conserv. Recycl.* **2016**, *107*, 174–184. [CrossRef]
97. Tukker, A.; Bulavskaya, T.; Giljum, S.; de Koning, A.; Lutter, S.; Simas, M.; Stadler, K.; Wood, R. The Global Resource Footprint of Nations: Carbon, Water, Land and Materials Embodied in Trade and Final Consumption Calculated with EXIOBASE 2.1. Available online: http://www.truthstudio.com/content/CREEA_Global_Resource_Footprint_of_Nations.pdf (accessed on 24 August 2017).
98. Söderholm, P.; Tilton, J.E. Material efficiency: An economic perspective. *Resour. Conserv. Recycl.* **2012**, *61*, 75–82. [CrossRef]
99. Schatzberg, E. Symbolic culture and technological change: The cultural history of Aluminum as an industrial material. *Enterp. Soc.* **2003**, *4*, 226–271. [CrossRef]
100. Shove, E. *The Design of Everyday Life*; Berg: Oxford, UK, 2007, ISBN 1-84520-683-5.
101. Bethell, L. Historia de América latina. In *América Latina Colonial: Economía*, 1st ed.; Crítica: Barcelona, Spain, 1990, ISBN 84-7423-477-8.
102. Ruiz, M.D.C.C. El atractivo turístico de una de las minas de mercurio más importantes del mundo: el parque minero de Almadén (Ciudad Real). *Cuad. Tur.* **2008**, *21*, 9–31.
103. Pauliuk, S.; Sjöstrand, K.; Müller, D.B. Transforming the Norwegian dwelling stock to reach the 2 degrees Celsius climate target. *J. Ind. Ecol.* **2013**, *17*, 542–554. [CrossRef]
104. Sousa, T.; Brockway, P.E.; Cullen, J.M.; Henriques, S.T.; Miller, J.; Serrenho, A.C.; Domingos, T. The Need for Robust, Consistent Methods in Societal Exergy Accounting. *Ecol. Econ.* **2017**, *141*, 11–21. [CrossRef]
105. Nakićenović, N. Diffusion of pervasive systems: a case of transport infrastructures. *Technol. Forecast. Soc. Chang.* **1991**, *39*, 181–200. [CrossRef]
106. Nakićenović, N.; Gilli, P.V.; Kurz, R. Regional and global exergy and energy efficiencies. *Energy* **1996**, *21*, 223–237. [CrossRef]
107. Schaeffer, R.; Wirtshafter, R.M. An exergy analysis of the Brazilian economy: From energy production to final energy use. *Energy* **1992**, *17*, 841–855. [CrossRef]
108. IEA Energy Technology Perspectives. 2012. Available online: www.iea.org/media/etp/2012/ETP2012_Sankey.pdf (accessed on 5 May 2017).
109. Daily, G. *Nature's Services: Societal Dependence on Natural Ecosystems*; Island Press: Washington, DC, USA, 1997, ISBN 1-55963-476-6.
110. Costanza, R.; d'Arge, R.; De Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'neill, R.V.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
111. *Millenium Ecosystem Assessment Ecosystems and Human Well-being: A Framework for Assessment*, 1st ed.; World Resources Institute: Washington, DC, USA, 2005, ISBN 1-55963-403-0.
112. De Groot, R.S.; Fisher, B.; Christie, M.; Aronson, J.; Braat, L.; Haines-Young, R.; Gowdy, J.; Maltby, E.; Neuville, A.; Polasky, S. Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. In *The Economics of Ecosystems and Biodiversity (TEEB): Ecological and Economic Foundations*; Earthscan: London, UK, 2010, ISBN 1-84971-212-3.
113. Modi, V.; McDade, S.; Lallement, D.; Saghir, J. *Energy Services for the Millenium Development Goals*; United Nations Development Programme: Washington, DC, USA, 2005.
114. Anastas, P.T.; Warner, J.C. *Green Chemistry: Theory and Practice*; Oxford University Press: Oxford, UK, 1998, ISBN 0-19-850234-6.
115. Henckens, M.; van Ierland, E.C.; Driessen, P.P.J.; Worrell, E. Mineral resources: Geological scarcity, market price trends, and future generations. *Resour. Policy* **2016**, *49*, 102–111. [CrossRef]
116. Henckens, M.; Driessen, P.P.J.; Ryngaert, C.; Worrell, E. The set-up of an international agreement on the conservation and sustainable use of geologically scarce mineral resources. *Resour. Policy* **2016**, *49*, 92–101. [CrossRef]
117. Braungart, M.; McDonough, W.; Bollinger, A. Cradle-to-cradle design: creating healthy emissions–a strategy for eco-effective product and system design. *J. Clean. Prod.* **2007**, *15*, 1337–1348. [CrossRef]

118. Lavoie, E.T.; Heine, L.G.; Holder, H.; Rossi, M.S.; Lee, R.E., II; Connor, E.A.; Vrabel, M.A.; DiFiore, D.M.; Davies, C.L. Chemical Alternatives Assessment: Enabling Substitution to Safer Chemicals. *Environ. Sci. Technol.* **2011**, *45*, 1747. [CrossRef]
119. Young, S.B. Responsible sourcing of metals: certification approaches for conflict minerals and conflict-free metals. *Int. J. Life Cycle Assess.* **2015**. [CrossRef]
120. Hosseinijou, S.A.; Mansour, S.; Shirazi, M.A. Social life cycle assessment for material selection: a case study of building materials. *Int. J. Life Cycle Assess.* **2014**, *19*, 620–645. [CrossRef]
121. Llevot, A.; Meier, M.A. Renewability—A principle of utmost importance! *Green Chem.* **2016**, *18*, 4800–4803. [CrossRef]
122. Sikkema, R.; Junginger, M.; van Dam, J.; Stegeman, G.; Durrant, D.; Faaij, A. Legal harvesting, sustainable sourcing and cascaded use of wood for bioenergy: Their coverage through existing certification frameworks for sustainable forest management. *Forests* **2014**, *5*, 2163–2211. [CrossRef]
123. Sundararajan, A. *The Sharing Economy: The End of Employment and the Rise of Crowd-based Capitalism*; MIT Press: Cambridge, USA, 2016, ISBN 0-262-03457-3.
124. Baines, T.; Lightfoot, H. *Made to Serve: How Manufacturers Can Compete through Servitization and Product Service Systems*; John Wiley & Sons: Hoboken, NJ, USA, 2013, ISBN 1-118-58528-3.
125. Baxter, R.K. *The Membership Economy: Find Your Super Users, Master the Forever Transaction, and Build Recurring Revenue*; McGraw-Hill: New York, NY, USA, 2015, ISBN 0-07-183932-1.
126. Mazzella, F. BlaBlaCar et le tourisme collaboratif. In *Annales des Mines-Réalités industrielles*; FFE: Dallas, TX, USA, 2015; pp. 54–57.
127. Guttentag, D. Airbnb: Disruptive innovation and the rise of an informal tourism accommodation sector. *Curr. Issues Tour.* **2015**, *18*, 1192–1217. [CrossRef]
128. Cusumano, M.A. How traditional firms must compete in the sharing economy. *Commun. ACM* **2015**, *58*, 32–34. [CrossRef]
129. Belk, R. You are what you can access: Sharing and collaborative consumption online. *J. Bus. Res.* **2014**, *67*, 1595–1600. [CrossRef]
130. Müller, D.B.; Cao, J.; Kongar, E.; Altonji, M.; Weiner, P.-H.; Graedel, A.T. Service lifetimes of mineral end uses. Available online: https://minerals.usgs.gov/mrerp/reports/Mueller-06HQGR0174.pdf (accessed on 24 August 2017).
131. Skelton, A.C.; Allwood, J.M. Product life trade-offs: what if products fail early? *Environ. Sci. Technol.* **2013**, *47*, 1719–1728. [CrossRef] [PubMed]
132. The Role of Transport in the Sustainable Development Goals. Available online: https://www.itdp.org/the-role-of-transport-in-the-sustainable-development-goals/ (accessed on 5 May 2017).
133. McDonough, W.; Braungart, M. *The Hannover Principles*; William McDonough Architects: New York, NY, USA, 1992.
134. McDonough, W.; Braungart, M. *The Upcycle: Beyond Sustainability—Designing for Abundance*; North Point Press: New York, NY, USA, 2013, ISBN 0-86547-748-5.
135. Ellen MacArthur Foundation What Is a Circular Economy? Available online: https://www.ellenmacarthurfoundation.org/circular-economy (accessed on 13 Aug 2017).
136. Henckens, M.; Driessen, P.P.J.; Worrell, E. How can we adapt to geological scarcity of antimony? Investigation of antimony's substitutability and of other measures to achieve a sustainable use. *Resour. Conserv. Recycl.* **2016**, *108*, 54–62. [CrossRef]
137. Benyus, J. *Biomimicry: Innovation Inspired by Nature*; William Morrow & Company: New York, NY, USA, 1997.
138. De Pauw, I.C.; Kandachar, P.; Karana, E. Assessing sustainability in nature-inspired design. *Int. J. Sustain. Eng.* **2015**, *8*, 5–13. [CrossRef]
139. The Hemp Trading Company. Available online: https://shop.thtc.co.uk (accessed on 15 June 2017).
140. Warrillow, J. *The Automatic Customer: Creating a Subscription Business in any Industry*; Penguin: London, UK, 2015, ISBN 1-59184-746-X.
141. Company Sustainable Products. Available online: http://materialimpacts.c-and-a.com/sustainable-products/ (accessed on 15 May 2017).
142. Cumming, D. A Case Study Engaging Design for Textile Upcycling. *J. Text. Des. Res. Pract.* **2016**, *4*, 113–128. [CrossRef]

143. Oyenuga, A.A.; Bhamidimarri, R. Upcycling Ideas for Sustainable Construction and Demolition Waste Management: Challenges, Opportunities and Boundaries. Available online: https://www.researchgate.net/publication/315762443_Upcycling_ideas_for_Sustainable_Construction_and_Demolition_Waste_Management_Challenges_Opportunities_and_Boundaries (accessed on 1 August 2017).
144. Klein, N. Change the System Not the Climate World Social Forum Montreal 14th April 2017. Available online: https://www.youtube.com/watch?v=bjDXjVIdLnA (accessed on 15 June 2017).
145. Raworth, K. *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist*; Chelsea Green Publishing: Vermont, VT, USA, 2017, ISBN 1-60358-674-1.
146. Transforming Our World: The 2030 Agenda for Sustainable Development. Available online: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (accessed on 24 August 2017).