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Research article

Product longevity and shared ownership: sustainable routes to satisfying the world's growing demand for goods

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Abstract: It has been estimated that by 2030 the number of people who are wealthy enough to be significant consumers will have tripled. This will have a dramatic impact on the demands for primary materials and energy. It has been estimated that with improvements in design and manufacturing it is possible to maintain the current level of production using 70% of the current primary material consumed. Even with these improvements on the production side, there will still be a doubling of primary material requirements by the end of the century, with accompanying rises in industrial energy demand, if the rise in demand for goods and services is to be met. It is therefore clear that the consumption of products must also be explored. Product longevity and using goods more intensively are two strategies which could reduce the demand for new goods. If products last longer, then manufacturing output can concentrate on emerging markets rather than the market for replacement goods. There are many goods which are infrequently used, these seldom wear out. The total demand for such could be drastically reduced if they were shared with other people. Sharing of goods has traditionally been conducted between friends or by hiring equipment, but modern communication systems and social media could increase the opportunities to share goods. Sharing goods also increases access to a range of goods for those on low incomes. From a series of workshops it has been found that the principal challenges are sociological rather than technological. This paper contains a discussion of these challenges and explores possible futures where these two strategies have been adopted. In addition, the barriers and opportunities that these strategies offer for consumers and businesses are identified, and areas where government policy could be instigated to bring about change are highlighted.

Keywords: industrial emissions limits; satisfying global demand for goods; product longevity; improved utilisation; barriers benefits & drivers

1. Introduction

It has been estimated that the global middle class will rise from 1.8 billion in 2009 to 4.9 billion in 2030 [1]. Assuming that they will aspire to a western consumerist lifestyle this will result in a proportional rise in the demand for goods and services needing industrial products. This will have a severe impact on the demand for primary materials (steel, aluminum, plastics, cement etc.) and the industrial energy required to make them into finished goods. At the same time there is a general consensus that something needs to be done to reduce global greenhouse gas emissions (GHG) [2]. The International Energy Agency (IEA) estimate that to avoid damaging climate change GHG, emissions will need to be lowered by 50% from today's level by 2050. Some sectors of the global economy are easier to decarbonise than others. It is recognized that industrial production is hard to decarbonise and this is reflected in the IEA's de-carbonisation target, a 23% reduction for this sector [3].

It is hard to see how these two aspirations, for increased demand in goods and services and for adequate reduction in GHG emissions, can be reconciled with current business practices. This paper estimates the extent of the problem and demonstrates the insufficiency of production-side measures alone to meet them, introduces techniques that can help ameliorate it through improving product utilisation and reports on the finding of a workshop that discussed opportunities, drivers and barriers to changing business practices so that they can prosper in a world where there are limits to expansion.

2. Nomenclature

E total global greenhouse gas emissions from global industry.

N is the number of a hypothetical typical goods that the manufacture of would produce the same global environmental impact as global industry.

C is the GHG emissions associated with typical goods so $E = NC$

U is utilisation, a multi-dimensional measure of how much use is made of a particular good.

S is a multi-dimensional measure of the global demand for the service provided by goods so $S = NU$

The following suffixes are used:

D for direct emissions

P for emissions associated with primary material production

M for emissions associated with the manufacturing, distribution and retailing of goods

I for indirect emissions

Numerical suffixes represent years

3. Materials and Methods

3.1. Impact of emission target on industrial production

Industrial emissions are made up of direct emissions (E_D) that are emitted from the industrial plants themselves and indirect emissions (E_I) which are those associated with providing energy for industrial process and transporting materials and fuel to production facilities. The IEA estimate that 56% of direct industrial GHG emissions come from the production of primary materials that are used to make other goods. Manufacturing processes account for the remaining emissions [3]. Indirect emissions account for 31% of all industrial emissions. The principle source of indirect emissions is electricity generation. Electricity generation and transport are subject to different emission targets from industry.

If we consider emissions in 2010

$$E = E_D + E_I = E_{PD} + E_{MD} + E_I \quad (1)$$

applying the IEA energy distribution fractions

$$E_D = 0.69\,E\ ,\ E_{PD} = 0.56E_D\ , E_{MD} = 0.44E_D \quad (2)$$

the values of each component of the industrial emissions are

$$E_{PD} = 0.4E,\ \ E_{MD} = 0.3E\ and\ E_I = 0.3E \quad (3)$$

Industrial plants and processes are subject to ongoing improvements which will result in reductions of GHG emissions. For the majority of industries most of the emissions associated with their products come from the production of the primary material used to make the product rather than the manufacturing process. Not all industrial plants are designed or operated to minimise emissions. Estimates of the GHG savings that may be made by adopting world's best practice in individual primary material sectors are given in [4,5]. An emissions weighted average of potential GHG saving that could be achieved by bringing all operations up to world's best practice across all primary material sectors produced an estimate of 24%. Primary materials tend not to be used in their basic form and it has been estimated that through improvements in manufacturing practice to reduce manufacturing waste and product design optimisation it should be possible to improve material efficiency by 30% [6,7] i.e. the amount of primary material needed to make goods could be reduced by 30%. If these improvements in the production and use of primary materials were made it would reduce direct industrial emissions by 47%.

An estimation of the potential GHG emissions savings for the manufacturing sector can be inferred from estimations of potential energy saving. The IEA estimate that by adopting best practices it should be possible to reduce specific industrial energy demand by 20 to 30% [3] by improved process efficiency and operational practice. This is consistent with estimates in other literature [5,6].

Electricity accounts for the majority of energy used by industry. From the IEA world Energy Outlook [8] it looks likely that the reduction in carbon intensity of electricity generation could be in the order of 30% to 60% by 2030. This would give a combined GHG emissions saving from indirect emissions in the range of 44–72%. As the GHG intensity of electricity varies considerably with location, it was decided to use the lower estimate of potential savings.

If we assume that the savings identified above have been made by 2030 we have:

$$E_{2030} = 0.53E_{PD2010} + 0.75E_{MD2010} + 0.56E_{I2010} \tag{4}$$

Which if the ratios between direct and indirect emissions remain constant gives:

$$E_{2030} = 0.60E_{2010} \tag{5}$$

The IEA reduction target for industrial emissions is 23% which appears to be achievable by adopting world's best industrial practices and partial decarbonisation of the electricity sector. However, this disregards the effect of rising demand for goods. To stay within the emissions target:

$$E_{2030} \leq 0.77E_{2010}$$

So

$$N_{2030}C_{2030} \leq 0.77N_{2010}C_{2010}$$

It can be implied from equation 5 that: $C_{2030} = 0.6C_{2010}$

So the limit for the increase in production that is possible within these constraints is:

$$N_{2030} \leq 1.28N_{2010} \tag{6}$$

If the utilisation of goods remains the same, and the increase in the number of goods is proportional with the increase in the global middle class, then $N_{2030} = 2.7\,N_{2010}$. This presents additional challenges including massive investment in new production plants and an increase in the supply of raw materials, some of which are already considered to be scarce [6]. This increase in production is much higher than the maximum amount permitted under equation 4. Clearly even if the best available practice is adopted across the World's industry it will not be possible to produce enough goods to meet this demand and stay within the IEA's industrial emission target.

An alternative strategy is to see if the utility provided by goods can be maintained with a reduced supply of new goods. There are two ways that this can be achieved, by making goods last longer so they don't need replacing so often and sharing infrequently used items amongst groups of users to reduce demand for actual goods.

If the service supplied by the goods is defined as:

$$S = UN$$

$$U_{2030} = \frac{S_{2030}}{N_{2030}}$$

If the production is limited to the value from equation 4 and the demand for service increased in line with the growth in consumers:

$$U_{2030} = \frac{2.7S_{2010}}{1.28N_{2010}} = 2.1U_{2010} \tag{7}$$

This looks like a high target. However, if cars are considered as an example, in a 2008 report on UK car ownership, (published before the car scrappage scheme was introduced) prepared for the RAC foundation [9], it was reported that cars were scrapped at a steady rate from 9 to 20 years old with 50% of cars being scrapped by the time they were 14 years old. To get the required improvement in utilisation by increasing product life would require an increase in the average life to 29 years. Although this is a considerable extension it is technically possible as demonstrated by the number of classic cars in everyday use [10,11]. Alternatively as most of the growth in the middle class is predicted to be in urban areas, vehicle utilisation can be improved by joining car clubs. It has been reported that car clubs have around 4.3 members per cars [12] so a doubling of car utilisation could be achieved if 33% of people used car clubs rather than owning their own cars. Either of these approaches could be adopted, but would appear to be a major change in the way we approach car ownership. However in combination, they become less extreme and the same outcome is achieved by extending the average car life to 20 years and 15% of the population using car clubs. There are a number of ways to achieve longer product life and higher utilisation. In most cases there will need to be new business models developed to enable these strategies to be adopted in a way that is advantageous to the business community, consumers and the wider community.

3.2. Strategies for increasing product longevity

The following environmental benefits of increased product longevity have been recognized [13,7]:

- Reduction in the need for replacement products leading to reduced requirements for raw materials,
- Lower industrial energy requirements,
- Lower industrial greenhouse gas emissions,
- Reduced volumes of end of life waste to deal with.

There are a number of different strategies for increasing product life and the appropriate one needs to be selected for each type of good. The following strategies: product durability, serviceability, upgradability refurbishment/remanufacture and alternative use are outlined in the following sections.

3.2.1. Durability

Most products have components that suffer wear or are prone to damage. The impact of this can be mitigated during design through the provision of more durable components, resulting in a product with a longer life span. This approach could have some of the following drawbacks:

- uses more material or more sophisticated materials resulting in a higher production cost and impact
- increased weight may increase operational energy requirement
- increased weight and bulkiness may make the object harder to use
- locks the user into an old design with limited opportunity to improve performance
- limited repeat sales for manufacture

3.2.2. Serviceability

An alternative approach, is designing the product to be deconstructed and maintained so that parts that are susceptible to wear and damage can be readily replaced.
This strategy has the following potential drawbacks:

- higher cost associated with a undoable fixtures
- repair by poorly trained staff or the use of substandard replacement components reduce reliability
- locks the user into an old design with opportunity to improve performance limited to the replaceable components
- limited repeat sales for manufacturer, although this can be offset by increase in business for the manufacturers' authorised service agents

Historically most complex goods were serviceable, but improved manufacturing techniques and lubricants allowed sealed for life systems to become prevalent as a way to overcome the need to maintain a service infrastructure. However, providing servicing is carried out within a manufacturer's controlled environment it can be used to provide valuable intelligence into how the product degrades with use which can be fed back into new designs.

3.2.3. Upgradable

Until recently the ability to upgrade the performance of products has been limited to those that consist of a collection of modules or components that can be replaced with ones of an improved specification during the product's operational life. However, as more functionality is achieved by embedded intelligent and electronic controls there is a widening scope for in-service upgrades. Upgradability is a strategy that reduces the risk of technological redundancy for the consumer, but this reduces the opportunity for the manufacturer to make repeat sales. However, if the cost of materials and manufacturing represent a high proportion of the cost of a new product, the manufacturer's profit margin on the sale may be quite small and vulnerable to outside influences. Whereas, the cost associated with an in-house upgrade are likely to be under the manufacturers' control and the profit margins can be much higher (while still representing a saving for the consumer). Consequently product upgrading can be as profitable as manufacture in the case of rapidly developing high technology products. The problem with designing for upgrade is that it depends on the designer having a good idea of the developments that are likely to happen. Likewise if consideration has been made for a future upgrade it constrains the designer of the upgrade to fit it within the accommodation made.

3.2.4. Refurbishment and Remanufacture

Refurbishment is the process of replacing or repairing worn parts of a product to considerably increase its service life. A product must be serviceable to be refurbished, whereas serviceability is about dealing with premature failure caused by a weak component, refurbishment is undertaken on a wider range of components to increase the service life beyond its initial design life.

Remanufacture is the process of disassembly, cleaning, inspection, replacement of worn components and reassembly into a new product that is indistinguishable from one made of new components. This is an expensive procedure but can be cost effective on high value items that have components that wear at different rates. Assessment tools have been developed to evaluate the suitability of remanufacturing as a strategy for a particular item [14,15]. There are established refurbishment businesses for a wide range of products including white goods and wind turbines [16,17]. Remanufacturing is carried out on high value items such as aero engines and construction equipment where in-service failures are either unacceptable or expensive [16,18].

3.2.5. Alternative use

The construction sector showcases many examples of alternative uses of materials, including reuse of salvaged steel beams, stone work, bricks, telegraph poles and railway sleepers [7,19,20]. The main niche for alternative use is as a way of utilising obsolete or hard to recycle products. It is a mindset that treats old goods as a resource to be exploited rather than as a collection of materials to be recycled back into primary materials. Sometimes the alternative use may be in a different field for example the production of thermal insulation from a variety of waste goods [21] or the production of craft goods from discarded products. Improved coordination between the waste sector and product supply chain could expand this market and open up currently unforeseen opportunities.

3.3. Strategy selection criteria

There are clearly a number of tradeoffs to be considered when setting the design life for a product. The parameters that need to be considered have been grouped under six domains:

- Economic
  - purchase price
  - annualised purchase price
  - annual running cost
  - refurbishment cost
- Material consideration
  - common material use
  - rare material use
  - ease of material recovery at end of life
  - material required for maintenance
- Energy consideration
  - energy embodied in the construction of the good
  - annualised embodied energy
  - annual operational energy
  - energy needed for maintenance
  - energy needed to recycle
- Environmental impacts
  - life time emissions to land, water & air

  - annualised emission to land, water & air
  - local environment impact from manufacture
  - local environmental impact from use
  - local environmental impact from recycling
  - consequential environmental impact from energy and material use
- Functional evolution
  - sensitivity to change in technology
  - sensitivity to fashion
- Fragility
  - susceptibility to loose functionality over time
  - degradation of appearance over time

It is recognised that it is not possible to quantify each of these parameters to the same extent but as the purpose is to compare alternative strategies it may be sufficient to use a five point scale for many of the parameters. The utilisation of a product can be improved by product sharing schemes like car clubs or plant hire and selling or donating unwanted goods to new owners. The potential for these strategies is still under investigation, and is part of further research in this area.

3.4. New business model Barriers and Drivers

Although there are a number of current and historic examples of businesses that use these life extension strategies it is likely that new business models will be needed to fully exploit a low material future (i.e. a future with a low demand for new primary materials). In particular if products last longer manufacturing and retail businesses will get less repeat sales. This means that they will have to either chase the developing markets or get involved with all phases of a product life so that they can get future income from the goods they sell. This shift from pure manufacturing into a broader provision of services where the manufacture provides an ongoing facility to their customers rather than just the equipment to realize a facility is known as servitizationq. This can allow companies to maintain their profits without having to maintain their sales of new goods. A trend towards the servitization of industry has been witnessed over recent years [22,23,24], this strategy could help businesses thrive in a low material economy. Figure 1 shows the framework of activities that constitute a product life cycle in a low material future including those needed to enhance product life. It should be noted that Figure 1 shares features of circular economic models [25,26] i.e. very high rates of primary material recycling. However it is not considered practical for global industry to be solely reliant on recycled and renewable raw material in times of rapidly rising demand. The main difference between the framework shown in figure 1 and the traditional linear or circular economy models is a difference on the emphasis placed on maintenance, renovation and repair at the expense of manufacturing. This is to minimize the energy used to produce primary materials and reduce the need for raw material.

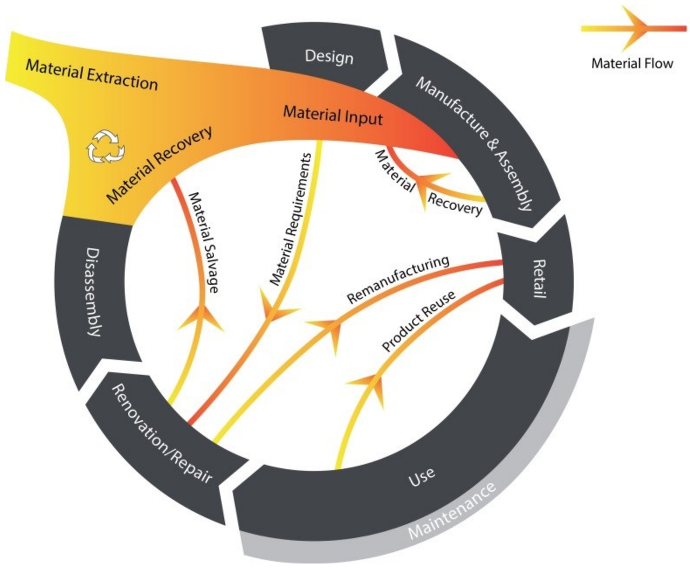

Figure 1. Framework of Activities involved in a product life cycle.

This would involve a shift from centralised high volume, highly specialised, mass production facilities into smaller, localised, flexible batch production facilities. Many people may consider this a giant step backwards but advances in additive manufacturing, improved flexibility of robots and machine tools means that many of the original drivers for large scale production are diminishing in importance [22,27,28,29]. A move towards more localised production would allow increased customer involvement with the specification and design of the goods they buy, and keep a higher proportion of the economic added value resulting from production in the region where the goods are purchased, produced and serviced.

3.5. Methodology

Although advancement in flexible manufacturing facilities and servitization will encourage the adoption of practices which are consistent with a low material economy there are still a number of barriers inhibiting its adoption. Issues relating to the adoption of strategies discussed in this paper formed the basis of a workshop in the "Industry seminar on optimising product lifetimes" held at Nottingham Trent University on 25 June 2014 [30]. Representatives of manufacturers, retailers, consultants, academics, government advisors and government department were asked to consider list of potential benefits, drivers and barriers and participants asked to rank them in order of importance. The participant were additionally asked to suggest other benefits, drivers or barriers that were absent from the original list. The participants were split into seven groups of 7 or 8 people to encourage discussion following guidelines in "Qualitative Research Skills Workshop: A Facilitators Reference Manual" [31]. The results of the ranking exercise are shown in Tables 1, 2 & 3. As the point of the exercise was to identify those factors that were considered significant, it was decided to record all factors that at least one participant thought was in their top 5 these are shown in the "mentioned" column with those that were identified as being in the top 3 by any group shown in the "in top 3" column.

4. Results and Discussions

Factors that were mentioned but did not make the top 3 are likely to be issues for particular industries. It was noticeable that intellectual property was not considered to be a barrier. This may be due to the presentation given in the workshop that showed refurbishment and remanufacturing activities being carried out by the manufacturers or their licensed agents. Cost issues were seen as key barriers, but the ability to remove exposure and save material cost were also identified as potential benefits. The fact that subsidizes were not mentioned indicates that the participants did not consider these to have a major influence on costs. Likewise, user demand / attitudes were seen as drivers and consumer perception, behavior and expectation for new models were seen as barriers. There is a rich literature on the drivers and influences on consumers and it would be wrong to assume that they are fixed. Further work is needed to explore this aspect.

Table 1. Participants' perception of the benefits to industry from reduced material demand.

Benefits of reduced material demand	mentioned	in top 3
Reduced risk of material supply disruption	TRUE	TRUE
Less price volatility of materials	TRUE	TRUE
Potential for new business models	TRUE	FALSE
Reduced environmental impacts	TRUE	TRUE
Potential profits	TRUE	TRUE
Reduced material costs	TRUE	TRUE
Greener company image	TRUE	FALSE
Prolonged commercial relationship with customer	TRUE	TRUE
Opportunities for collaborative partnerships	TRUE	TRUE
Benefit for society	TRUE	FALSE

Table 2. Participants' perception of drivers to move industry to reduce material demand.

Drivers to move industry towards reduced material demand	mentioned	in top 3
Material Scarcity	TRUE	FALSE
Disruption of material flows	TRUE	TRUE
Disruption of energy supply	TRUE	FALSE
User demand/attitudes	TRUE	TRUE
Policy	TRUE	TRUE
Carbon tax	TRUE	FALSE
Impacts on profitability	TRUE	TRUE
Future price and cost uncertainty for materials	TRUE	TRUE
Future price and cost uncertainty for energy	TRUE	TRUE
Reduced waste disposal cost	TRUE	FALSE

Table 3. Participants' perception of barriers to a low material future.

Potential Barriers to reduced material demand	mentioned	in top 3
Intellectual Property	FALSE	FALSE
Cost restraints	TRUE	TRUE
Lack of investment capital to develop & build new facilities	TRUE	FALSE
Lack of operational capital e.g. to store reused materials	TRUE	FALSE
Time constraints	TRUE	FALSE
Current policy requirements	TRUE	FALSE
Lack of knowledge	TRUE	TRUE
Lack of certification procedures for alternative practices i.e. reused steel	TRUE	FALSE
Complex supply chains	TRUE	TRUE
Complex information flows within the supply chain	TRUE	TRUE
Consumer perception	TRUE	TRUE
Consumer behavior	TRUE	TRUE
Producers/consumers locked-into the current economic/market system	TRUE	TRUE
The amount of price subsidies in key materials, gas and petrol	FALSE	FALSE
Cultural expectation for new models	TRUE	TRUE
Take back process limits reuse due to unknown supply quality and quantities	TRUE	FALSE
Close loop supply chains & reverse loop supply chain could increase cost of logistics, transportation and energy	TRUE	TRUE

While Tables 1 and 2 identify advantages for businesses in adopting business models that reduce the need for new goods while still providing a service to consumers, our research has not addressed the additional challenges for business to meet the rising global demand for goods by simply increasing production without improving product utilisation. We did not do this as we have identified that it is not a sustainable option from a GHG perspective. However, individual businesses may consider GHG emissions reduction as a matter for regulators not themselves. In this scenario, the challenges of conducting business as usual should not be underestimated, these may include the following considerations:

- Fluctuating growth rates for specific developing markets,
- Changing governments attitudes to foreign investment,
- Availability of finance,
- Inadequacy of industrial infrastructure,
- Shortage of trained workforce.

If these challenges are added to the factors identified in Tables 1 and 2, the business cases for adopting the strategies discussed in this paper become stronger. There is also evidence that new business models that include through life product support are beginning to be implemented [23, 32, 33, 34].

The number of goods in the world and their intensity of use is currently unknown; however, material flow analysis (MFA) can be used at enterprise and national level to give annual consumptions of key materials [35, 36]. These can be used with measures of economic activity like GDP or company turnover to produce an estimate of the Material Intensity of an economy or enterprise. If companies adopt the strategies proposed in this paper their material intensity should drop over time.

5. Conclusions

The demand for goods from the expanding global middle class cannot be met using the predominant manufacturing business model without seriously compromising industrial emission targets. However, if product life and utilisation is improved it should be able to meet the demand for service and stay within emission targets. The fact that the risk of disruption in material supply was considered to be a more significant driver than absolute material scarcity is revealing. It indicates that even if new sources of key materials are found they will only have an impact if they become globally available and if trade in key material is not considered to be at risk of political interference.

A number of benefits, drivers and barriers have been identified. It is noticeable that cost issues and consumer attitudes are considered to be both barriers and drivers indicating that more research is needed into these aspects to reveal their true impact. The lack of knowledge relating to business models that incorporate life extension and product sharing was also identified as a barrier so further work in this field would also be a benefit to business. Policy was identified as a driver and although current policy requirements were identified as an issue they were not considered to be a key one.

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Conflict of Interest

All authors declare no conflicts of interest in this paper.

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