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Full Length Research Paper

Sustainability and value of steel recycling in Uganda

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This paper assesses the value of recycling based methods of steel manufacture in Uganda and the level at which it is likely to be successfully depended on especially if no serious iron ore exploitation is done. By analyzing the factors that underlie steel re-melting in Uganda, this study aims at highlighting the conditions that surround the reliable production of scrap based steel and the sustainability credentials and strategies involving steel with particular attention to the recycling at the end-of-life of products and the ultimately related product recycled content, spelling out the life cycle related issues for steel products basing on International Organization for Standardization (ISO) standards on life cycle assessment (LCA)/Life cycle inventory (LCI) ISO 14040:2006 and 14044:2006 as adopted by the International Iron and Steel Institute (IISI). The results of this investigation show that owing to the relatively low quality of scrap, the burden lifted from the environment when the recycling route is used is lower in Uganda than in more industrialized countries. It has also been shown that only 300 kg of each 1000 kg of obsolete steel equipment are recycled to the national stock of steel scrap; showing that the amount of steel available for recycling is significantly lower than the current national demand for new steel products, creating a problem of continuity in the national steel production.

Key words: Recycled content, recycling value, steel making, steel recycling, sustainability, Ugandan steel.

INTRODUCTION

Sustainability requires that products are designed for their whole life cycle comprising production, distribution, usage and disposal, with minimized, acceptable influence on the environment; meeting the needs of the present without compromising the ability of future generations to meet theirs.

The management of the world's resources is therefore closely tied to sustainability.

Recycling on the other hand, is considered an effective way of waste management with its expanded benefit of resources conservation and energy saving by avoiding fresh raw material exploitation and in this way reducing their influence on the environment. Thus attaching a value to steel recycling involves estimating the extent to which the end of life steel products reach the liquid steel level and their contribution to the reduction of the environmental impact of the finished product.

Steel has played a significant role in the world economic development. The main reasons for the popularity of steel being it's relatively low cost of making, forming, welding and processing, the abundance of its two raw materials namely; iron ore and scrap, and its unparalleled range of mechanical properties. There are over 2500 steel grades either published, registered or standardized worldwide, all of which have different chemical compositions although up to 90% of the world steel production falls in the plain carbon range (Vogel et al., 2006*)*. In addition, all the different possible heat treatments, microstructures, cold-forming conditions, shapes, and surface finishes mean that there is an enormous number of options available to the steel user.

One of the most positive aspects of steel, however, is

Abbreviations: ISO, International organization for standardization; **IISI,** international iron and steel institute; **LCA,** life cycle assessment; **LCI,** life cycle inventory; **IF,** induction furnaces; **EAF,** electric arc furnaces; **RR,** recycling rate; **BF,** blast furnace; **DRI,** direct reduced iron.

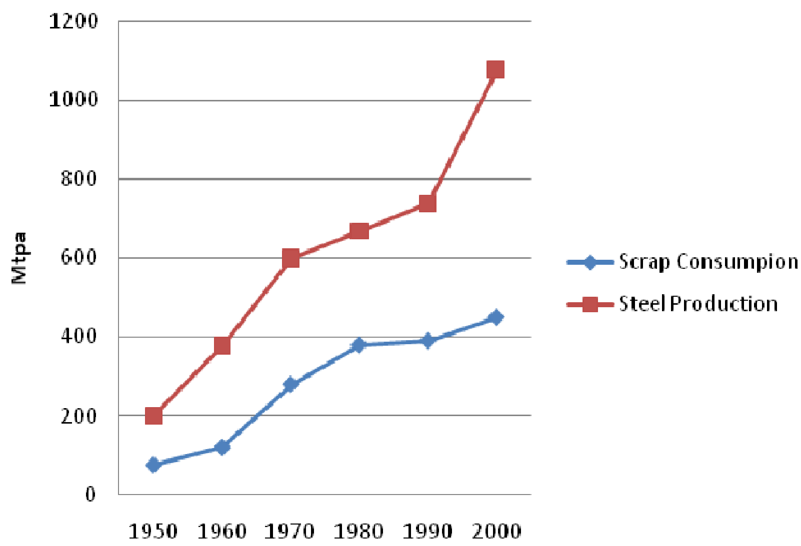

Figure 1. Global steel production Vs scrap consumption (Eurofer, 2006).

its ease and limitlessness of recycling repeatedly without substantial degradation in quality when steel products reach the end of their designated lives. This has made possible the production of long products from the recycling industries, also called mini mills, to be directed into especially the construction industry although internationally, there are strong tendencies to produce flat products too and even improve on their quality range, thereby competing strongly with integrated mills (Raymond, 2004).

The ability to recover and collect old steel products for subsequent re-melting is greatly enhanced by the inherent magnetic properties of steel and consequently, a large tonnage of steel becomes available for recycling every year.

History has shown, however, that scrap availability is never sufficient to meet global demand for new steel (Figure 1). This means that although the tonnage of steel recycled globally is the highest compared to any industrial material, the level of recycled content which is sometimes used as an indicator of resource efficiency, could slowly be diminishing (Chatterjee, 1995).

For these and other related reasons, there must be some kind of predictability and value attached to the phenomenon of recycling which has acquired such wide spread global use; not only in steel, but in all important essential items related materials.

The occurrence of obsolete scrap depends on previous manufacturing numbers of end-of-life steel products. This is a largely challenging position for the developing world, for while in Germany, for example, it was found that on the average 70% of the tonnage of steel end products is returned into the materials cycle 20 years after the manufacturing (Janke et al., 2000), the conditions of collection and consumption of obsolete scrap in developing countries definitely make it impossible to obtain even a fraction of such levels of recycling even as the steel production in these countries is increasingly dependent on scrap.

There certainly exists interdependence between the rate of obsolete scrap generation, scrap collection and quality, the life cycle of the common consumer goods made of steel on the one hand and the reliability of recycling on the other. In view of their importance, the complex nature of these interrelations calls for in-depth research.

This paper sets out to investigate environmental benefits of recovering and recycling steel by spelling out some life cycle related issues for steel products and based on this analysis some conclusions have been drawn as to how best to achieve value from recycling steel in terms of long term reliability and environmental performance.

Steel recycling

All new steel has a recycled content, and this can vary between 10 and 100% depending upon the availability and price of scrap, the specification of the steel and the steel production route. The global demand for new steel, however, exceeds the world scrap supply by an average factor of around two (Figure 2a) and so it is not currently possible to meet the demand for all new steel entirely from scrap (Bassam and Michael, 2006).

There are basically two different technological routes for steel production: One is based primarily on the reduction and smelting of iron ore, called blast furnace–oxygen converter route (BF-BOF) based on the equation;

$$yC + 2Fe_xO_y \rightarrow 2xFe + yCO_2$$

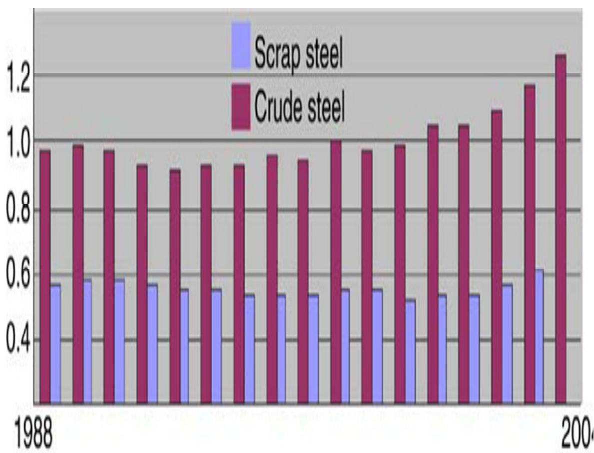

Figure 2a. World crude and scrap steel in billions of tones (Bassam, 2006).

Figure 2b. Scrap collection heap in Kampala.

and the other one is based on steel scrap remelting using induction furnaces (IF) and electric arc furnaces (EAF). Steel scrap is used as a source of iron in both processes but the scrap proportions in the charge are quite different in each case almost reaching the100% mark in the later mode (Vogel et al., 2006).

Recycling content

The recycled content of steel is the amount of scrap that ultimately ends up in the crude liquid steel. The recycled content of steel world wide is averagely 50% although steel is 100% recyclable. The discrepancy is to be explained by the life span of steel products and to an extent the overall recovery or collection rate in the given zone and time since in many instances steel products are reused or land filled at their end-of-life. In terms of tonnage, the steel industry's major market is construction of mainly buildings and civil engineering works. Recent findings by the author show that steel which is utilized in buildings has an average lifespan of 50 to 60 years while that used for bridge construction would have a life span of no less than 100 years in Uganda. An average car has a life span of 15 years. Packaging materials would recycle within less than a year while steel cans take only up to six. Hence the amount of scrap that becomes available from this sector is significantly lower than the amount it consumes in any measurable period of time (Figure 2b).

MATERIALS AND METHODS

Recycling value

To quantify the benefits of recycling in terms of sustainability, one of the best approaches is to look at the environmental credentials of steel in the form of a life cycle assessment (LCA). LCA is a tool used for the quantification and evaluation of the environmental burden and impact associated with product systems and activities right from the extraction of raw materials in the earth to end-of-life and waste disposal. Understanding the factors that influence the sustainability of steel requires an analysis of the full product life cycle. LCA methods are used to quantify the benefits of both recycling and reuse.

LCA is always associated to a functional unit, a quantity to which environmental burdens can then be apportioned. Environmental burdens can be recorded as a series of flows such as emissions to air, to water etc., referred to as a life cycle inventory (LCI). These flows are recorded from ore up to a defined boundary, the factory gate in this case on exit. LCI data quantify the material, energy and emissions associated with a functional system. The procedures of LCA are part of the International Organization for Standardization (ISO) 14000 environmental management standards in ISO 14040:2006 and 14044:2006.

These standards recognize that recycling a material can either take the open or closed loop form. The closed loop system is defined as one in which 'no changes occur in the inherent properties of the recycled material'. Under circumstances where the product is not the same, but the material is the same, the material is still closed loop but the product is described as open loop.

Within this framework, steel can be classified as a material recycled in a closed loop system since there is no limit to the level of steel that can be recycled and steel can be recycled repeatedly without downgrading to a lower quality product.

Accordingly, a value for scrap is calculated which reflects the embodied environmental impact that can be avoided by recycling this scrap. This provides a mechanism for a credit and debit system when scrap is produced or consumed.

Taking the functional unit as 1 Kg of steel outside the factory gate, ready for use in the community and assigning that 1 kg of scrap has the potential to produce Y kg of recycled steel (the through process yield), the recycling rate RR to represent the percentage of steel that returns to the factory for recycling, X_{pr} the environmental burden caused by the production of 1 Kg of steel through the Blast furnace (BF) or primary route using mainly virgin iron resources while X_{re} is the environmental burden attached to the recycling process accorded to the 1Kg. and referring to the systems diagrams in Figure 3(a) and 3(b), the LCI for steel scrap would be given as:

LCI for scarp,

$$X = \left(X_{pr} - X_{re}\right)Y \ldots\ldots\ldots\ldots\ldots\ldots i)$$

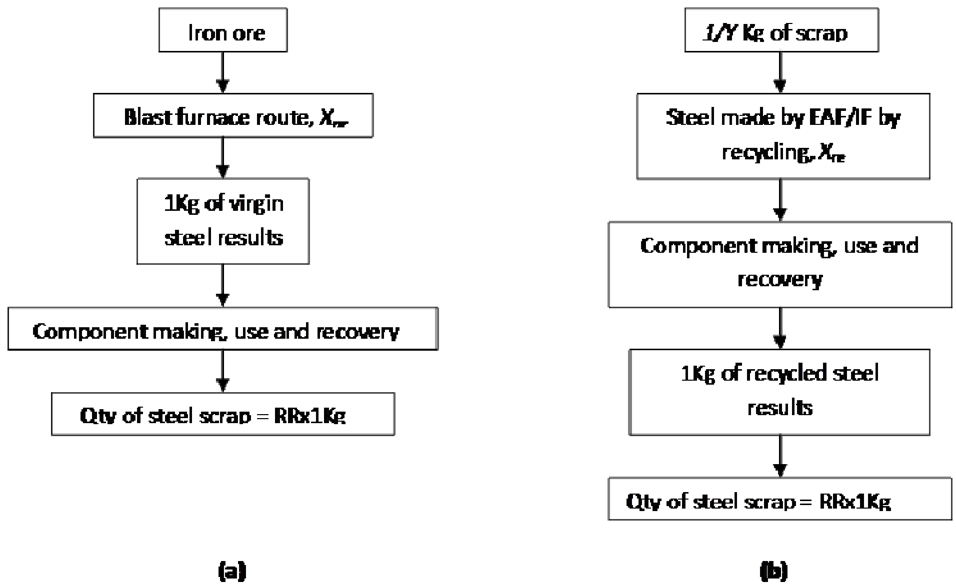

Figure 3. (a) System for primary route. **(b)** System for secondary route.
Y -Kg of scrap produce 1Kg of liquid steel (the through process yield)
RR -the recovery rate, the %ge of scrap that returns to form new liquid steel.
X_{re} -Environmental burdens due to recycling, given as Life Cycle Inventory (LCI) per Kg of steel.
X_{pr}- Environmental burdens due to primary processing, given as Life Cycle Inventory (LCI) per Kg of steel.

This, for the purpose of this study, represents the value of scrap. It essentially provides a mechanism to assess credit systems which produce scrap at the end of their life and debit systems that consume scrap.
For the full cycle (involving both primary and secondary routes) this then becomes as;

$$X = X_{pr} - r(X_{pr} - X_{re}) ....ii)$$ (IISI, 2002)

where $r = RR \times Y$

Here, r is recycling rate, *RR* the rate of recovery and *Y* the recycling yield.

The average manufacturer in Uganda using Induction furnace produces 1 kg of liquid from 1.2 kg of scrap; a yield Y, of $1:1.2 = 0.833$. Subsisting in (Eq. *i*);

$$X = (X_{pr} - X_{re})Y$$

$$= (22 - 10)0.833$$

$$= 9.996 MJ/Kg$$

This figure represents the burden lifted from the environment when the recycling route is used.

Sustainability

Sustainability is about the existence of a net positive value on considering the overall production of steel. Thus for steel production, the recycled material released for new use at end of life, minus the amount of recycled material used during manufacturing should bear an image on the overall sustainability of the material recycling.

If this net is positive, more recycled material will be available for future use. If it is negative, more primary resources will have to be used in the future. (Hiroyuki and Toshiyuki, 2005).

In Uganda, when cars reach the end of their useful automotive lives, a large percentage of them are reused as in making of the popular charcoal stoves and similar items mainly for internal consumption while many cases of reuse are in body parts and spares fitted directly on other automobiles. Many car bodies still remain rotting in land fills in the less urban locations of the country where recycling them would not be commercially viable due to their limited quantities, distance and infrastructure considerations. The recycling of packaging materials has much the same fate. The average national recycling ratio is as low as 30% according to recent estimates made from the two major steel recyclers.

The steel recycled content on the other hand is practically 95% since only scrap steel is fed into the blast/Induction furnaces.

For future recycling at end of life to be taken into account, a net value must be assessed in the relationship;

Recycled material released for new use at end of life – (minus) Recycled material used during manufacturing.

If this net value is positive, more recycled material will be available for future use. If on the other hand it is negative, more primary resources will have to be used in the future.
Hence for each tonne of steel that leaves the factory gate in Uganda, some 950 kg of scrap were involved.

At the end of their useful lives, however, only 300 kg of each 1000 kg of steel equipment are recycled to the national stock of steel scrap. Consequently, a net value of 300 – 950 = -650 kg per ton of recycled material (scrap) is being saved for future to use.

The manufacture of steel from scrap is therefore not sustainable on its own and the availability of a continuous flow of steel from the steel factory doors cannot be expected to last without a reliable primary source. This is the more so if consideration is taken of the likely growth of national demand for steel at no less than 10% annually (UIA, 2000).

Additionally, the average recycling yield in the local steel practice being assessed as assessed in the range of 1.2 as seen earlier means that every 1.2 tonnes of scrap yield a tonne of molten steel while the RR, defined as the 'Material recovered as scrap / Total scrap from end of life products' was similarly estimated in the range of 30%.

Using, IISI Appendix 5 Equation, [Equation (ii) above and considering that steel has a whole life energy burden of approximately 22MJ/kg, which is about 50% of the burdens without recycling (IISI, 2002)], LCI for the whole system can be evaluated as;

$$X = X_{pr} - r\left(X_{pr} - X_{re}\right)$$

$$X_{pr} = 22\,MJ/Kg;\, X_{re} = 10\,MJ/Kg$$

$$X = 22 - \frac{0.30}{1.2}\left(22 - 10\right)$$

$$= 19.0\,MJ/Kg$$

Recycling in Ugandan steel factories can therefore be estimated to avoid $\frac{22 - 19.0}{22} \times 100 \approx 14\%$ of the environmental burden due to the manufacture virgin steel (from the ore).

RESULTS AND DISCUSSION

a) Recycling of materials is the basic measure of increasing resource efficiency and decreasing environmental load. The recycling of industrial materials contributes to conservation of natural resources and environment improvement. LCA methods are used to quantify the benefits of recycling. The value of scrap has been determined in many instances to quantify the significance of recycling in a country. While in Uganda, the calculated value from Equation (i) is 9.996 MJ/Kg, a similar value according to Brimacombe et al. (2005) in the UK and Hiroyuki et al. (2005) stands at 11.22 MJ/Kg. The difference here is related to the low process yield in the local recycling industry here being typically 1.2 as opposed to the lower 1.07. This is due to the relatively low quality of scrap and ultimately means that the burden lifted from the environment when the recycling route is used is lower in Uganda.

b) Similarly, substituting in Equation (ii) the Life Cycle Primary energy for the whole system can be evaluated at 19 MJ/Kg. Considering that $r = RR \times Y$, the value of RR, the material recovered as scrap / total scrap from end of life products, the amount of material recovered is relatively small in Uganda and rough estimate in 2009 stood at some 30 percent. This makes the *X* value which represents the energy in the recycling process remain big so that the final value of the environmental burden due to the manufacture virgin steel still big, and so the recycling effect is still relatively small. Only 14% of the energy necessary to produce virgin steel is avoided by the recycling process nationally. With process yields of 1.07(Y=0.935) and recycling rated in the range of 0.95 as is the case in many developed countries (Brimacombe et al, 2005), actually the energy for the whole system becomes 11.34 MJ/Kg. This represents a 48% of the energy necessary for the production of virgin steel saved. This difference is mainly due to low through-put yield and an extremely low recycling rate in the local steel recycling.

On the more positive side, however, the level of reuse of especially vehicle components and sheet paneling is much higher on the local scene. Although much of the scrap available for recycling is not received at the steel factory gate, making the recycling rate, RR relatively small, much of this material is reused in the local small scale recycling who cannot afford new sheet metal.

Products should be first reused after their first use stage and the use life span of products should be extended so that the priority order of a sustainable ecosystem of the 3R (reduce-reuse- recycle) is adhered to in the process of developing circular economy.

c) Although steel recycled content in Uganda is practically 95% since almost only scrap steel is fed into the blast/Induction furnaces, the fact that the not so much of the recyclable material released at their end-of-life reaches the recycling industry makes the sustainability recycling as the major source of steel negative.
The net value in the relationship;

Recycled material released for new use at end of life – (minus) Recycled material used during manufacturing;

Calculated as; 300 – 950 = -650 kg/ ton, actually means that unless a substantial amount of virgin steel joins the system, the recycling process is bound to meet a dead end at one point in the near future, painting a bleak picture for the steel manufacturing in Uganda. The cumulative effect, with all factors considered, is that the amount of steel available for recycling will always be significantly lower than the current national demand for new steel products. UIA in 2001 put the scrap stock pile at 150,000-200,000 tons.

Conclusions

Overcoming the shortcomings seen has to do with serious undertakings that almost always point towards government initiative, either in the administrative realm or directly as investors/co-investors.

a) Low recycling ratio has been shown to have a substantial influence on the effectiveness of recycling. This is likely to be due to the use of long cycle scrap like that from buildings and bridges (more then 60 years) and automobiles (more than 12 years) due to their long useful lives. Small cycle scrap is known to be from packaging materials (1 year). Brimacombe (2005) speaks of 60% collection rate in UK. This rate would be less than a half in Uganda where no effort has been made to collect packaging, especially cans such as aerosols. Estimates accessed in the local industry seem to suggest that every 30 tonnes of scrap processed contain up to 1.2 tonnes of packaging scrap. Can recycling could be improved by positioning specifically can collection bins in shopping points in the urban areas to improve on the percentage of collection and also prevent them for being mixed with other scrap materials where they very often get damped into landfills. Awareness creation would be essential along the way.

b) The feed quality has also been seen to reduce the value of scrap. Some of the scrap inclusions are not able to contribute to liquid steel, remaining as slag and dust from the process. This speaks more of the average chemical composition of scrap, collecting and sorting processes. This must be improved on.

SUGGESTIONS

It can be seen that there is a substantial amount of virgin steel needed to make the steel production process sustainable. Large amounts of iron ore have been confirmed in Western Uganda and other parts of the country, many of them of very high quality. Studies have shown that extraction of direct reduced iron (DRI) would be viable (GSMD, 1997). There is need for the state to move towards the production of DRI to beef up the steel production as an additive to scrap steel. This can be through the institution of incentives to investors or the use of joint ventures between government and investors.

Intensifying the collection of packaging materials could contribute to the improvement of the recycling rate, RR especially as they are less given to reuse although this would increase the costs associated with cleaning and sorting.

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