From an Environmental Viewpoint Large ICT Networks Infrastructure Equipment must not be Reused

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Abstract: - Circular strategies must and will vary for different product groups. Life Cycle Assessment (LCA) will help show which is the best strategy in any given situation as not all Circular Economy initiatives lead to universal sustainability benefits. There is a misunderstanding that lifetime extension via remanufacturing and refurbishment is ecologically effective for Business-to-Business ICT goods like ICT network infrastructure (ICTNI) products. This is shown herein by typical relations between manufacturing and the use of environmental impact for ICTNI products as a function of the energy efficiency and lifetime of the product at hand and the next corresponding product model. Full LCA would come to the same conclusion, as the ratio between the use stage and the production stage will not change dramatically. To avoid doing very significant harm to the environment, older than 5 years ICTNI products must not be reused. The reasons are that the energy efficiency improvement rate of the following generation of most ICTNI products is constant, the lifetime is usually more than 10 years and the share of manufacturing environmental impact will be relatively low even when low environmental impact electric power is used for the operation.

Key-Words: - circular economy, energy, energy efficiency, ICT, life cycle assessment, lifetime, material efficiency, network equipment, refurbish, reuse

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1 Introduction

In the ecosphere there is no waste, i.e. Nature itself is a perfect circular economy (CE). Then on the other hand in the technosphere, 99% of all new products become waste after 6 months and less than ≈2 billion tonnes of waste is created annually, [1]. Electronic waste is an important issue as it accounts for about 5% of all solid waste generated, [2]. So-called CE business models can help address the problems of primary resource use. Reuse happens when a product or its parts, having reached the end of their first use, are used again for the same purpose for which they were conceived, [3]. Anyway, striving for a complete CE – especially involving reuse - is not appropriate for all kinds of products in all situations, [4], [5]. In other words, not all CE initiatives lead to universal sustainability benefits. The benefit or impact of something ‘more circular’ should be assessed using tools such as Life Cycle Assessment (LCA), [6], and Product Specific Rules, [7]. CE metrics and LCA scores are integrated and compared when they are implemented at the same time, [8], [9].

Anyway, unless an LCA has been carried out for the circular solution, there is no certain way of knowing if the circular solution has a low environmental impact.

Information and Communication Technology (ICT) technologies network infrastructure (ICTNI) products will not become waste until after at least 10 years or longer. Moreover, ICTNI products have completely different LCA profiles and waste handling than end-user consumer ICT goods. Several ICTNI products can be upgraded by changing the boards but keeping the older chassis. Moreover, several technologies can be provided by the same hardware instead of several hardware, [10]. In other words, ICTNI products have already adopted several ideas from CE. In 2017 electronics including ICTNI products used 10% of global electricity, [11].

Looking at the big picture in Fig. 1, Fig. 2, and Fig.3, the production of ICTNI products may just be a few percent of the entire Internet production impact, [12], [13], which in turn is a much smaller share than the use stage. In Figures 1 to 3 environmental impact is approximated with electricity use. However, carbon and weighted single score methods would likely show similar shares.

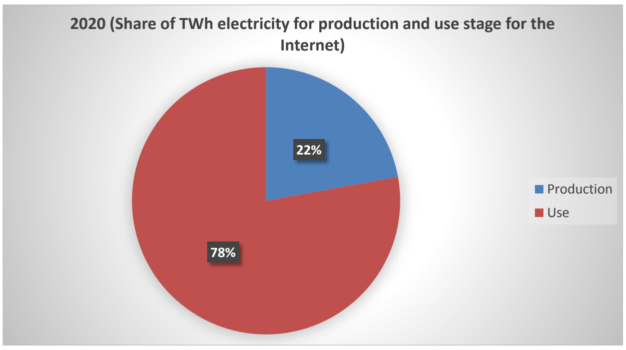

Fig. 1: Approximate shares of electricity consumption for internet production and use in 2020.

Fig. 2 shows the breakdown of the use stage shown in Fig.1.

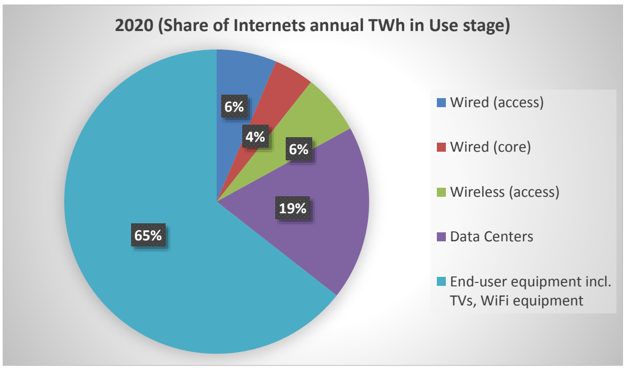

Fig. 2: Approximate shares of electricity consumption for the internet's use stage in 2020.

Fig. 3 shows the repartition of the production stage shown in Fig.1.

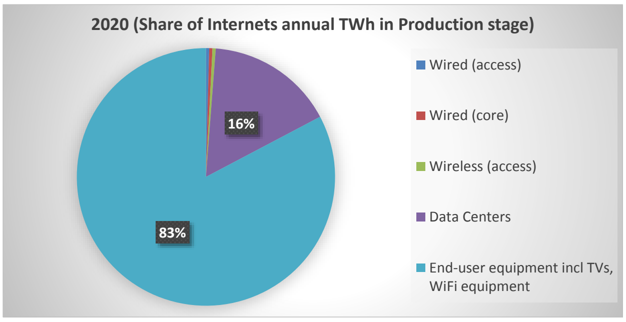

Fig. 3: Approximate shares of electricity consumption for the internet's production stage in 2020.

Fig. 3 is supported by Fig. 5 and Fig. 6 in [14], for 4G wireless networks in Peruvian cities in which the embodied carbon footprint (≈manufacturing) for the corresponding ICTNI products (Evolved Packet Core/IP Core network, base band units, radio frequency unit, base band unit cabinet, integrated battery cabinet, power bank, antennae) is hardly visible compared to the operational carbon footprint (≈use).

Fig. 4 shows that the use stage dominates for ICTNI products both for traditional grid mixes and those dominated by intermittent sources.

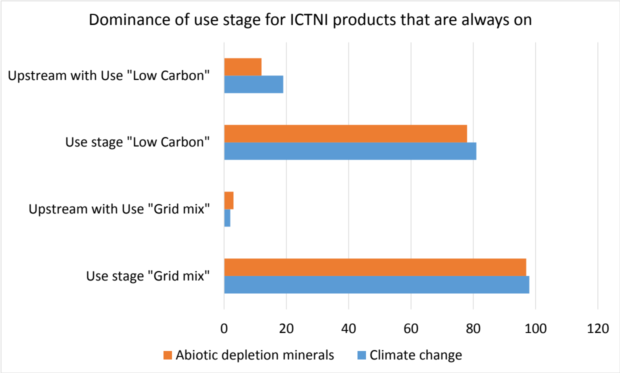

Fig. 4: Typical repartition between the use stage and upstream for ICTNI products using grid-mix and low carbon power in the use stage, [4].

Figures 1 to 4 suggest that the use stage is the most important for typical ICTNI products regardless of the grid mix used for the use stage.

The waste created by wired and wireless equipment is rather small as such ICTNI products use around 80% less mass per subscriber per year than the end-user equipment, [14]. From the literature (Table 2 and Table 3 in [14]) and the useful lifetimes – in section 2.2.4.11 in [14], – for the equipment used by a 4G wireless access network, it can be concluded that the share of the ingoing annual mass flow is around 80% for end-user equipment and 20% for ICTNI products. From a primary resource perspective, however, it is important to recover as much as possible of the ICTNI products.

Typically for energy-using products is that the new corresponding product models are almost always more energy efficient than their predecessors, [15]. This creates a "green" motivation to replace old products and is particularly important for many types of ICTNI products, whose use phase impacts far outweigh their production impacts. In such cases old products should be removed from circulation and rather be recycled, [15].

In this context, it has been shown useful to make trade-off analyses of lifetime and energy efficiency improvement using a so-called use phase÷ production phase ratio, [4]. For ICTNI products, which are always on, it does not matter for life cycle stage dominance which impact category or source of electricity are used. As shown in Fig.4, the use stage

will dominate (≈80% of life cycle impacts) e.g. carbon and resources, etc., [4].
Compared to [4], the present research will show the magnitude of the global electricity risk which will be introduced if ICTNI products are not replaced but refurbished.

2 Problem Formulation

The hypothesis is that refurbishment of large ICTNI products is harmful if the energy efficiency improves more than 10% between the product at hand and the next corresponding product model.

3 Problem Solution

The solution is to use typical relations between manufacturing and use impacts for ICTNI products as a function of the energy efficiency and lifetime of original and next-generation equipment. The lifetime and energy efficiency improvements are varied.

The relation between manufacturing and use will vary between ICTNI product types. Based on an LCA of an enterprise server (Table 2 in [16]), the weighted impact of the use stage is ≈68% for a four years lifetime. Of 15 environmental impact categories (Abiotic depletion minerals, Acidification, Climate change, Ecotoxicity: freshwater, Eutrophication: freshwater, Eutrophication: marine, Eutrophication: terrestrial, Human toxicity, cancer, Human toxicity, non-cancer, Ionising radiation, human health, Ozone depletion, Particulate matter/respiratory inorganics, Photochemical ozone formation, human health, Primary energy demand, Resource depletion water), the use stage is the highest contributor to 8 (Primary energy demand, Climate change, Photochemical ozone formation, Eutrophication: terrestrial, Eutrophication: marine, Acidification, Ionising radiation, and Resource depletion water).

The Environmental Footprint Method, [17], has proposed the following weighting of midpoint environmental impact categories: Abiotic depletion 7.55%, Acidification 6.2%, Climate change 21% (GWP100 is the overall indicator, and $GWP100_{CO2}$ impact indicator for CO_2), Ecotoxicity: freshwater 1.92%, Eutrophication: freshwater 2.8%, Eutrophication: marine 2.96%, Eutrophication: terrestrial 3.71%, Human toxicity, cancer 2.13%, Human toxicity, non-cancer 1.84%, Ionising radiation 5%, Ozone depletion 6.31%, Particulate matter/respiratory inorganics 8.96%, Photochemical ozone formation 4.78%, Primary energy demand 8.32%, Resource depletion water 8.51%.

For enterprise servers these weighting factors lead to the following weighted result for the enterprise server, [16]:

Abiotic depletion of minerals 10.4%, Acidification 3.45%, Climate change 21.5%, Ecotoxicity: freshwater 0.78%, Eutrophication: freshwater 0.07%, Eutrophication: marine 3.87%, Eutrophication: terrestrial 6.62%, Human toxicity, cancer 0.07%, Human toxicity, non-cancer 0.03%, Ionising radiation 3.37%, Ozone depletion 0%, Particulate matter/respiratory inorganics 18.5%, Photochemical ozone formation 8.61%, Primary energy demand 22.8%, Resource depletion water 0.03%.

It is sometimes argued that the abiotic depletion of minerals is an economic problem and that the impact of material production covers the issue, also for recirculation of materials and recycled content, [18]. If abiotic depletion of minerals is not considered the relevance of the use stage for ICTNI products would be even higher in Table 4.

Table 1 shows primary energy demand results for the universal situation for two life cycles for the enterprise server, [16], with no improvement of the energy efficiency between the product at hand and the next corresponding model.

Table 1. 4 years lifetime and no improvement of energy efficiency for 2nd generation used 4 years for primary energy demand indicator.

Phase	**Impact**	
M1	15	
U1	85	
E1	≈0	
M2		15
U2		85
E2		≈0
SUM	**200**	

Where
M1 = manufacturing impact of ICTNI product at hand.
U1 = use stage impact of ICTNI product at hand.
E1 = end-of-life treatment impact of ICTNI product at hand.
M2 = manufacturing impact of the next corresponding ICTNI product model.

U2 = use stage impact of next corresponding ICTNI product model.
E2 = end-of-life treatment impact of the next corresponding ICTNI product model.

Table 2 shows what happens if the energy efficiency of the next corresponding product model is improved by 18%.

Table 2. 4 years lifetime and 18% improvement of energy efficiency for next corresponding ICTNI product model used 4 years for primary energy demand indicator.

Phase	**Impact**	
M1	15	
U1	85	
E1	≈0	
M2		15
U2		70
E2		≈0
SUM	**185**	

Table 3 shows what happens if the product at hand is reused with the original energy efficiency. For the sake of simplicity, the same lifetime of the reuse period is assumed. U1=U2 if the energy efficiency of the product at hand cannot be improved in the refurbishment process.

Table 3. 4 years lifetime of product at hand which is refurbished and reused 4 years.

Phase	**Impact**	
M1	15	
U1	85	
E1	0	
M2		≈0
U2=U1		85
E2		≈0
SUM	**185**	

The relative shares of M1 and U1 will vary with the lifetime according to Table 4 showing the approximate relations for ICTNI products for weighted impacts.

Table 4. Shares of environmental impact for manufacturing (M1) and use stage (U1) for different lifetimes of a typical ICTNI product.

Lifetime of first life of ICTNI product	**M1 (impact units)**	**U1 (impact units)**
1	38.33	61.67
2	23.71	76.29
3	17.16	82.84
4	13.45	86.55
5	11.06	88.94
6	9.39	90.61
7	8.16	91.84
8	7.21	92.79
9	6.46	93.54
10	5.85	94.15
11	5.35	94.65
12	4.92	95.08

Table 4 shows that the longer the lifetime, the higher the share of the use stage. Most LCAs for ICTNI products would show the pattern of Table 4 for a weighted life cycle impact assessment using the Environmental Footprint Method, [17].
However, Customer Premise Equipment used in homes may show different relations than those shown in Table 4 for the ICTNI products used in the field.

4 Discussion

Fig. 5, Fig. 6 and Fig. 7 show after which time ICTNI products should be replaced depending on the energy efficiency improvement of the next product generation.

Fig. 5 shows that ICTNI products should be replaced after around 2 years if the energy efficiency is improved by 25%.

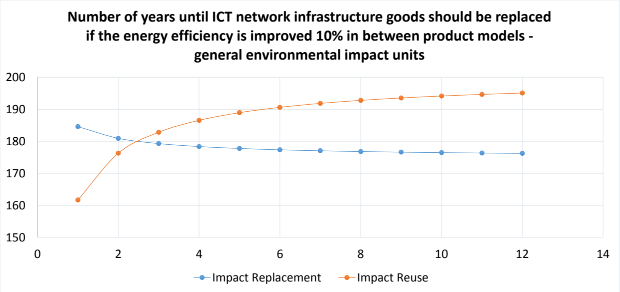

Fig. 5: Environmental impact of replacing or refurbishing the first ICTNI products as a function of a lifetime with 25% energy efficiency improvement of replacement.

Fig. 6 shows that ICTNI products should be replaced after around 6 years if the energy efficiency is improved by 10%.

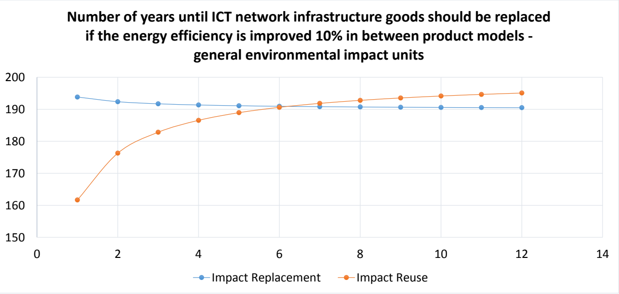

Fig. 6: Environmental impact of replacing or refurbishing the first ICTNI product as a function of a lifetime with 10% energy efficiency improvement of replacement.

Table 5 and Table 6 show how the values are derived for 6 years in Fig. 6.

Table 5. 6 years lifetime and 10% improvement of energy efficiency for next corresponding ICTNI product model used 6 years for primary energy demand indicator

Phase	**Impact**	
M1	9.39	
U1	90.61	
M2		9.39
U2		81.6
SUM	**190.9**	

Table 6 shows what happens if the product at hand is reused with original energy efficiency using numbers from Table 4.

Table 6. 6 years lifetime of product at hand which is refurbished and reused 6 years

Phase	**Impact**	
M1	9.39	
U1	90.6	
M2		≈0
U2=U1		90.6
SUM	**190.9**	

Fig. 7 shows that the ICTNI product should be replaced after around 12 years if the energy efficiency is improved by 5%.

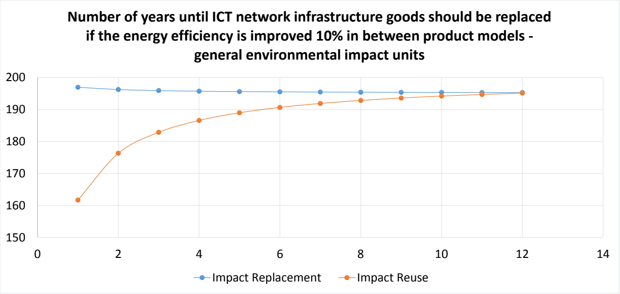

Fig. 7: Environmental impact of replacing or refurbishing the first ICTNI product as a function of a lifetime with 5% energy efficiency improvement of replacement.

The energy efficiency has so far improved ≈by 20% in between product generations for metrics like (bits/s)/W and for the energy to transport one bit, [4].

Compared to business as usual with no improvements, the assumption of 2+2 years for ICTNI products results in a 9.5% reduced impact with a 25% improvement of energy efficiency for the next corresponding product model, and an 11.8% improvement for the reuse business model. Compared to business as usual with no improvements, the assumption of 3+3 years for ICTNI products results in a 10.3% reduced impact with a 25% improvement of energy efficiency for the next corresponding product model, and an 8.6% improvement for the reuse business model. So for less energy efficiency than 25%, for a 2 to 3 years lifetime, the CE reuse seems beneficial. However, 2-3 years is not common for many types of ICTNI products in networks and data centers.

Compared to business as usual with no improvements, the assumption of 5+5 years for ICTNI products results in a 4.45% reduced impact with a 10% improvement of energy efficiency for the next corresponding product model, and a 5.53% improvement for the reuse business model. Compared to business as usual with no improvements, the assumption of 6+6 years for ICTNI products results in a 4.53% reduced impact with a 10% improvement of energy efficiency for the next corresponding product model, and a 4.69% improvement for the reuse business model. So for less energy efficiency than 10%, for a 6 to 7 years lifetime, the CE reuse seems beneficial. 6-7 years is not unrealistic for certain types of ICTNI in networks and data centers, [19].

As shown in Fig. 5 and Fig. 6 for typical ICTNI products having a lifetime of >10 years, replacement is much more beneficial than reuse.

For a 10% improvement in energy efficiency, the border lifetime is between 5 and 6 years.

Moving to the macro scale, what will replacement or refurbishment mean for the global electricity use of ICTNI?

Fig. 8 derived by updates of earlier studies, [13], [20], shows that enormous amounts of electricity will be used globally if worn-out ICTNI products are not replaced by new energy efficient equipment. A refurbishment scenario - with no improvement in energy efficiency - would use thousands more TWh than replacement! This is excluding TWh from other ICT and electronics.

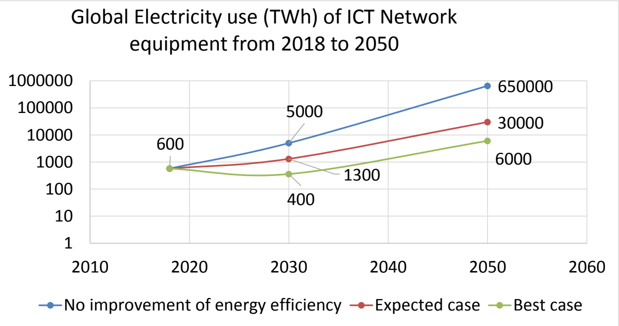

Fig. 8: Electricity to be used by ICTNI products in the use stage under different energy saving scenarios.

The expected case scenario assumes that the energy efficiency (expressed as global data traffic over electricity used) is improving by 10% per year from 2018 to 2050 and the best case assumes that the energy efficiency is improving by 15% per year for the same period. The “no improvement scenario” in Fig.8 is an impossibility but is shown as a reference to the risk of refurbishment. As shown by Fig.8 - with the continued growth of data generated - if decisions are taken to reuse old equipment, with no improvement of their energy efficiency, the World risks using >3000 extra TWh of electricity in 2030 and >600000 TWh in 2050. As far as ICTNI products are concerned, this underlines that energy efficiency is one of the key mitigation measures to save energy.

Is the software-related upgrade to improve the energy efficiency of refurbished ICTNI a realistic strategy, i.e. U2 in Table 2 and Table 6 can be reduced so that U2≠U1? Given the rapid development of technology for new products, it is unlikely that such upgrades are possible.
Refreshing ICTNI products with refurbished equipment generally does not make sense, but needs to be analysed case by case.
Safety issues must also be investigated for refurbished products.

Moreover, the manufacturing environmental impact could change marginally between M1 and M2 for the replacement scenario due to changes in manufacturing technology. If M2 is increased by 5%, Figures 5-7 do not change significantly.

Apart from this, maintenance will be more costly for refurbished ICTNI products beyond their expected average durability.

5 Conclusion

Reuse of ICTNI products with an expected durability lifetime of >6 years is inappropriate from an ecological viewpoint if the energy efficiency between the product at hand and the next corresponding product model is improved by >10%. To avoid doing very significant harm to the environment, old worn out ICTNI products must not be reused, but should be recycled as far as feasible.

6 Outlook

The present research is also linked to LCA modelling of reuse. Each product has a total lifetime irrespective of the number of owners. If reused a product causes less manufacturing related environmental impacts per year than if the same product is not reused. However, the reused product will often cause higher use stage related environmental impacts than the next corresponding product model. Both the absolute LCA of the lifetime extension of one product and the comparative LCA of several lifecycles may be relevant. Straightforwardly standardizing this modelling is a challenge but would be useful for customers seeking the environmental footprint of reused products.

As a next step, using different lifespans for the reuse of the product at hand and the next corresponding product model should be modelled, and the environmental impact expressed per year, e.g. for 4+4 years for a replacement and 4+2 years for reuse. Upgrades within the first life of the ICTNI product could also be investigated in this kind of modelling. The link between system architecturebased energy saving, [20], and CE is not yet well understood.

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The authors have no conflict of interest to declare.