Circular Economy 2 (2023) 100051

Contents lists available at ScienceDirect

Circular Economy

journal homepage: www.journals.elsevier.com/circular-economy

Perspective

# The challenge of introducing design for the circular economy in the electronics industry: A proposal for metrics

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ARTICLE INFO

*Article history:*
Received 15 May 2023
Received in revised form
21 August 2023
Accepted 21 August 2023
Available online 9 September 2023

*Keywords:*
Circular economy
Design
Reuse
Recycling systems

ABSTRACT

The introduction of design for the circular economy (DfCE) in the electronics industry can strongly build on the earlier experiences in the field of applied ecodesign. Although the design methodology DfCE as such is identical compared to traditional ecodesign, DfCE needs different metrics because it includes apart from the environmental dimension also supply criticality and recyclability. Such metrics are proposed in the present paper. These will allow to come to prioritized action agendas for DfCE. Moreover, the numbers will allow to position the actions appropriately in the internal and external value chains. The basis for such metrics is to assign to each individual material in a product a weight based resource factor (RF). Such RFs include 'factors' for supply criticality, environmental load and recyclability. This allows to calculate 'consolidated' RFs for products as well. This approach will very effective in promoting circularity, because it starts from its core. That is: looking to how (and why) specific materials are applied and using a numerical method to put this into perspective. Primarily this is helpful to address the internal value chain. Also supply side issues and demand side issues (consumers) will get a lot of attention in this paper, both at the front side (design) and the back side (discarding behaviour of users). The combination of both aspects will allow to come to develop the best strategies for reuse for different product groups. For the informal sector application of the metrics is still premature, but in future there could be contributions as well. In the discussion section, issues are raised as regards possible contradictions between resource issues and emission issues and about conflicts of interest between DfCE and business interest in more general. Moreover, attention is paid to the way DfCE can contribute to enrich traditional ecodesign.



## 1. Introduction

### 1.1. Circular economy and value creation

Circular economy (CE) thinking focuses on resources rather than on emissions. It concentrates on all aspects of material flows in product systems: supply of materials, their transformation into products and reuse/recycling after discarding of these product by their owners. This makes that the total material life cycle is the system boundary rather than just one life cycle of a product.

The philosophy behind CE is to create 'value' while minimizing the consumption of resources. This is an approach which links much better with the role of commercial companies than with traditional environmental thinking. In the CE philosophy, supply of materials is to be seen as 'enabling value creation'. Materials have to be chosen in such a way that the functionalities can be realized in an optimum way. The physics behind creating artefacts can imply however those resources have to be used which are scarce or are subject to supply constraints ('criticality'). This is a supply chain issue rather than an environmental one as such. It has to be addressed thoroughly in order to make the circular economy concept to work in practice.

The next stage, the design stage of products is the core stage. Minimizing resource use has to be reconciled with the functional value which has to be delivered. The best way to do this is to tailor this as good as possible to the requirements of users (Stevels, 2007a). User groups include price buyers (chief design strategy: minimize resource use), feature buyers (chief design strategy: enable reuse after discarding by first owner) and quality buyers (chief design strategies: maximize price/resource cost ratio and life time extension). This difference basically makes that there is no universal CE strategy for companies; there is a clear need to relate

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https://doi.org/10.1016/j.cec.2023.100051

this strategy to the customer base. However, for these groups, the room to manoeuvre is quite different. Indirectly this means that increasing circularity could imply even a shift in customer base.

The discarding behaviour of owners is determining to a large extent at what level products can be reused (repair, refurbishment, remanufacturing, component reuse/recycling of materials). Motives to discard vary from wishes for more functionality to 'wear and tear', from the wish to buy something new to (ir)repairable breakdown, from 'just superfluous' to due to change in civil status. Also in this stage, factors outside the environmental domain determine the potential to achieve a more circular economy. A key element in circular economy is also 'postponement of discarding'. Apart from 'front end 'and 'back end' design for CE, design for maximum conservation of value and resources is therefore a definite constituent of the concept.

All these aspects mean that circular economy thinking is a clear enrichment of traditional Eco (Design) thinking. Through this approach, environmental issues are taken out of their 'environment only' views and considerations. Moreover, a clear integration with other business issues (supply chain, customers, money) is being achieved.

Simultaneously the circumstances sketched above make that coming to an appropriate action agenda which will achieve more circularity while simultaneously enhancing business is even more complicated than making an agenda just for environmental improvement.

### 1.2. Circular economy and the management perspective

This very integration implies that issues in which circular economy thinking is the core need to be actively managed in a business context. Starting point is that the companies see the potential of CE thinking and want to do better with the implementation of it than they did so far. In order to make to take place, metrics are needed to make this really happen. Such metrics will primarily assist to characterize the current status as regards circular economy aspects. As soon as 'actions' (in the supply chain, at initial design, during life time or after final discarding) are considered, the metrics before and after the action give insight what such actions entail in terms of advancement in CE terms and in terms of money as well.

Experience with traditional ecodesign (Stevels, 2007a) has shown that there are three chief reasons to set up a relevant database and to connect simple calculation mechanisms to it.

- If you know where you stand, you know better where to go (stimulating creativity);
- Develop a meaningful action agenda (including priorities in it);
- Measure progress on individual products and on product portfolio's (validation).

So far, few companies have embraced the idea to support such self-driven action. It is however badly needed because it has been concluded for a long time that environmental issues have been insufficiently on board by the electronic industry.

This bottom up approach is contrary to the wide spread idea for instance in academia that external drivers like legislation and customer demand would be most effective. External demands have the advantage that a minimum of performance is ensured industry wide. However, there is evidence that once such minimum requirements have been complied with in practice, many companies tend to stop or slow down further actions. Therefore such requirements have a tendency to leave a lot of potential unexploited. However, managing 'Eco' (and thus 'circular economy as well) as 'bottom up' means seeing it as an opportunity rather than an (external) threat. This is the basic reason why such an approach delivers much better results.

Building credibility in the internal value chain (Ishii & Stevels, 2007) of companies is a first key condition for success (Brezet et al., 2007; Stevels, 2016, 2017). A second one is to integrate the CE approach in all operations. For this purpose, there tangible action agendas with clear priorities have to be developed. Such agendas should have a CE basis but fit into a wider context (customers, regulators, other stakeholders) as well. All these mean that in the end compromises have to be made (but also can be made!). Getting it right as good as possible is much more difficult than just being right!

### 1.3. Circular economy means focus on resources and materials

In the circular economy approach, there is a focus on resources/material application. These are considered to be dominant in the complete supply chain. In the design and development stages, materials determine to a large extent how the functionalities required by consumers/users are to be realized.

Also in the end-of-life stage, issues materials are seen to be dominant. As regards all of these are aspects, the industry is best positioned to manage them.

On the contrary, Eco aspects of energy are determined to a large extent through the way electricity is generated and distributed. These items are strongly regulated by authorities, as regards resource policy, as regards environmental aspects (emissions) and as regards tariffs as well. The energy in the use phase is (apart from the hours of use which are difficult to influence as such) determined by technology. Both the ever increasing functionality of integrated circuits (ICs) and miniaturization of printed circuit boards (PCBs) contribute to lower energy consumption of next product generations. Such technology improvements 'happen' and is therefore to a large extent beyond control of producers and government policies. Joint roadmaps of producers and IC/PCB suppliers will (just) enable to plan better ahead but will not essentially determine how technology as such develops in the future. Nevertheless such planning will also allow to make meaningful calculations about what product reuse strategies are to be prioritized (for instance from an emission perspective). For instance, products for which energy consumption in the use phase is expected to drop considerably in the future have limited reuse potential, at least from an overall environmental perspective. On the contrary, the economic potential of such products can be big.

### 1.4. Organization of this paper

Section 2 explains how data can be used to support actions promoting the circular economy. First of all, 'factor methods' are discussed. These are methods in which dissimilar aspects (in this case supply criticality, environmental loads of materials and material recycling) can be brought together in one number score for product designs, see Section 2.1. Due to the fact that such scores have a subjective element that is explained in Section 2.2. The factor methods discussed in Section 2.1 are only to be used in a comparative way which is sufficient for management purposes. In Section 2.3, the factors for material criticality are considered in more detail. Section 2.4 discusses the factors for the environmental load. Section 2.5 is about the ones for materials recyclability.

Section 3 is focusing on the metrics for design for the circular economy. In Section 3.1, general formulae for specifying numerically resource application in products will be presented. The resource factors (RFs) which are calculated in this way can be applied in making action agenda in the field of 'front end' product design, more effective treatment technology and for better CE management in more general. In Section 3.2, it will be discussed how these business models for reuse are to be positioned in a wider sustainability context. It will also be demonstrated how these RFs can be used to manage the internal value chain of companies. In Section 3.3, a special design strategy CE domain, design for resource value (DfRV) is presented. This approach is combining traditional supply side considerations with demand side ones. It is a new basis for 'CE creativity'. It can be used to develop additional ideas that can be incorporated into the program of requirements for the creation of new products. In Section 3.4, it is discussed how the basic formulae proposed in Section 3.1 can be extended to a complete product line up. In this way managing complete product portfolio's from a circular economy perspective is enabled.

In Section 4, it is stressed that design for the circular economy is to be tailored to the characteristics of individual products. In Section 4.1, this is discussed in more detail. Section 4.2 shows how clues for design for CE can be found after products have been sold. Section 4.3 addresses how better conservation of resources and value can be achieved after discarding by the first owner.

Design for the circular economy is a necessary but not sufficient condition for getting closer to a circular economy. Since for CE the elements of supply criticality and reuse are much more relevant than in traditional sustainability, existing concepts in this field have to be reconsidered and to be extended. Better collection of finally discarded products, more focused treatment and more specific upgrading processes are conditions for success as well. Therefore, in Section 5, suggestions are done how the resource factors originally defined for design purposes also could be used as an analysis tool to support improvement take back and treatment systems. RF calculations are helpful to support better legislation and rule making (Section 5.1), but can also lead to more focus in collection programs (Section 5.2) and to treatments taking specific resource issues much more into account (Section 5.3).

As regards better dealing with the informal sectors (Section 5.4), there are superseding issues to be addressed first like information dissemination (IT) and preventing polluting and inefficient upgrading processes to happen through appropriate financial schemes. At the moment the informal sector gets better connected, resource Factors can be used to give guidance to this sector as well.

In the discussion in Section 6, it will be explored to what extent the metrics for design for the circular economy will lead to design decisions which will be different from the ones for traditional ecodesign. This both refers to products themselves and to product portfolio management as well.

It will be concluded (Section 7) that the proposed metrics for design for circular economy cover the three chief dimensions of it (supply criticality, environment and recyclability) but that, due to these dissimilarity of these, the resource factors (RFs) developed contain subjective elements. Nevertheless these are excellently fit to make meaningful and prioritized action agendas.

Due to the very character of the circular economy concept, the RFs can be put in a wider context than traditional ecodesign. Both supply and demand sides can be considered in a much broader business and societal context. This will require from the designer a broad vision about and beyond sustainability.

This paper is building on experiences which are described in the book '*Adventures in Ecodesign of Electronic Products*'. In this book (Stevels, 2007a), an extensive description of applied ecodesign has been described as could be derived from experiences at Philips consumer electronics. This 'bottom-up approach' has been supported by research at the Design for Sustainability Lab of Delft University of Technology. The more than 80 conference contributions and scientific publications presented in the book underpin the framework which was developed on basis the empirics.

There are two consistent strong messages throughout the book: 'Eco' and therefore also ecodesign has to be based on metrics and on calculations. For design for the circular economy this holds even stronger. For several issues existing concepts have to be extended and even completely changed.

The other one is that 'Eco' always is to be seen in its context: design, technology, product system management and management of internal and external value chains. For circular economy orchestrating the external value chain is even an essential condition for success. Each product or product group deserves specific attention; priorities in actions to improve can vary greatly.

## 2. Data to support the making of action agendas to achieve more circularity

### 2.1. Factor methods

As pointed out above, 'circular economy' has three dimensions: material criticality, environmental impact and forms of reuse. In order to give proper guidance to designers and product managers, these dimensions have to be weighted with respect to each other. This can be done by assigning for each material used an importance/relevance factor in each of these three categories. These are to be multiplied to form one overall circular economy coefficient. By multiplying this coefficient with the physical weight of the material concerned, integral circular economy weights (CEWs) can be obtained. A product (or a design of a future product) can be subsequently characterized by adding the CEWs for all materials present. This is called the product resource factor (RFp).

Such a type of approach is not new; in the nineties of last century a similar approach has been successfully used in the domain of traditional ecodesign (Brezet et al., 2007; Griese et al., 1997). In that case, the goal was to bring together environmental aspects like impact ('scientific green'), legal and regulatory requirements ('government green') and perceptions by users ('customer green'). Such methods were called factor methods or simply environmental weight methods.

The advent of life cycle analysis (LCA) has made that the application of factor methods to support ecodesign have been considered to be outdated. LCA is a scientific approach focusing exclusively on environmental impacts for one life cycle only; circular economy, leave it alone managerial and societal aspects are not considered. Minimizing the environmental impact was therefore thought to be the chief task of ecodesign. This brought practitioners of applied ecodesign into a squeeze what should be best done from a (pure) environmental perspective and what needs to be done to get maximum acceptance by internal and external stakeholders. Broader sustainability issues were said to be important. However, in practice issues superseding environment exist, and this has put outspoken LCA proponents into a self chosen isolation.

This tension between 'environment only' and the much broader reality in which companies, consumers and society as a whole are operating has hampered in practice the progress of ecodesign. In spite of this substantial successes have been scored as well. Often this has been achieved by using environmental weight based methods for creativity purposes (particularly at the front end) and LCA for specific environmental validation if a product is already in place. On top of that appropriate 'context management' has contributed as well to realize these successes.

Due the very character of the 'circular economy' concept (addressing supply chain, environmental impact and reuse), a factor approach is needed to come to product design and product management in which the CE concept has been incorporated in a direct way.

In the sections below, it will be further elaborated on how factors for CEWs can be developed. Subsequently it will be discussed how these can support design for the circular economy. Moreover, it will be demonstrated how the CEWs can support to position circular economy aspects in a broader context.

### 2.2. The need to use comparative metrics

In order to know better where products or product line-ups stand in terms of circularity and to assess the effectiveness of improvement actions three types of data are needed.

- Data about the environmental impact of resource use,
- data about supply criticality of these resources,
- and data about the material recyclability and about higher forms of reuse of the products in which these materials have been used.

Such data are dynamic. This means that their values can change over time. Since decisions about product design and the composition of product portfolio's work out for long time spans, such data dynamics are in principle a matter of concern. The approach to make sure that decisions which are taken are resilient is to use metrics about circularity consistently in a comparative fashion only. This implies looking at ratio's between circularity scores before and after an 'action'. Such an action can be a change in supply sources, a design change (material reduction, material substitution), a change in product recyclability (change of product architecture or of internal fixtures), a change in treatment technology or a change in the business model.

The use of ratios limits the effect of data dynamics. Generally changes with affect both the reckoner and the denominator in basically absolute values, but the changes will be in the same direction. Errors will be therefore much less than in the absolute considerations.

Decisions about an 'action to achieve more circularity' are digital; the only explicit requirement is that it works out in a positive way. If a calculated positive effect of an intended action is decreasing over time as a result of the dynamics of the data used, this is as such not a problem as long as it does not turn into the negative. If there is doubt about this, a sensitivity analysis can explore to what extent a decision for a seemingly positive action can become counterproductive.

### 2.3. Factors for supply criticality

When metrics for supply criticality are to be developed, first thing to do is defining the boundary of the user community for which such numbers are supposed to be valid. This can be a region in the world, a specific country, an industry sector or an individual company. Once this has been done, the mix of supply origins is determined for each of the materials has to be determined. This is because each of these origins could have a different criticality factor.

An overall criticality factor for each material is then established by looking at the supply stability of each source of a material on a weighted basis. This stability can be geology related (depletion issues), technology related (efficiency of operations at the suppliers) and related to societal/political issues as well. These can include political stability in the supply region, interference of governments or other organizations with the supply chain. Child labour or lack of business ethics in more general are issues as well. In view of all this, criticality factors have a high degree of subjectivity. For each user or user community, numbers can be different. The European Union (2017) has developed a set of general criticality factors as a whole on a scale ranging from 1 to 5. Specifically for the electronics industry, criticality factors have been calculated using the same systematic as by the EU. The results of these calculations are presented below for the most critical elements.

In Table 1, the highest numbers refer to the elements which are most critical. For individual operators inside the industry, the numbers might differ slightly, because for them the supply mix is not necessarily identical to the one of the industry as a whole. If data are used only in a comparative way as described in Section 2.2, this is most likely not a problem for managerial decisions.

The requirement of 'relative use only' for the factors applies in particular to the issue of resource depletion. Although more and more recycling will compensate partly for it, overall depletion of mineral resources definitely takes place in our society. This means irrevocably that in future minerals from which the materials have to be extracted will become poorer over time. This means that more and more ore has to be treated to get the same amount of material. This will require more energy. This will change the value for the Eco indicators (both the 'complete' and the 'stripped' ones) as basically discussed in Section 2.2.

### 2.4. Factors for the environmental impact of using resources

Like for traditional ecodesign, the core of circular economy considerations is the environmental impact of producing (and recycling/reusing, in the current section) materials from resources. This impact can be described by life cycle analysis. For a full analysis, according to the ISO standard 14,040 series, the amount of data needed is in practice too big. This is very costly. Moreover, companies usually have insufficient time collect them all. Time is too short due to the limited 'time to market' of new products. On top of that, the environmental profiles generated by the full analysis are very detailed but are less suitable for operationalization like the making of prioritized action agendas. Therefore, industry is using mostly a consolidated form of LCA, the so called Eco indicators (Goedkoop & Spriensma, 2001). Such Eco indicators are readily available from a data bank which stores them as (regularly updated) single scores.

By multiplying the weight of individual materials applied in a product with the Eco indicator for this material and summation over all materials, the total traditional environmental impact of material application can be calculated. By comparing Eco indicator scores before and after an action (see Section 2.1), the effect of this action can be assessed. It is to be realized however that in the traditional Eco indicators three types of impact categories are being consolidated. These are.

- human health,
- biodiversity,

**Table 1**
Criticality factors for most critical elements in the electronic industry.

| Material | Criticality factor |
|---|---|
| Cobalt | 4.50 |
| Antimony | 4.03 |
| Manganese | 3.19 |
| Lithium | 3.71 |
| Heavy Rare Earth elements | 3.55 |
| Germanium | 3.30 |
| Platinum | 3.15 |
| Chromium | 3.10 |
| Tungsten | 3.02 |
| Gallium | 2.88 |
| Indium | 2.86 |
| Niobium | 2.86 |

- and resources (in fact the component relevant for CE).

For application in assessing the environmental component of circular economy strictly speaking only last named category needs to be considered. This means that for this application the traditional Eco indicators have to be 'stripped' from the contributions of their 'human health 'and 'biodiversity' dimensions. An exercise in this field on the chief types of metals and plastics however showed that this would reduce the Eco indicators applicable to 30%–60% of their original value, the only exemption being materials with an explicit potential toxicity like lead-its figure is much lower (15%).

Using 'stripped Eco indicators' is, however, subject to debate. It can be argued in favour that physics and economy as such act autonomously according to their own laws and therefore have little to do with human health or with biodiversity. However, it can be said that 'circular economy' has a social dimension as well, so that these categories cannot be omitted.

For the time being, this dilemma is posing an interesting research question: to what extent are these differences in environmental or circular product design, if stripped or full Eco indicators would be applied as a basis for making the 'eco/circular' chapter of the program of requirements. It would be interesting to see whether such differences are big in plastic dominated products (which have 'stripped indicators' mostly in the 50%–60% range) or metal dominated products (most of them are in the 30%–35% range, iron is at 50%).

There is also a chance that there will be little differences between the design agendas generated by the two different Eco indicator datasets. This is because in design of products, primarily functionality requirements are the overarching issue. Generally the functionality requirements do not allow radical design changes in between product generations. It is generally acknowledged that some 80% of the environmental impact is fixed in the early design stage. However, this is chiefly due to the physics which is needed to realize the required functionality and not as many ecodesign authors seem to believe to smart or not so smart design choices.

This means that designers become more and more 'design managers' that is professionals taking on board developments in science and technology and in IT/software to enhance their designs. This can lead to drastic changes over the product generations. Such drastic changes can also occur because different underlying physics have been used (for instance replacing cathode ray tubes by liquid crystal displays in TVs). However also in such a case, there is little other choice for the designer than just to follow.

### 2.5. Factors for recyclability

All products, even the ones which go through several reuse cycles, will finally be discarded. The good news is that subsequent material recycling can be applied to 100% of such products. Material recycling is therefore the 'baseline' if no higher level forms of reuse (see Sections 4.2 and 4.3) can be realized anymore. Final discarding can be due to wear and tear, to lack of economy of scale of the reuse operations, to deficiencies in the value chain or to lack of acceptance of such products by future users.

In such situations, parts harvesting offer seldom a way out for the same reasons. Moreover, it is to be realized that avoiding new parts to be produced brings little gain in comparison to outright material recycling. Materials (the kilograms) to be used in mechanical parts constitute on average 80% of the environmental load, bringing these materials in specific forms only 20%. For electronic parts these percentages are on average some 70% for the kilos, some 15% for form and some 15% for function. From a circular economy perspective, most likely similar numbers apply.

It is to be realized that material recycling even with help of the most advanced technology is far from 100% effective. Partly this is due to the laws of physics (like the second law of thermodynamics). These imply that every transformation involves losses. Moreover, recycling treatments and upgrading of secondary streams —even the best ones-are far from perfect from the point of view of organization, for instance, lack of investment in logistics and in specific treatment technology.

In particular this holds for the secondary streams resulting from treatment. Often these are upgraded in processes that are optimized for natural minerals. For materials originating from 'urban mining', this can mean that in such processes their recycling potential is not fully used.

Also the legal requirements for recycling of electronics are based on (physical) weight of materials to be recouped and not on environmental-leave it alone circular economy-relevance. This very type of 'not-to-landfill' requirements (Huisman et al., 2007a) make that in practice a lot of critical materials are recouped with low efficiency simply because they occur in low amounts and/or concentration in electronic products (often such critical materials have high resource factors, see Section 3.1) A specific treatment/upgrading industry to deal with materials occurring in products in low concentrations (sometimes called 'the spice materials') has not been set up so far, but is badly needed to realized the best circular economy.

All of this makes that from a circular economy perspective and recyclability of materials is to be considered on an individual basis. Overall recyclability of a product (defined in whatever way) is simply irrelevant.

In order to derive factors for this individual material recyclability (IMR), the current status of the treatment and upgrading industry needs to be considered. By applying appropriate input/output analysis such IMRs can be derived. In Table 2, a factor scheme is proposed. These factors are meant to represent the weight factor of the recyclability component in the overall resource factors proposed in Section 3.1.

Like for Table 1 (criticality factors), this table is to be used for management purposes only; as such it has no scientific basis. As discussed in Section 2.2, applying these factors in the calculation of circular economy weights has no absolute meaning as well. Results have therefore to be used in a comparative way only.

## 3. Metrics for material application from a circular economy perspective

### 3.1. A general formula characterizing resource application

The use of resources of a material can be characterized by the resource factor (RF, $x$) in the following:

$$\mathrm{RF}(\text{material}, x) = \mathrm{S}(x) * \mathrm{E}(x) * \mathrm{IMR}(x) * \mathrm{W}(x)$$

Where S($x$) is the supply criticality factor for material $x$ (see Section 2.3), E($x$) is the environmental load factor for material $x$ (see Section 2.4), IMRg($x$) is the recyclability factor for material $x$ (see Section

**Table 2**
Recyclability factors to be used in resource factor calculations.

| Recyclability of material concerned (%) | Factor to be used in RF |
|---|---|
| 0–3 | 5 |
| 3–10 | 4 |
| 10–20 | 3 |
| 20–50 | 2 |
| 50–100 | 1 |

2.5) and W($x$) is the physical weight of material $x$. The formula above enables to compare the resource relevance of individual materials, for instance when substitutions of materials are being considered.

For a product, the resource factor (RF, $p$) becomes

$$\mathrm{RF}(\mathrm{product}) = \Sigma(x)\ (\mathrm{RF}, x)$$

Where $\Sigma(x)$ is the summation of all materials x present in the product. This formula enables to assess from a resource perspective the application of materials in products, thus allowing resource based design. Like for traditional ecodesign, this is a 'supply side' activity; customer perceptions or opinions about material application are not accounted for. This is to be done at the moment when the design options developed on basis of the formula are evaluated in a wider context.

Similarly for a group of products, the resource factor RF (pg) can be written as

$$\mathrm{RF}(\mathrm{product\ group}) = \Sigma(p)(\mathrm{RF}, p) \times \mathrm{V}(p)$$

Where (RF, $p$) is the resource factor of a product $p$ and V($p$) is the volume of product p sold in the market. This formula allows portfolio management of groups of products from a resource perspective. It has both supply side aspects (characteristics of individual products) as well as demand side ones (volume sold). This perspective offers an extra opportunity for companies: next to efforts to minimize RF for individual products, also products which have already lower RFs can get extra promotion in the market.

As explained in Sections 2.1 and 2.2, the absolute figures generated through the formulae above have as such no scientific significance and can only be used in a comparative way. From a management perspective these have to be put into an appropriate context. However, when used in a comparative way (calculating RFs before and after an 'action') the RF concept can become very powerful. The effectiveness of actions can be accessed through RFs. Priorities in an action agenda can be determined using RF (and feasibility) as well.

Actions can for instance be.

- Changing sourcing of materials (purchasing)
- Material reduction or substitution; use of recycled material (product design)
- Simplifying product architecture, changing types of fixtures, modular design (product design)
- Reduction/substitution of auxiliary material (production)
- Changes in product mix brought to the market (product management)
- Enhancing value orientation of the product portfolio-see also Section 3.3. (product management)
- Promotion of products with low RFp (marketing & sales)
- Selection of recyclers with more effective treatment technology and having better access to effective upgrading of secondary streams (management).

Many of the actions mentioned above are also occur in the field of traditional ecodesign. Only the metrics to prioritize them from a circular economy perspective are different. Traditional applied ecodesign (Stevels, 2007a) also puts 'Eco' in a wider business and societal context; this needs to be done for design for the circular economy as well.

A distinct moment at which RF considerations are helpful is in addressing circular economy aspects are brainstorms about product generations (front end DfCE) or in reviews of product strategy (from a CE perspective) in more general. In practice there are very complex issues to be addressed. Cramer and Stevels (2007) explained that best approach is to decompose this complexity and organize a separate brainstorm devoted to CE aspects next to brainstorms about mechanics, electronics, software, marketing, etc. and to integrate the idea's and results later in one target specification.

### 3.2. Positioning resource factors in a wider context

#### 3.2.1. Considering the resource factors in a wider sustainability context

By comparing RFs before and after an 'action', a numerical yardstick for the CE impact of this action can be found. By analysing the ΔRFs can be found for the effect of the action; the bigger the decrease in RF the better and the higher priority the action will get on the action list. However, apart from the numerical RFs, also contextual considerations have to determine the final priority on this list.

The first contextual level is the circular economy elements themselves. The formulae of Section 3.1 bring together these three elements when concerning material application in a circular economy context (supply criticality, environmental load and recyclability). This can be called the first level of aggregation of single issues. This aggregation means that contrary singles issues are 'consolidated' into one overall score which will be worse due to this phenomenon. As a result of that an idea pertaining to it will get a lower priority in the action agenda.

Inside the domain of material application, the most well known contrast is that reducing the amounts of material employed in a product generally leads to a reduction in recyclability. In circular economy, using more material (for instance by making product architecture more modular) is acceptable as long as this allows a product to have more lifecycles. In traditional ecodesign, material reduction as such is often the 'outright winner'. Since the outside world often thinks in terms of single issues (wants therefore 'less materials and simultaneously better recyclability') compromises on the issue as described above, will be seen with suspicion—particularly when these are worked out by companies. A proper evaluation in terms of RFps could also be of help to counteract such emotions.

This holds even stronger for the next level for which compromises in this respect have to be struck. This level entails compromises between the three dimensions of environment: emissions (energy consumption is dominating for electronics), materials (circular economy aspects) and potential toxicity. Wanting to reduce energy consumption often entails use of a material mix that has a higher RF score. What has priority: the dimension the one of emissions or the one of resources?

When reuse is being considered (see Section 4) it is to be realized that energy consumption of older product generations tend to be higher. The resulting dilemma: accept more energy consumption while saving on resources through life time extension or consume more material through buying a new product which has lower energy consumption in the use phase.

Well known examples of conflicting issues between material application and potential toxicity are the use of lead-free solder and the application of flame retardants. Lead free means use of solder materials with higher RF. Elimination or substitution of the most effective flame retardant plastics results in use of more resources.

The fact that contradictions as sketched above exist should not upfront hamper creativity to reduce RFps. Contextual reviews should therefore happen after such creative sessions and not before. Practice for traditional applied ecodesign, where similar issues plays a role (Cramer & Stevels, 2007; Stevels, 2007b) shows that in many cases there are no contradictions at all. Nevertheless also in that field the experience has been that sometimes there is a difference between ‘being right’ and getting it right.

### *3.2.2. Positioning resource factors of products in a business context; managing the internal value chain*

The next higher context level is going beyond sustainability: it is the business context. Proposals like an action list to come to more ‘circular’ products have to be accepted by the complete organization simply because the cooperation of all departments is needed to get optimum results. Convincing the internal value chain (Ishii & Stevels, 2007; Stevels, 2016, 2017) to do so make it necessary that the CE proposals are confronted with an overarching criterion for the business: money. If circularity proposals also contribute to cost reduction (and this is often the case) credibility and acceptance will not be a problem.

In circular economy considerations this is of utmost importance; even more than for traditional ecodesign, a wide spread prejudice is that actions for more circularity will cost money anyway. An analysis for this purpose works as follows: assuming unchanged functionality of the products (and therefore unchanged sales prices), the primary issue to be considered in such a context is the cost price (CP) or in fact ΔCP as a result of the intended action.

When confronting ΔRFp and ΔCP there are four possibilities.

- Both Δ’s show a decrease of RF and CP. Basically this means: GO, consider feasibility (technical, managerial, financial investment)
- Both Δ’s show in increase of RF and CP. This means: NO GO.
- ΔRFp shows a decrease of RF, ΔCP shows an increase of CP: basically no GO but a proposed action can be executed for external reasons (regulation, image, sales)
- ΔRFp shows an increase of RF, ΔCP a decrease of CP. In such a case, quantitative circular economy arguments are generated against proposals which might be generated in other brainstorms. (‘prevention’)

For traditional ecodesign and for improving take-back and treatment systems, Philips Consumer Electronics used to analyse idea's generated in a similar way (Jansen & Stevels, 2007; Stevels, 2007a). In order to visualize this, diagrams were constructed with the sustainability parameter on the *Y*-axis and the business parameter (usually money) on the *X*-axis. The situation before an action is represented in the origin of such diagrams. Changes as a result of an action are represented as Δ’s in the sustainability and the business parameter considered. In this way the changes are represented as a vector in the diagram.

A diagram representing vectors of a set of proposals used to be called ‘a road sign diagram’ because the four possibilities as described above can be described by road signs, see the example below.

As shown in Fig. 1, actions leading to possibility 1 as above are in the upper right corner (priority). Possibility 2 is lower left corner (forbidden), possibility 3 is in the upper right (bumpy road) whereas possibility 4 gets a warning sign. Diagram of this type are very useful in explaining to all parts of the internal value chain of a company sustainability issues and very helpful in mobilizing support for sustainability issues; for circular economy analysis issue this will work as well. There is even more value in the diagrams. Since each action can be represented by a direction and a length, the discussion about priorities can be sorted out in an easy and transparent way.

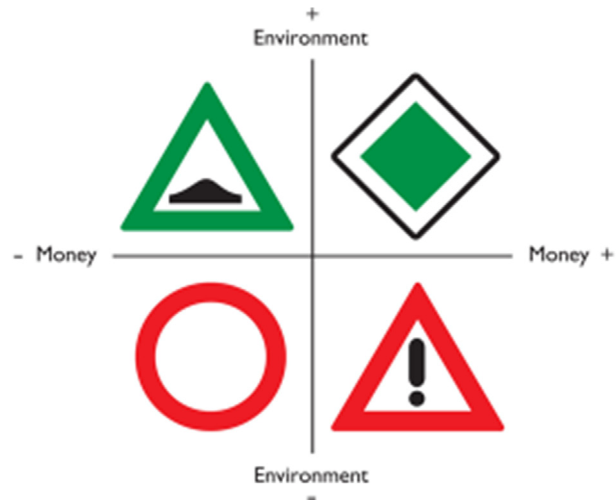


**Fig. 1.** Four domains for action represented by road signs.

### *3.3. Design for resource value, an opportunity in the external value chain*

The RF considerations as outlined in Sections 3.1 and 3.2 lead to a prioritized action agenda for promoting the circular economy on a company level. This agenda is in line with the overarching goal of the economy as a whole. This goal can be best formulated as ‘minimize the resource intensity per unit of gross domestic product’. In terms of RF, this can be formulated as

Resource Intensity (Economy) = Σ RF (all economic activities)/Σ (Value of all economic activities).

In this formula, the concept of ‘Value’ comes into the equation. Value is a parameter related to the demand side; it represents what customers are prepared to pay for a product.

For companies, the above formula means that there is—apart from the supply side CE design strategy outlined in Section 3.2—another design strategy to reduce resource intensity: maximize the value of products while keeping their RFp constant. This strategy is called design for resource value (DfRV).

In order DfRV to be successful, the behaviour of (potential) buyers of such value products needs to be studied in detail. Value of products as seen by buyers is a concept that clearly goes beyond just physical functionality. It includes intangibles like simplicity of installation, ease of use and connectivity. Also positive emotions of individuals can contribute higher valuation. These include items like feel well with the product, nice design, upgradable, recyclable and not containing toxics (Stevels, 2018).

In many markets, particularly in regions in the world with a high average income/head, higher value due to improved intangible functionality and high emotional value can be converted into higher prices paid by the customer. In Western Europe, approximately one third of all potential buyers are sensitive to product attributes in these categories. On the other side of the spectrum are the ‘price buyers’, in Europe also about one third of the total. For this group, a DfRV strategy will not apply: perhaps more functionality is wanted but this group is not prepared to pay for it. The remaining group is constituted by ‘tech buyers’, customers with an outspoken interest in new features and new technology. In terms of DfRV, they form a ‘mixed bag’. Initially such tech products can fetch high prices, but these prices drop soon. Successful DfRV implies a very detailed functionality analysis of the whole product line up to be marketed. The core question is again and again: what product functionality for what target group? Further details about this are given in ref Stevels (2018).

Increasing value for customers through enhanced intangible and emotional functionality implies often that RFp cannot be kept completely constant and will increase as well. In traditional 'Eco' this is a problem because it is thinking in absolute terms of 'environment only'. Since resource intensity thinking as outlined in Section 2.2 is in relative terms, such an increase of RF due to enhanced functionality is not a problem as long as the relative increase of the value achieved is bigger as the one of the corresponding RFp.

A well chosen DfRV design strategy can be an important element in developing a product portfolio which is optimally matched to the circular economy perspective. This will be discussed in more detail in the section below.

### *3.4. Managing a product portfolio from a circular economy perspective*

The basic ideas as set forth in Sections 3.1, 3.2 and 3.3 will allow managing product portfolios from a circular economy perspective.

Doing the RF (material, $x$) calculations (see Section 3.1) for individual products allow to identify the product improvement potential of the products concerned. Making such calculations needs to bring together a lot of information. Most of it is present somewhere in the organization but often only in a scattered way. Just bringing such information together (for instance for a brainstorm session) is already the start of creativity—people start first to ask why things are as they are. Soon after it will turn out that there is a lack of logic and consistency in the design decisions in the past: (design) tradition, neglect of technological/IT opportunities, consumers have changed, lack of communication between departments and last but not least pressure from time to market. All of these will already allow to formulate improvement plans.

A new concept like the circular economy can be inspiring as such but can also act as a catalyst to rethink broader product issues such as the ones mentioned above. Moreover, playing with RFp numbers in order to bring them down can be an attractive 'game', even for people with limited personal engagement for CE itself.

When juxtaposing the RF's of individual products, the consistency in the product line up brought to the market can be analyzed. Again this can be a source of discussion and inspiration. Analysis of the RF 'logic' can be done from the supply side ('technical') but also from a demand side (consumers). In last named case volumes sold can be brought into the equation as well (see Section 3.2). When doing so the current centre of gravity of a business can be identified. This allows balancing development and marketing efforts done for the different consumer target groups. Through this analysis also so the future directions to go can be defined.

When applying ratios between RFp and price also logic in pricing can be tested. Condition to do so is that the RFs in themselves have already got a consistent pattern through appropriate action. (If not there is a backlog in RFp improvement). Testing pricing in this way can be a tricky issue. Fifteen years ago, the author had graphs made of Eco value (environmental load/sales price) versus sales price. University students did the work under his guidance and showed the results just to the management before his retirement. The effect was an amazing one: many products were under-priced in comparison with the competition, some were overpriced. Even if the environmental part of the equation was left out, the analysis showed a patchwork rather than consistency in pricing. The forthcoming retirement saved him from being fired. Product managers and the senior managers shared the opinion that technical people, leave it alone sustainability managers are not hired for having idea's about pricing of products.

This incident shows two important issues. On one hand, sustainability and circular economy thinking can foster company consistency on a wide range of issues even (like product portfolio as a whole and product pricing) outside the very DfCE itself, on the other hand acceptance and trust are absolutely crucial to make sustainability and circular economy thinking work.

## 4. Tailoring design for the circular economy to the characteristics of individual products

### *4.1. The need for differentiation on top of the general approach of CE thinking*

In Section 3, a general approach of design for the circular economy has been proposed. In spite of the big variety in electronic products as regards material, composition, weight and size this approach can be applied to all products. All companies, irrespective of their specific business or size can manage the core of design for the circular economy from the same perspective. Therefore Section 3 deals however basically with the supply chain perspective only. In order to make circular economy more effectively in the market, the demand side has to be considered as well.

In this section, circular economy aspects of the electronics to business to (individual) consumers (B2C) will be discussed; these are quite different from the ones for business to business (B2B).

Also in circular economy matters, individual consumers behave as individuals: there is a large variety of opinions and perceptions in this field (Agema et al., 2007). Moreover, many consumers—not all of them—have 'superseding issues', particularly as regards 'preowned' products., that is products having more than one lifecycle. Such products are an important cornerstone of Circular Economy, but will often be perceived as cheapy, unreliable, old fashioned and inconvenient. Only for a minority of the general public 'sustainability' or circular economy ranks in the top 3 of issues in their buying (and discarding) behaviour.

The importance and relevance of sustainability and hence of circular economy on a societal level is broadly agreed upon but when it comes down to individual decisions a substantial part of the consumers take a more self-centred attitude. Most of them want from products 'benefits' which go clearly beyond just benefits in the sustainability domain. For businesses this means that is has to go for a 'linked benefit strategy'. Dilemma's which can result from this (Agema et al., 2007).

What is the best compromise is strongly dependent on the product characteristics and on the segment of the public buying these products? This means in practice that at least part of the total design approach should be differentiated per product category and geared towards the perceptions of the buyers of these products.

### *4.2. Clues for design for the circular economy from returns directly after sales*

Design clues after sales of products can be found through a systematic analysis of reasons for returns directly after sales or even more importantly by analysing why product guarantees are being invoked. Calls for service/repairs after the guarantee period also belong to this category.

- The product does not look as I thought it did (particularly relevant for internet sales). Circular Economy dimension: need for changibility of outer looks.
- It is difficult to make the product work or to connect it to other electronics. Circular economy dimension:attention for information and for connectivity, also in a second life.
- Outright mechanical of electrical failures, particular when kinds of failures are recurring frequently: CE dimension: attention for repairability.

Depending of the type of product, this kind of information will bring a variety of useful design issues. What needs to be organized to make this work in practice is that the organization selling the products ('trade') gives relevant feedback to the producers/ designers.

### 4.3. Design for better conservation of resources and value by postponing discarding by the first owner

#### 4.3.1. Product characteristics and discarding of products

A thorough analysis of the reasons why first owners want to discard electronic products can give meaningful design clues to postpone this intent (and in this way increase life time already in the first cycle). Like in Section 4.2., such reasons vary widely and are strongly dependent the product functionality. Therefore, there is a clear need for differentiation in approaches; also for this issue there is no one-size-fits-all.

Design for better conservation of resources and value is already dealt with as of 2001 (Rose et al., 2007). At that time issues associated with it were considered from a technical perspective that is to be related specifically to product characteristics only.

Products with fast development in underlying technology (a 'short technology' cycle) were identified as ideal candidates for a design approach that allowed easy to install upgrades when required. For high-tech products with a high level of function integration, this may be a too simplistic idea. Taking them back through trade-in and trade-up schemes might be a better one; products turned in might be resold to buyers who are less demanding on having the latest technology, like, for instance, price buyers described in. However, this kind of strategy is strongly dependent on the cooperation of trade which is by no means guaranteed. The power of the trade channels might be one of the reasons why, for instance, Apple Inc. has its own brand specific stores. However, only very few brands have the organizational and financial power allowing them to have these in place.

A product category for which a different design strategy applies is the one for which 'wear and tear' is dominant in the later stages of their total life. If 'wear and tear' occurs throughout the product, this difficult to be overcome by design. In cases where wear and tear is of specific parts whereas others keep their integrity, design for easy accessibility of these is an obvious strategy. This strategy is to be supported by the set up of a spare parts provision system.

Possibilities for a high level of reuse through repairing products that first owners want to discard are often related to the number of parts in a product (complexity): the more parts, the more complicated the repair. Organizing all these parts better through modular design will make such repairs easier. However, it is to be realized that modular designs often involve use of more material. This can be offsetting the potential gains through a longer life time. Decisions of this kind need careful balancing. These can be made for instance on basis of making FRp calculations (see Section 4.3.1).

Too expensive repair is, in the developed world, a frequent reason why products are discarded: professional labour rates are simply high compared to cost of component and materials. If the expected gain in life time through costly repairs of an old product is equal or higher than an equivalent cost of buying a new one, consumers will usually go for buying new. Nowadays electronic products are cheap compared to the income of many consumers. This is a circular economy fate which cannot be circumvented by design. The relatively low price/average income ratio of most electronic products also explain why 'renting instead of ownership' approaches which are supposed to lead to longer lifetimes before discarding have rather lost than gained popularity.

#### 4.3.2. Engagement of producers in post use markets

There are also a variety of 'non-technical reasons' why owners want to get rid of their products in spite of the fact that these still have substantial functionality and therefore resource and economic value. Such non technical reasons include.

- changes in 'household size: marriage/start to live together, decease,
- do not like the product anymore, product appearance does not fit anymore to other new items which have been bought,
- and there is money available to be spent, so why not buy new items.

Such reasons for discarding by the first owner account—on average for all electronics—for some 30% of the total (van Nes et al., 2007). Such percentages suggest a substantial reuse potential. Particularly this phenomenon raises the question whether this is an opportunity for producers to engage themselves more actively in the post first use market.

To make this happen first of all paradigm shifts are required. For producers, this means a departure from the idea of only selling new products. Consumers have to give up the idea that second hand is inferior by definition and to be associated with poverty. The biggest issue is, however, that the current organization of the value chain makes such an engagement problematic; the core of this problem is that powerful mass outlets for electronics (responsible for the far majority of sales in many countries) make it difficult to organize brand specific return streams. Such specific return streams are necessary to realize a high level circular economy. As a result, products still functioning but disposed of after first use will be still kept by their owner as a spare, or given to family members like 'kids in college'. Also donating to charity of second hand shops with social objectives occur frequently.

When buying new products in shops which do not belong to big chains 'trade-in' frequently occurs. Here chances for brand specific post use activities are better. The opposite holds for situations in which peddlers go actively from door-to-door to buy used electronics; such products 'disappear' into informal circuits. On one hand is OK because there is a lot of value conservation in the informal sector. On the other hand, this can also imply substandard treatment. Even a lot of uncontrolled waste can be generated in this way. Such dilemmas are quite common in a lot of countries in the developing world. This analysis shows that there are three conditions for success for engagement of producers in post use market:

- proper positioning of the post use products with respect to new products (price, brand image),
- ensuring an appropriate input stream for the reconditioning activities
- and ensuring appropriate output channels for the post use products.

## 5. Application of resource factors beyond design for the circular economy

### 5.1. Support of resource factors for better rules for take back and treatment systems

Design for the circular economy is a necessary but sufficient condition to come substantially closer to a circular economy for electronic products. This is because in the end products will be discarded by the final owner. This happens at the moment that the functionality has dropped below a level at which actions to extend product life make no sense anymore. For such products, the only thing which can still be done is parts harvesting or recycling of the constituent materials while controlling potential toxicity. Towards this end, products will have to be collected and treated according to appropriate standards. Subsequently, the secondary streams resulting from the treatment are to be upgraded in order to become suitable for reapplication.

However, the value of the materials present in electronics cannot pay for all the cost of take back and treatment according to sustainability standards; there is a structural end-of-life deficit. Even the best design for recycling or the most effective treatment cannot close this gap. Therefore legislation setting targets for collection and recycling and determining the financial responsibilities has to be in place. Nowadays, many countries in the world have such legislation and have systems in place for take back and treatment running. Having these in place is not the end of the story. On the contrary, it is just the beginning of proper resource management. Complex systems like these need continuous adaptation as a result of lessons learnt in practice and since circumstances (infrastructure, technology, labour cost, proceeds of recycled materials) continuously change. This requires regular deliberation by stakeholders. Using resource factors as a basis for analyzing proposed or planned changes in the regulation could assist in making the discussions about these much more effective (Huisman et al., 2019).

### 5.2. Support of resource factors for more effective collection of discarded products

In the EU system, last owners have to bring their discarded electronics to collection points. It can be done for free, but it can be inconvenient as well. Smaller items tend to 'disappear' in the standard municipal waste streams. For big and heavy items, many consumers have no adequate transportation themselves. This circumstance creates waste streams parallel to the official one as well. Moreover, many last owners trade in their old products and the shops get sometimes rid of these through 'back door trade'. Even near (or even at) official collection point there is such kind of 'trade'.

It is therefore no wonder that in the Netherlands the collection rates in the official—that is the one operating according to official (and high) standards—system are only some 40%; the average for all EU countries is even lower, that is 30%. Part of the discarded electronics (some 30%) is treated in one way or another in the country of origin itself, most likely in a substandard way. The balance is (il)legally exported (again some 30%) or has 'disappeared with unknown fate (Huisman et al., 2012).

It is too easy to say that better policing of all these streams is a solution to prevent all this. Tackling the problem at the source would be better. A financial system offering incentives to last owners to discard in the right channel would be of great help in this respect. One of the effective items to offer these is introduction of deposit systems. Producers and trade are firmly against this; governments are hesitant. However, in cases where such systems have been introduced (mostly for packaging) these have been successful. In the opinion of the author, introduction of a deposit system, for instance for cellphones, is pretty urgent. This is because the phones have high RFps and are being used by billions of people. Tackling all collection issues at once and for ever is unrealistic and impossible. However it is feasible to make on basis of resource factors an action agenda for collection improvement. Key words for making such an agenda are differentiation in the requirements for the different categories of electronic products and priority setting within each of the categories. What is argued for is in fact a kind of RF based 'portfolio management' for collection of discarded products.

### 5.3. Use resource factors to better manage the treatment and upgrading sector

Today, most legal requirements for treatment of discarded electronics are basically 'not to landfill' requirements since recycling targets are based on weight and not on relevance for environmental impact on relevance for the circular economy. Treatment technology and upgrading processes are strongly geared towards this situation. This makes that only materials where the products for which the multiplier of concentration and economic value is sufficiently high (like copper and the precious metals) get special attention. However, materials with high criticality, with moderate price (so far) and occurring in too low concentrations (like tin) are not sufficiently considered (or not considered at all).

A resource factor analysis on the different categories of electronic products and the volumes of the different waste streams could identify the most important gaps for this category of materials. This could result in more 'circular economy' specific targets. Indirectly this can lead to more dedicated treatment (Huisman et al., 2019) and upgrading processes for selected streams.

### 5.4. More effectively dealing with the informal sectors

The informal sector dealing with discarded electronics is typical a low cost operating one. This means that repair and also disassembly of products are cheaper. Through this better conservation of resources and value can be achieved. Further, income can be generated by disassembly focused on the presence of valuable materials like copper and precious metals. For heavy products, metals like iron and aluminium and big plastics parts represent a source of income as well.

The flip side of this is that the sector is 'low tech' which means that upgrading processes for secondary fractions are often polluting and inefficient. Moreover, the sector goes after 'value' only, which means that everything which is not representing any form of value is considered to be waste and is disposed off. This happens often through uncontrolled landfill or dumping elsewhere.

Wanting the informal sector to disappear for this reason is unrealistic. It is a reality and it is well widely spread, particularly in developing economies. The best strategy is therefore to take the sector to higher levels, connect it better to the formal systems and to bank on the positive elements which are already in place (Wang et al., 2012). In last named respect the good news is that collection is more effective than in official systems. Also more detailed repair and disassembly can be done, provided that appropriate information how this is to be done is available. As mentioned in Section 5.2, detailed disassembly is still the best way to recoup valuable parts and materials. Last but not least it is ensuring a lot of employment.

A first action to improve is providing more information to the sector through IT. Through apps an 'electronic waste information forum' can be established. This could not only provide technical information but also information about supply and demand and about prices. Also through this financial arrangements for buying valuable fractions could be made. Eliminating intermediary trade and more economy of scale allowing less polluting and efficient upgrading processes would create 'win-win'. The flip side of this is that the small operators also have to be paid for waste which otherwise would be irresponsibly be disposed off. For such an activity, financing has to be found. Legislation in countries where the informal sector is dominating should therefore primarily focus on creating a financial mechanism enabling all of this to happen.

In China and India, there are now small scale experiments in place to create an ITbasis for the developments as sketched above. Getting momentum in these will allow to create more sophistication in the informal sector. If this situation can be reached, resource factors can be brought into play here to develop the sector to a more systematic base for resource conservation.

## 6. Discussion

### *6.1. The proposed metrics for design for the circular economy*

The proposed metrics focus on materials. Apart from environmental impact, the dimensions of supply criticality and of recyclability have been included in the analysis as well. It will be interesting to see to what extent this addition works out on design decisions taken from a traditional Eco perspective. Most likely products with a relatively high content of critical materials and/or low recyclability (like smart phones) are the best candidates for this kind of research.

Another contradiction that hopefully can be settled is the contradiction between reducing the amount of materials use in the initial designs and the increase of lifetime of products through modular design (which mostly requires more material to be used). The key question is here: what is more important; small reductions which can apply to a high volume of products, or substantial better use (more life cycles) for a small number of products for which longer lifetime can be realized?

### *6.2. Comparison of the proposed metrics with the ones for traditional ecodesign*

The proposed metrics for design for the circular economy focus on resource and resource issues whereas traditional ecodesign focuses on a different environmental dimension, the one of emissions. This is because traditional ecodesign in practice uses life cycle analysis based methods which are emission based. Although there is an interrelation between the two design approaches through the environmental impact of producing materials there could be contradictions in content and/or priority of the design recommendations. It expected that this will occur particularly for electronic products in which energy consumption in the use phase are dominant in an LCA analysis. This issue will play a role for instance for TV sets.

Before starting a huge discussion whether the ‘emission’ or the ‘resource’ dimension of environment should have priority in such cases, it is proposed to map the differences in on an practical basis for a number of electronic products and to deal with these in a pragmatic way.

### *6.3. What can traditional ecodesign methodology learn from the proposed approach for design for the circular economy?*

The very components of the metrics for design for the circular economy of supply criticality and recyclability put this approach already in a wider context than just the environmental one. Application of the vector method (see Section 3.2) to set priorities. It also helps to get acceptance in the internal value chain of companies are another example of this. Although the vector method has been applied for specific recycling issues (Huisman et al., 2007a), it has never been applied to overarching ecodesign issues. In applied ecodesign, the so called ecodesign matrix (Stevels, 2007b) is only qualitative due to its very nature.

Quantitative analysis of product portfolios with the aim of positioning them well towards specific consumer groups is a new issue which can be addressed by the proposed metrics. The Eco value approach developed for application in applied ecodesign (Pascual & Stevels, 2007) never got off due to conservatism in electronic companies. It is hoped that the current proposals give it a new momentum. Traditional ecodesign has been consistently focusing on ‘environment only’. This has made that in this field there is a substantial gap between theory and practice. It is hoped that circular economy thinking can contribute to close this gap and in this way new impulses can be obtained for a field which is currently stagnating in its implementation in the industry.

## 7. Conclusions

In this paper, resource factors (RFs) are proposed which support design for the circular economy (DfCE) in the electronic industry. In the RFs, the three dimensions of the circular economy (CE) are represented in a numerical way: supply criticality, environmental impact and recyclability. Due to the dissimilarity of these three elements, the analysis with help of the RFs can only be done in a comparative way. For making action prioritized agendas for product design and for managing product portfolios, the subjective character of the RFs is no problem whatsoever.

In order to make them work properly, the resource factors have to be considered in a wider context as well. Primarily this is the sustainability context: attention is to be paid to resolve possible inconsistencies between emission and resource related priorities. In a business context resource considerations have to be integrated in the overall design targets. Here the numerical character of the RFs can be of great help. Moreover, credibility in the internal value chain to apply the concept has to be built up. Since the core of DfCE (reduction of materials) and cost reduction run parallel, this generally works out better than for traditional ecodesign. Applying the concept of design for resource value will create an on top of this a clear link with business strategy.

Combining discarding behaviour of first owners and RF analysis brings useful clues for tailored strategies for resource conservation after sales.

Also beyond design for the circular economy, the proposed resource factors can contribute, particularly to support improvement of the formal take back and treatment systems. This pertains to collection, treatment as well as to upgrading of secondary fractions. Informal sectors for take back and treatment have to be structured more before RFs can be applied in this domain. In this paper, some suggestions are done how this could be set in motion.

## Declaration of competing interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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