CirculAbility Model ©

Methodological approach

Summary

1. Overview

Circular Economy represents a huge opportunity in terms of innovation, competiveness and environmental sustainability. As it covers many different fields of applications, one of the main challenges has always been the definition and the implementation of effective KPIs in order to measure, compare and improve circularity in projects and products. The definition of circular KPI is so difficult to be approached both for the fact that it is a relatively new topic and for the wide range of topics make it difficult.

Enel is developing many initiatives in the field of Circular Economy and, with the aim of further improving its activities, developed its own approach on KPIs. The aim of the approach is to define a final KPI that can be considered as a proxy of all the circularity parameters of the product or of the project.

Main challenges consist in the fact that:

- Physical indicators (e.g. renewable input) and use indicators (e.g. load factor') have to be compared
- Within physical indicators, it is necessary to compare both material flows and energy flows

The most straightforward solution would be to define different indexes, one for each homogeneous category, but such an approach would make the approach ineffective as an overall indication would be missing. For this reason, we preferred to define a final single index, based on some assumptions:

- Inclusion of some empirical formulas, i.e. not related to physical considerations but useful to achieve the target of a single indicator
- Taking into account of energy through their conversion into the material (i.e. in kg) used to produce such an amount of energy
- Use indicators that are pure numbers, through the use of ratios

The model considers an overall circularity index, Circular Index (C_i), so defined:

$$Ci = Cf + \frac{(1 - Cf) \times (Cu - 1)}{2 \times Cu}$$

The rationale of this formula is the following:

- The first addendum Circular Flow (C_f) consider the contribution in terms of circular inputs and outputs of material and energy
- The second addendum considers (1 - C_f) therefore the ‘not circular contribution’ from energy and material inputs/outputs and multiplies it for a component that considers a ‘use factor’ to consider what was the load factor of this ‘not circular’ contribution. The use factor is defines as:

$$\frac{(Cu - 1)}{2 \times Cu}$$

It is an empirical formula that let to take into consideration the use factor but with a weight within the range [0; 0,5] where:

C_f, Circular Flow: represents the circularity in the flows of materials and of energy

C_u, Circular Use: represents the circularity in the use approach

2. Circular Use

This indicator considers the solutions adopted to increase the load factor of an asset. The environmental benefit is related to the fact that if the same asset is used for example from two users, the amount of assets required is halved and therefore the consumption of material and of energy. This indicator is defined starting from three sub indicators:

$$\boldsymbol{Cu} = \frac{\boldsymbol{L}_{\text{ex}}}{\boldsymbol{L}_{\text{BAU}}} \times \frac{\text{U}_{\text{sh}}}{\text{U}_{\text{BAU}}} \times \frac{\boldsymbol{U}_{\text{SAP}}}{\boldsymbol{U}_{\text{BAU}}}$$

Where:

- L_{ex}: extended useful life (years) thanks to dedicated measures in terms of design/maintenance that can extend the useful life in a measurable and 'certified' way
- L_{BAU}: standard useful life of the project/product (i.e. without dedicated measures)
- U_{sh}: time of use of the asset (as % on total time) in case of sharing
- U_{BAU}: time of use of the asset (as % on total time) in Business as Usual case
- U_{SAP}: time of use of the asset (as % on total time) in case of 'service as a product'
- U_{BAU}: time of use of the asset (as % on total time) in Business as Usual case

All the above benefits have to be clearly defined and measured, i.e. generic benefits cannot be taken into account but only dedicated and specific ones.

2.1 Life extension

Consider the extension of the useful life of a product or project thanks to solutions such as modular design, predictive O&M, etc. These solutions have to be innovative and not be standard market solutions

2.2 Sharing

Through sharing it is possible to highly increase the load factor. With sharing we mean the sharing of an asset among two or more customers in a 'client to client' relationship.

2.3 Product as a service

The benefit related to the product as a service is because the Company does not sell a product to the client but just the service (i.e. the use); in this way it is possible to have one asset used from many client allowing an increase of the load factor.

3. Circular Flow

This indicator measures the circularity in the use of resources, with the aim of considering the effort to reduce not sustainable inputs and waste. The used formula is the following:

$$Cf = +\frac{\left(2 - \left(\frac{V}{Ti} + \frac{W}{To}\right)\right)}{2}$$

This index considers the weight of not sustainable inputs on total inputs (V/T_i) and the weight of the waste that goes to final disposition (W/T_0); where:

- *T_i: total inputs*
- *T_o: total outputs*
- *V: total input from not sustainable virgin material*
- *W: total output sent to disposal*

That are so computed

$$Ti = RC_i^n + RU_i + RES + V$$

where:

- *RC^n_i: total net input from recycle*
- *RU_i: total input from reuse*
- *RES: total input from renewable and from input reduction (efficiency)*
- *V: total input from not renewable virgin material*

$$To = RC_o^n + RU_o + O + W$$

where:

- *RC^n_o: total net output sent to recycle*
- *RU_o: total output sent to reuse*
- *O: output included in the final product*
- *W: total waste to disposal*

W is computed as

$$W = WRC_i + WRC_o + W_o$$

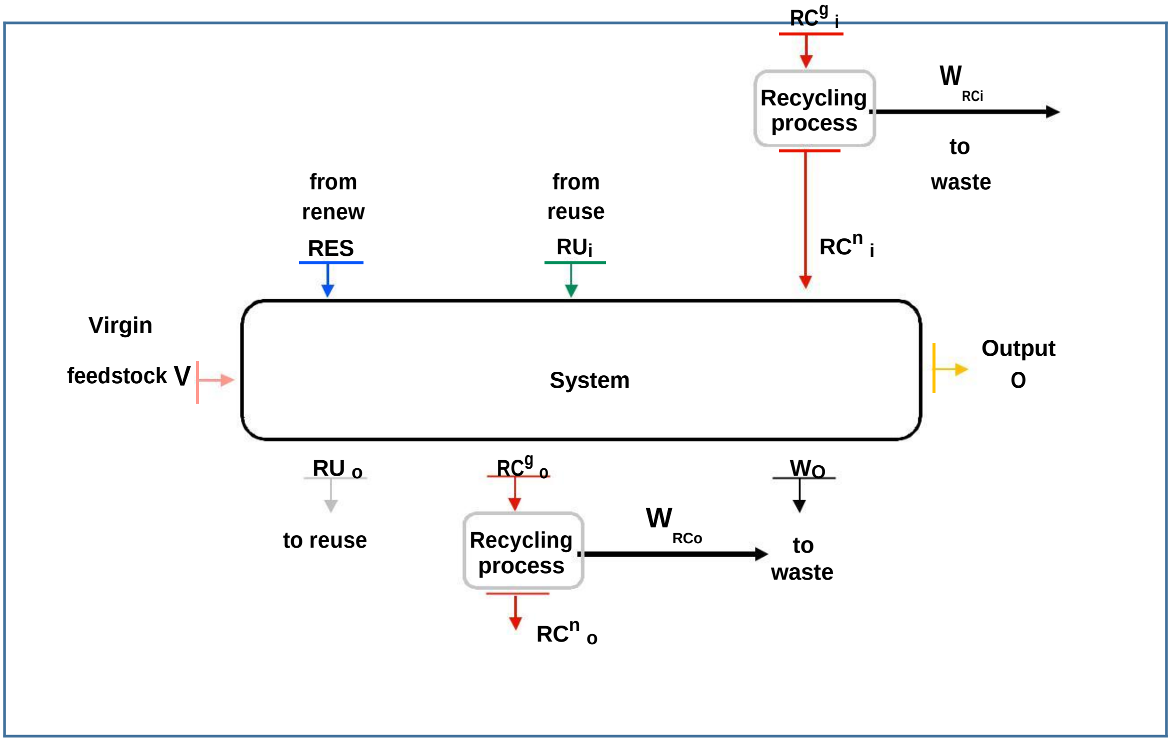
- *WRC_i: waste produced in the recycle phase before an input*
- *WRC_o: waste produced in the recycle phase after an output*
- *W_o: waste produced in the main process of our system*

Any of the variables considered in 'Circular use' is made up of two components, one related to materials and on to energy

The overall analysis that provides 'Circular Flow' indicators is therefore realized starting from four components:

- Materials inputs
- Energy inputs
- Materials outputs
- Energy outputs

The following figure provide an overall representation of the flows:



3.1 Material inputs

Considered indicators are the following:

3.1.1. Renewable materials (RES):

Represents the sum of the amount of renewable materials used. It's calculated by multiplying the total weight of each single used material for the related source percentage from renewables.

3.1.2. Input materials from reuse (RU i):

Represents the inputs from reuse (materials weight) that are calculated by multiplying the total weight of each single used material for the related source percentage from reused materials.

3.1.3. Input materials from recycle (RC i):

This indicator represents the amount of material from recycle. At first it is considered the amount of 'gross' material from recycle (RC^{g}_{i}) that is the output of a process before the process we are considering; then the net value is computed as difference between RC^{g}_{i} and WRCi (that is the waste produced during this recycle process). The result of this difference represents the amount of material that enters as an input into our process. This value is computed as:

$$RC_i^g = \frac{RC_i^n}{eff_i^{rc}} = \frac{RC_i^g - WRC_i}{eff_i^{rc}}$$

$$WRC_i = \frac{RC_i^n \times (1 - eff_i^{rc})}{eff_i^{rc}}$$

- $\mathrm{Eff}^{rc}i$: represents the recycling efficiency of the process before our.

It's calculated by multiplying the total weight of each single used material for the related source percentage from recycled materials.

3.1.4. Virgin material (V):

It is the amount of virgin and not renewable material that is used as input; it's computed multiplying each material by the related percentage from virgin materials.

3.2 Materials output

This section considers the contribution of each component. The indicators considered are:

- $RC^n{}_o$: process output to recycle (does not include the waste in recycle phase)
- *WRCo*: amount of waste produced from the recycle process, computed as

$$WRCo = \frac{RC_o^n \times (1 - eff_o^{rc})}{eff_o^{rc}}$$

Where $eff^{rc}{}_o$ is the efficiency in the recycle phase of the output of our process

- *RU o*: amount of material sent to reuse
- *O (kg)*: amount of material included in the final product
- *Wo (kg)*: amount of waste from the main process

3.3 Energy Input

In order to have a homogeneous computing of energy and material, the defined approach is that of representing the amount of energy in terms of the amount of materials used to generate such energy according to the used sources.

In this respect, it is necessary to define the following conversion criteria

3.3.1 Conversion factor for electrical energy

From the data of the Italian Transmission Operator (Terna) 2016 we have:

Generation Italy 2016

Virgin source	**GWh generated**	**% vs total**
Coal	32.149	10,23%
CCGT	122.876	39,10%
Other thermal	15.305	4,87%
renewables	106.849	34,00%
Import	37.083	11,80%
Total (GWh)	314.261	

We make a few assumptions:

- We consider zero the amount of used material to generate renewable energy.
- The input material calorific value (pci) that generated the "import" energy has been computed as the pci weighted average of the other energy sources.
  We define the electric conversion factor for energy (fc_e) as the ratio between the total amount of required fuel (kg) for power generation and the total amount of MWhe fed into the grid.

It is possible to calculate the related necessity/consumption of material (in kg) by multiplying this factor by the amount of used energy, for example by a product.

fc_e = 118,51 kg/MWh_e

3.3.2 Thermal energy conversion factor

For what concerns the thermal energy, we use the same calculation but considering MWht instead of MWhe. The result is:

fc_t = 66,72 kg/MWh_t

3.3.3 Inputs

Defined the conversion factors, we name the energy amount as 'material amount' considering the conversion factor above defined. A number of possible supply options have been identified for the main sources.

3.3.3.1 Input from renewables (RES_ Ener):

Total amount of equivalent material (computed through the conversion factor) related to the renewables input

3.3.3.2 Reuse

Total amount of equivalent material related to reuse energy inputs (RU i_ Ener)

3.3.3.3 Recycle

Total amount of equivalent material related to recycle energy inputs (RC i_ Ener)

3.3.3.4 Virgin material

Total amount of inputs (V_ Ener) from not renewable materials, computed as sum of thermal inputs

3.3.4 Energy production

The five indicators above mentioned are computed starting from the following sourcing options:

3.3.4.1 From Grid

For the energy from the grid, the conversion is computed according to the chosen generation mix and the fc_e factor as defined below. We can assume for a MWhe:

- 118,51 kg of fossil energy (that flows into V_Ener)

3.3.4.2 Auto producers

We assume that the autoproduction of electrical energy that can be classified in four cases:

- **Recycle**

  Input from recycle, $RC^e{}_i$

  To compute the input from recycle we consider the amount of energy before the recycle process and this value is multiplied by the electrical conversion factor (fc_e)

$$RC_i^e = \frac{ee_{riciclo} \times \mathrm{fce}}{eff_i^{rc}\ ee}$$

  Where:

eff^{rc}_i : efficiency of the recycle process
$ee_{recycle}$: electrical energy from recycle
fce: electrical conversion factor

Waste from recycle, WRCi
It is computed from the amount of energy used for the production:

$$WRCi_{ee} = \frac{ee_{riciclo} \times (1 - \%rinnovabilità) \times (1 - eff_i^{rc}\, ee)}{eff_i^{rc}\, ee}$$

- **Reuse**[2]
  For reuse, it is assumed that the whole amount of energy from reuse in input is converted into electric energy

$$ee_{riuso} \times \mathrm{fce}$$

ee_{riuso}: electrical energy from reuse
fce: electrical conversion factor

- **Renewables (biomass excluded)**

  To compute the amount related to renewable, the produced electrical energy is multiplied by the electrical conversion factor fc_e and by the percentage of renewable

$$RES_{ener} = ee_{res} \times fce \times \%rinnovabilità$$

In the case that some sources are not considered completely renewable, an amount of thermal is computed and added to the thermal amount hereafter

- **Solid fuel (thermal and biomass)**
  For this indicator we need to compute the amount of virgin material related to generation; we had to multiplies the generated electrical energy by the fc_e factor

3.3.4.3 Auto production of thermal energy

- **Recycle:**
  input from recycle, RC^t_i
  To compute the input from recycle we consider the amount of energy before the recycle process and this value is multiplied by the thermal conversion factor (fc_t)

$$RC_i^t = \frac{et_{riciclo} \times \mathrm{fct}}{eff_i^{rc}\, et}$$

W[1]here:
$eff^{rc}_i et$: efficiency of the recycle process of thermal energy
$et_{recycle}$: thermal energy from recycle
fct: thermal conversion factor

[2] With reuse we mean the direct use of an amount of energy coming from another process, whereas with Recycle we mean that before using the energy, this is somehow processed and some wastes are generated.

Waste from recycle, $WRCi_{et}$
It is computed both for the electrical and for the thermal part from the amount of energy used to produce it:

$$WRCi_{et} = \frac{et_{riciclo} \times (1 - \%rinnovabilità) \times (1 - eff_i^{rc}\ et)}{eff_i^{rc}\ et}$$

- **Reuse**
  It multiplies the amount of thermal energy sent to reuse by the thermal conversion factor fc_t

$$et_{riciclo} \times \mathrm{fct}$$

- **From renewable**
  To compute the amount of renewable energy related to the production from renewable sources the electrical energy produced is multiplied by the electrical energy factor fc_e and by the related percentage of renewable energy

$$et_{res} \times fct \times \%rinnovabilità$$

  In the case that some sources are not considered completely renewable, an amount of thermal is computed and added to the thermal amount hereafter

- **Thermal**
  We assume available the total amount of used fuel so that we can directly insert the kg of burnt fossil fuel.

3.3.4.4 Energy consumption during product lifetime

Since product production until the end of its life, we can have different situations about electrical needs:

- Products that don't need energy anymore (ex. static object)
- Products that need electricity to work
- Products that need fuel to generate energy for working (ex. a vehicle)

In the first case, no further details are needed.
In the second case, the calculation is the same used for energy inputs in the process analysis.
In the third case, we suppose to be able to compute the weight of needed fossil fuel to run. This weight (kg) will be added to the amount of total material computed in input.
Both in the second and third case it could be necessary to transform the generated energy into another type of energy (ex. mechanical), thanks to an engine. In this case, it's important to understand that not all the generated energy can be used and an adequate engine efficiency must be estimated to arrive at the real available energy and estimate the one lost (ex. by heat). Energy lost by conversion should be added to the process output waste.

3.4 Energy output

For what concerns wastes, these three king of wastes are considered:

- Wastes to recycle
- Wastes to reuse
- Thermal wastes not recovered

The considered final indicators are:

3.4.1 Output sent to recycle (RC o_ Ener):

Output to recycle, RCo

It referes to the amount of process waste that is recycled and used as input in an afterward process.

It is computed from the amount of waste heat produced in the recycle phase both for electricity production and for thermal production, computed as:

$$RCo = RCO_{el} + RCO_t$$
$$RCO_{el} = ee \times fce$$
$$RCO_t = et \times fct$$

Waste from recycle, WRCo

It considers the waste produced in the recycle phase. It is computed considering the waste produced during recycle, both for what concern electrical energy production and for what concern thermal energy production

$$\frac{RCo\ el \times (1 - eff_o^{rc}\ ee)}{eff_o^{rc}\ ee} + \frac{RCo\ et \times (1 - eff_o^{rc}\ et)}{eff_o^{rc}\ et}$$

3.4.2 Output sent to reuse (RUo):

It considers the amount of waste energy that is sent to reuse and used as input for an afterwards process. It is computed from the amount of heat sent to reuse both in the electrical autoproduction and in the thermal autoproduction, computed as:

$$RUo = RUo\ el + RUo\ t$$
$$RUo\ el = ee \times fce$$
$$RUo\ et = et \times fct$$

3.4.3 Waste directly sent to disposal (Wo_ Ener):

It considers the waste that is directly disposed, i.e. not recovered and directly dispersed in the air. They are computed as:

$$Wo_{ener} = ee \times fce + et \times fct$$

3.4.4 Output (O)

It considers the sum of the energy output for which the processi s designed. Is an indcator to be considered if the process considered is that of a power plant or of a thermal plant. The values to be inserted are directly those of electrical energy and thermal energy produced, that are then converted through the conversion factors:

$$O\_Ener = O\ ee + O\ et$$
$$O\ el = ee \times fce$$
$$O\ et = et \times fct$$