THE 10TH INTERNATIONAL CONFERENCE ON LIFE CYCLE MANAGEMENT, 05-08 SEPTEMBER 2021, STUTTGART (GERMANY)

Sustainability and circularity indexes of end-of-life scenarios of photovoltaic modules

Acknowledgements
Ayudas a la investigación 2019
Fundación IBERDROLA

Daniel GARRAÍN
Dep. Energy, Energy Systems Analysis Unit, CIEMAT, (Madrid, Spain)
daniel.garrain@ciemat.es

GOBIERNO DE ESPAÑA · MINISTERIO DE CIENCIA E INNOVACIÓN · Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

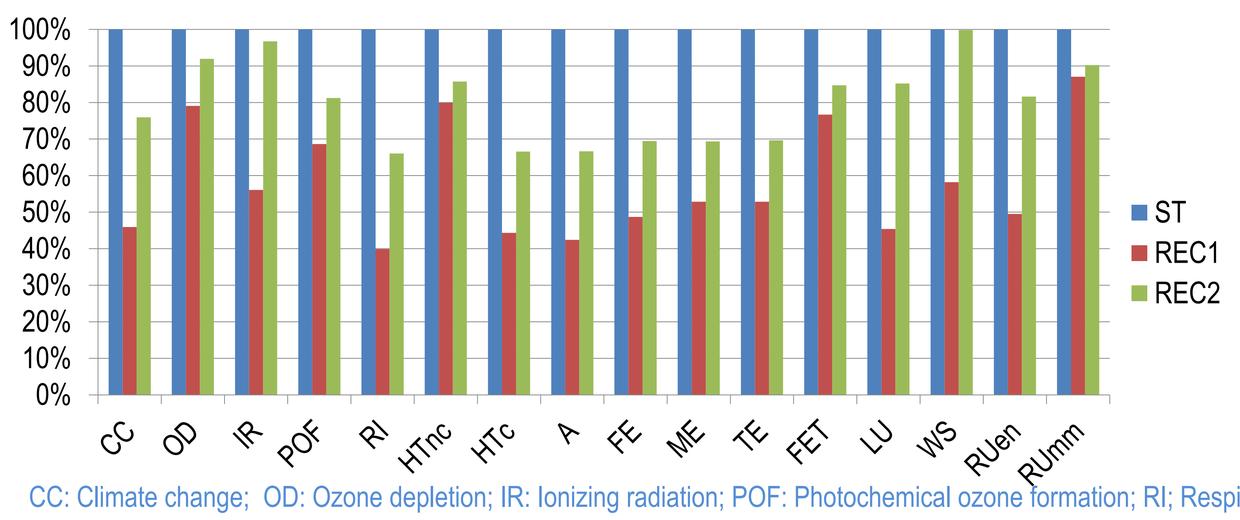
Introduction

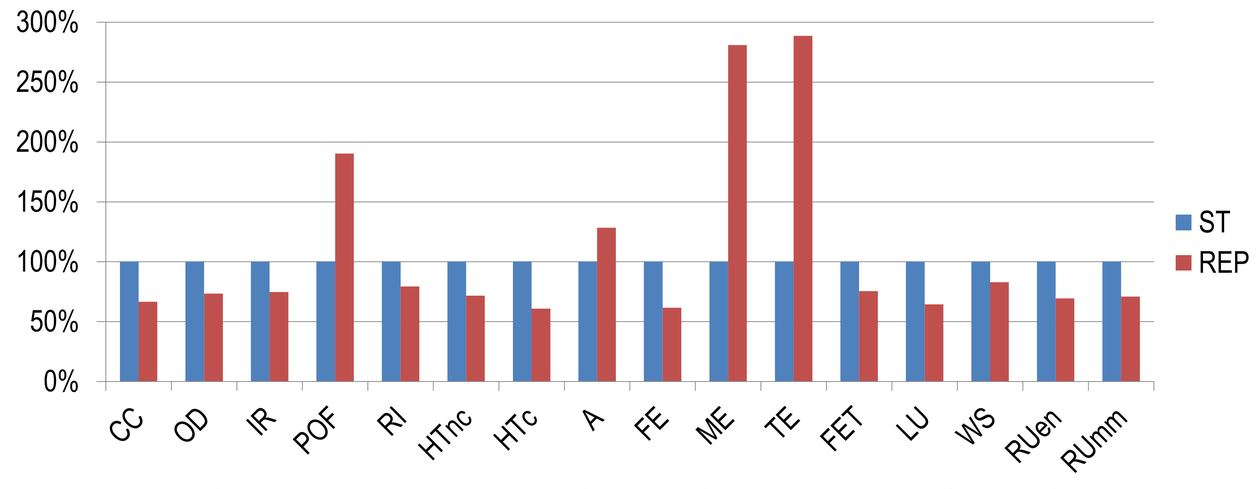
Photovoltaic energy has been considerably growing for the past few years. There are currently more than 500 GW installed worldwide and it is estimated that power could reach 8,500 GW in 2050. Therefore, one of the consequences of this increase will be the high volume of generated waste in the coming decades. The general objective of this work aims to analyze different management scenarios for photovoltaic modules at the end of their useful life, through the application of methods that allow the development of strategies to move towards a circular economy, namely LCA (by means of Environmental Footprint, EF), Material Circularity Indexes (MCI) and Input-Output (IO).

Methods & Results

EF has been applied to three different end-of-life (EoL) strategies: Landfill, Recycling and Reparation according these scenarios:

EoL scenarios	Main characteristics	Source
Manufacturing and disposal to landfill **(ST)**	Manufacturing of a standard PV module // Glass, Al and inerts to landfill (30 yrs)	Méndez *et al.* (2021)[1] // Ecoinvent
Manufacturing and recycling **(REC1)**	Manufacturing of a standard PV module // Mech & chemical recycling (30 yrs)	Méndez *et al.* (2021) [1] // Adaptation of Latunussa *et al.* (2016) [2]
Manufacturing and recycling **(REC2)**	Manufacturing of a standard PV module // '*Hot-knife*' recycling (30 yrs)	Méndez *et al.* (2021) [1] // Aurinka (firm) personal communication
Manufacturing and reparation **(REP)**	Manufacturing of a standard PV module // 50% mass reparation (15 yrs)	Méndez *et al.* (2021) [1]// Solucciona (firm) personal communication

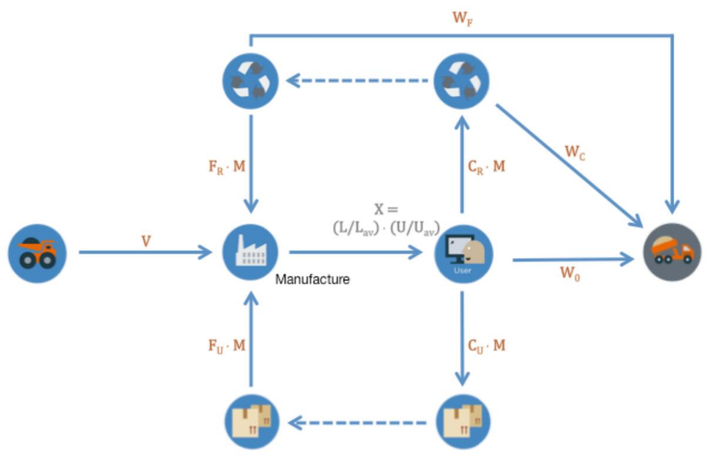




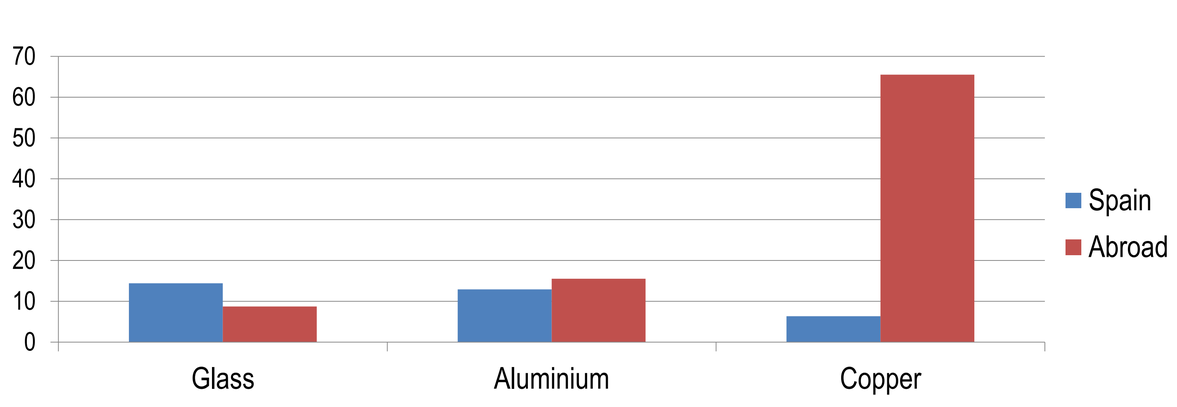
CC: Climate change; OD: Ozone depletion; IR: Ionizing radiation; POF: Photochemical ozone formation; RI; Respiratory inorganics; HTnc: Human toxicity non-cancer; HTc: Human Toxicity cancer; A: Acidification, FE: Eutrophication freshwater; ME; Eutrophication marine; TE: Eutrophication terrestrial; FEC: Freshwater ecotoxicity; LU: Land use; WS: Water scarcity, RUen: Resource use – energy carriers; RUmm: Resource use – minerals and metals.

MCI tool from the Ellen MacArthur Foundation[3] has been applied to the following different strategies:

EoL scenarios	Input (I) and output (O) materials characteristics	Intermediate values	MCI
ST*rec*	I: Virgin; O: Landfill	V = 1.00; M = 1.00; X = 1.00; F(X) = 0.90; LFI = 1.00	**0.10**
REC1	I: Recycled (eff: 99%); O: Landfill	V = 0.00; M = 1.01; X = 1.00; F(X) = 0.90; LFI = 0.50	**0.55**
REC1a	I: Recycled (eff: 99%); O: Recycling (eff: 99%)	V = 0.00; M = 0.01; X = 1.00; F(X) = 0.90; LFI = 0.01	**1.00**
REC2	I: Recycled (eff: 71%); O: Landfill	V = 0.00; M = 1.20; X = 1.00; F(X) = 0.90; LFI = 0.55	**0.51**
REC2a	I: Recycled (eff: 71%); O: Recycling (eff: 71%)	V = 0.00; M = 0.35; X = 1.00; F(X) = 0.90; LFI = 0.17	**0.85**
ST*rep*	I: Virgin; O: Landfill; Useful life (UL): 15 yrs	V = 1.00; M = 1.00; X = 1.00; F(X) = 0.90; LFI = 1.00	**0.10**
REP	I: Repaired (2%); O: Landfill; UL: 30 yrs	V = 0.98; M = 1.00; X = 2.00; F(X) = 0.45; LFI = 0.98	**0.55**
REPa	I: Repaired (2%); O: Recycling (eff: 99%); UL: 30 yrs	V = 0.98; M = 0.01; X = 2.00; F(X) = 0.45; LFI = 0.48	**0.78**



MRIO database of EXIOBASE 3.0 has been considered to carry out the socio-economic assessment. Glass, aluminium and copper recycling sectors have been considered. In the last update (2011), in Spain, these sectors employed around 5,000 people. The following figure shows the creation of employment, both in Spain and abroad (direct and indirect), for every million euros produced in the country in the selected sectors.



Discussion & Conclusions

Results highlight that recycling is the most viable alternative from all aspects of sustainability, favoring national and international government strategies in order to implement circular economy strategies in production processes. The MCI values of the recycling scenarios, considering quantities of materials mainly, are clearly higher than those of other scenarios, confirming the sustainable improvement both in the future learning curve of costs of these processes and in the generation of potential employment.

References
[1] https://doi.org/10.1016/j.scitotenv.2021.147969
[2] https://doi.org/10.1016/j.solmat.2016.03.020
[3] https://www.ellenmacarthurfoundation.org/resources/apply/material-circularity-indicator

LCM 2021