Comparative Life Cycle Assessment of alternating and direct current electric loads: the case study of a power supply unit

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The project Lowering Ortigia's Voltage - LOV

Goal: to design, develop and examine a **"micro-grid" model** that operates in **direct current**, to obtain an efficient distribution of electricity at low voltage level.

Partners: **UniPa**, Enerwave, Prysmian Group, Fornindustria, Adeo, 3 ESSE, CNR ITAE, I.E.ME.S.T.

The main role of UniPa:
to examine the **energy and environmental performance of microgrid prototypes applying LCA** methodology in an eco-design perspective.

LOV – Lowering Ortigia's Voltage
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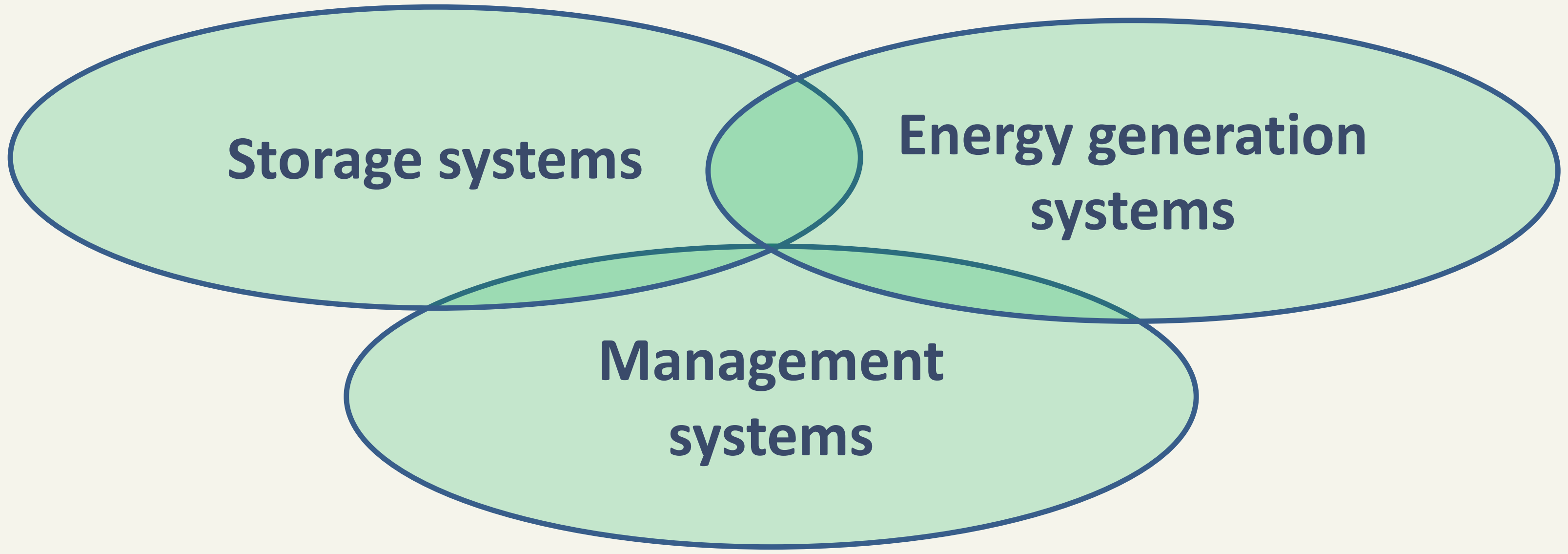
Introduction

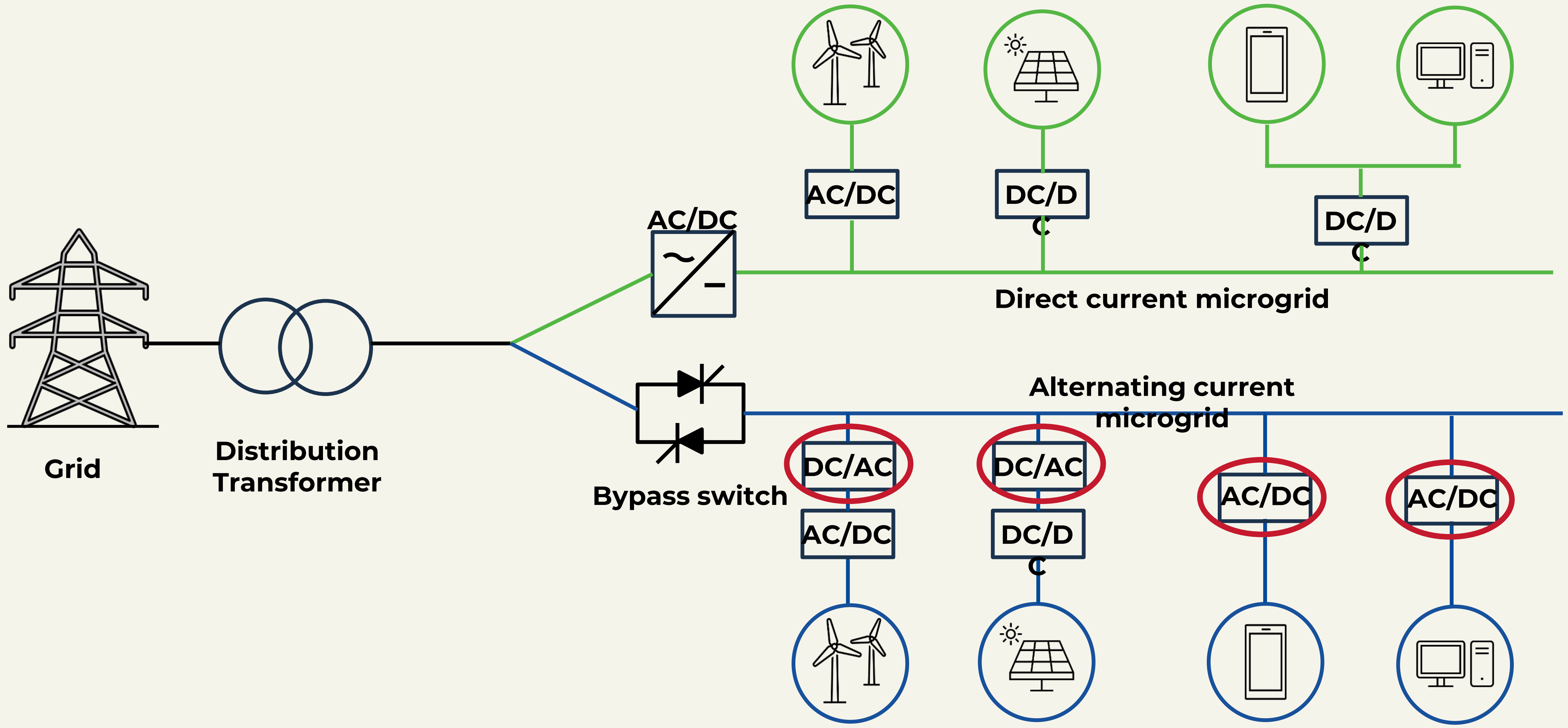
Distributed energy systems that integrate renewable energy technologies play an important role in the decarbonisation process of our economy.



«Micro-grids» versus centralized energy systems:

- based on renewable energy sources characterized by low environmental impacts
- potential to reduce the peak load demand by integrating the grid supplies with energy from distributed systems
- avoided/reduced cost of transmission and distribution
- improvement of energy security
- providing energy access to facilities that cannot be connected to the electricity grid.

Introduction



Distributed energy sources are connected to a DC bus

AC-to-DC rectifiers help to connect AC generating units

DC-to-AC inverters supply AC loads

Distributed energy sources are connected to an AC bus

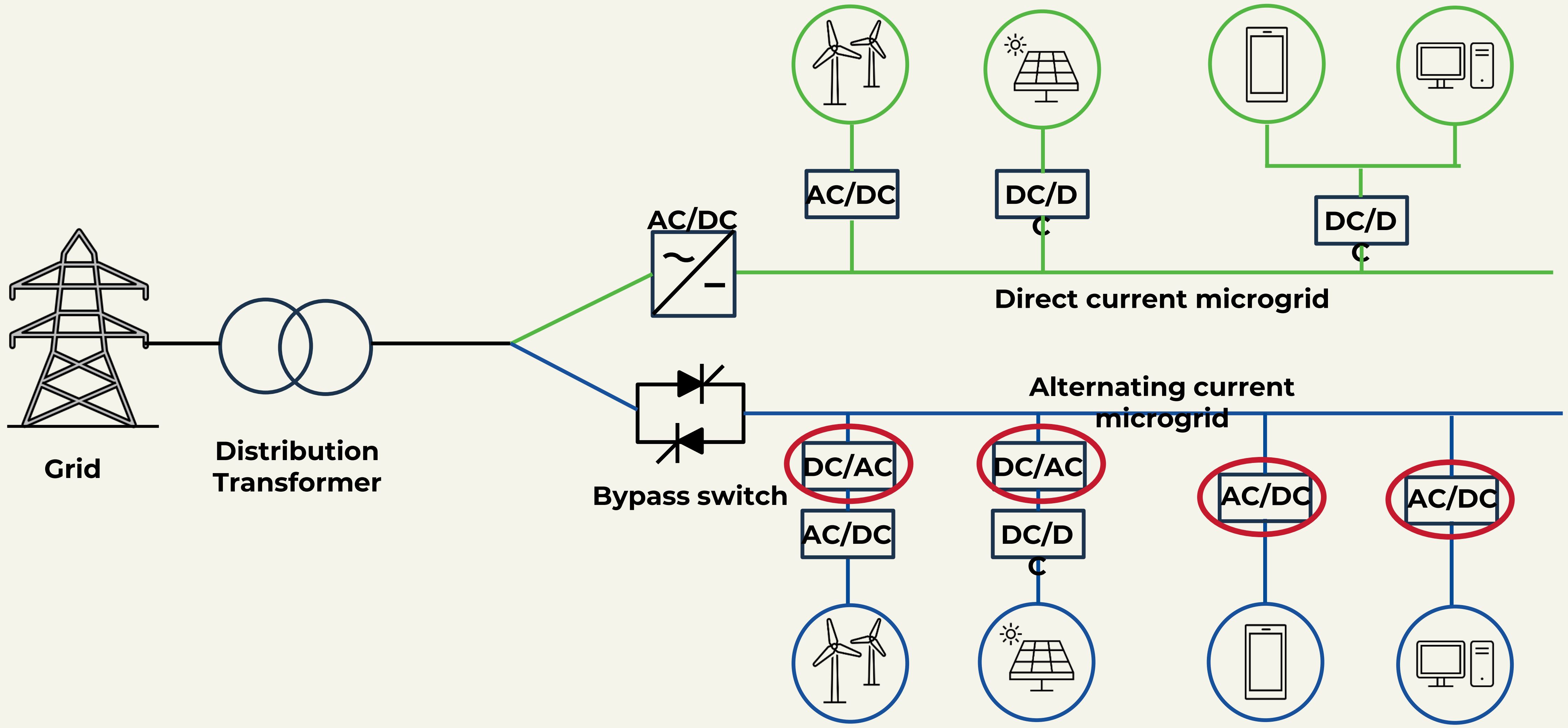
Units that generate energy in DC and units for energy storage use DC-to-AC inverters to be connected to the AC bus

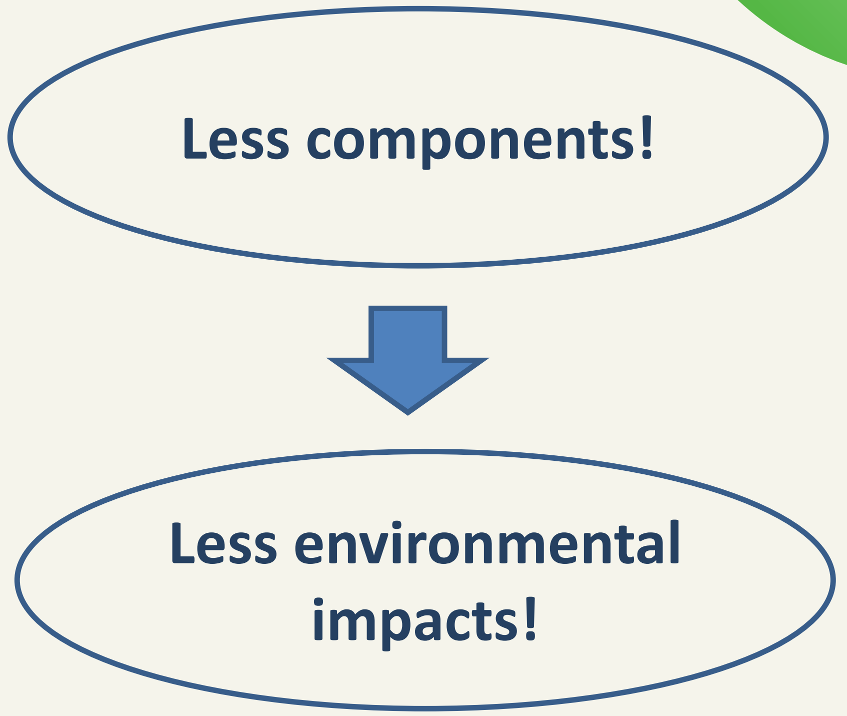
AC-to-DC rectifiers supply the energy to the DC loads

DC versus AC micro-grids:

- Reduction of multiple energy conversions from AC to DC and vice versa
- Improved energy efficiency and reduced losses
- Simplified configuration: less components
- Reduced costs.

Introduction





<u>Need of research:</u>

Detailed analyses focused on the life-cycle energy and environmental impacts/benefits of using electric loads that operate with DC microgrids.

Life Cycle Assessment

LCA is a powerful tool to evaluate the sustainability of a product by analysing the whole product life-cycle.

Goal and Scope Definition

Identification of goals, scope, audience, system boundaries, functional unit, impact categories and calculation methodology

Inventory Analysis

Primary and secondary data collection, evaluating resources consumption, direct emissions and wastes

Impact Assessment

Starting from data collection the selected methodology is applied obtaining the results

Interpretation

The results are summarized and commented,
at the end conclusions and recommendations

Case study

Goal of the study: to evaluate the life-cycle benefits of using electric loads that operate directly with DC microgrids

Case study: **computer's power supply unit (PSU),** a typical electronic load frequently included in the places of work and houses.

Configuration 1 – AC-PSU:
PSU operating with an AC-DC conversion.

Configuration 2 – DC-PSU:
PSU directly working in DC-DC.

Case study

Functional unit: **computer's power supply unit (PSU)**

Model: DELL N° L290AM-00
Dimensions (W x L x H): 15 x 14 x 8,5 cm
AC Input: 100-240 V/5.4 A
Input frequency range: 50-60 Hz
DC Output: 12 V
Max output power: 290 W
Max operative temperature: 50 °C

System boundaries: from cradle to gate

Case study

To apply LCA a comprehensive list of components and sub-components is needed (inventory analysis).

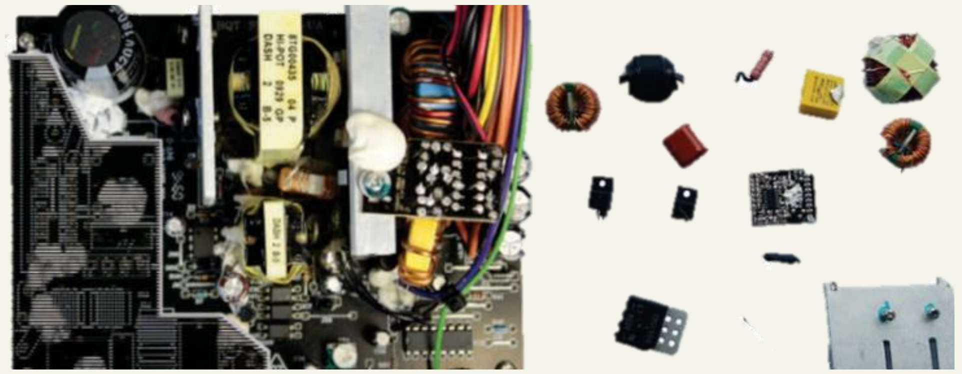
Configuration 1 – AC-PSU

Disassembly of the PSU at University of Palermo “LCA and Eco-design Lab”

Weighting and cataloguing of PSU components (including Printed Wiring Board (PWB))

Configuration 2 – DC-PSU

Based on Stippich et al. (2017) and Kockel et al. (2022): modeling of DC-PSU by removing extra components used for the AC-DC conversion.



Modeling with Simapro. Secondary data: Ecoinvent

Case study

To apply LCA a comprehensive list of components and sub-components is needed (inventory analysis).

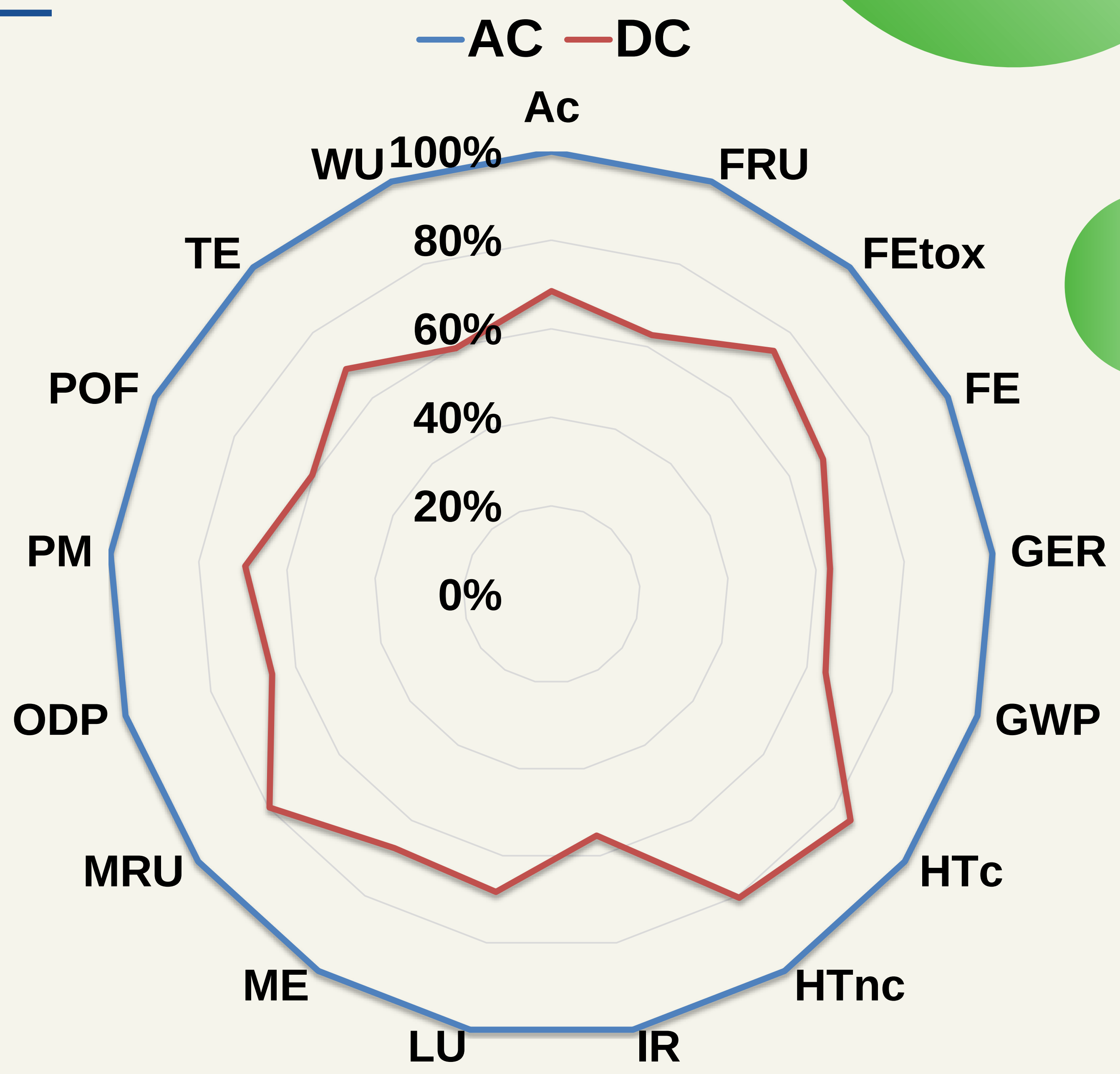
	AC PSU	DC PSU
Cables and plug	4.41E-02 kg	4.41E-02 kg
Fan	7.37E-02 kg	7.37E-02 kg
PWB	3.81E-01 kg	2.60E-01 kg
PWB's surface	1.72E-02 m^2	1.29E-02 m^2
Steel	5.67E-01 kg	5.67E-01 kg

Sub-components of AC PWB	**Mass (kg)**
Aluminium heat sinks	7.42E-02
Capacitors	5.77E-02
Diodes	4.26E-03
Inductors	7.88E-02
Integrated circuit	4.94E-04
Resistors	2.55E-03
Transformers	6.51E-02
Transistors	1.14E-02

Removed sub-components for DC PWB	**Mass (kg)**
Aluminium heat sinks	2.83E-02
Capacitors	4.98E-03
Diodes	8.60E-04
Inductors	7.80E-02
Resistors	1.16E-03
Transistors	7.67E-03

Impact assessment

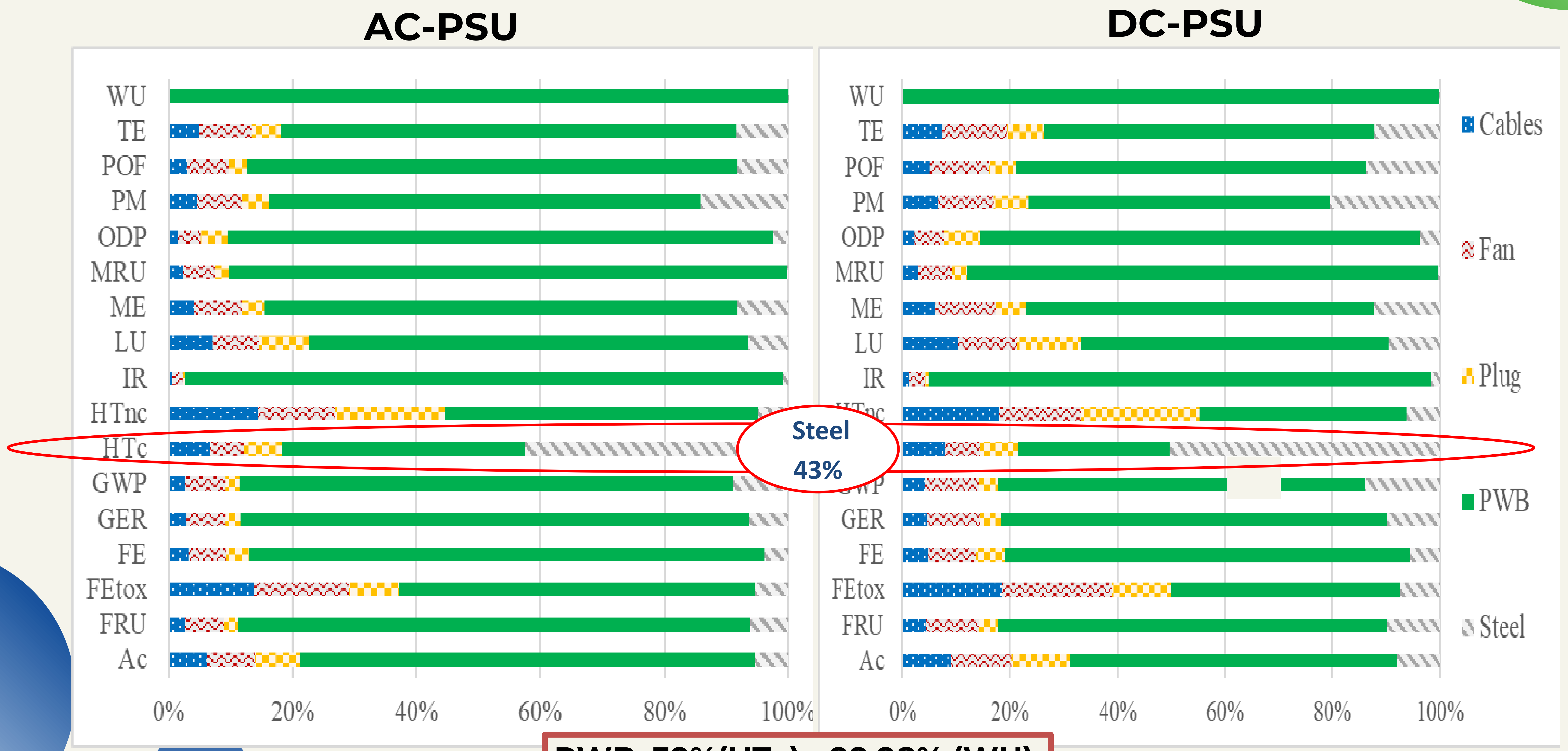
Impact category	Unit	AC PSU	DC PSU
Acidification	mol H^{+}_{eq}	1.20E-01	8.20E-02
Fossil resource use	MJ	2.65E+02	1.66E+02
Freshwater ecotoxicity	CTUe	1.40E+02	1.04E+02
Freshwater eutrophication	kg P_{eq}	1.79E-02	1.23E-02
Global energy requirement	MJ	3.03E+02	1.91E+02
Global warming potential	kg CO_{2eq}	1.66E+01	1.06E+01
Human toxicity, cancer	CTUh	2.44E-08	2.07E-08
Human toxicity, non-cancer	CTUh	5.69E-07	4.58E-07
Ionising radiation	kBq $U\text{-}235_{eq}$	7.01E+00	3.89E+00
Land use	Pt	7.33E+01	5.01E+01
Marine eutrophication	kg Neq	1.80E-02	1.21E-02
Minerals and metals resource use	kg Sbeq	4.63E-03	3.70E-03
Ozone depletion potential	kg $CFC11_{eq}$	1.04E-06	6.80E-07
Particulate matter	disease inc.	8.56E-07	5.95E-07
Photochemical ozone formation	kg $NMVOC_{eq}$	8.51E-02	5.14E-02
Terrestrial eutrophication	mol N_{eq}	1.81E-01	1.25E-01
Water use	$m^3_{depriv.}$	4.51E+03	2.69E+03



Reduction from 15% (HTc) to 45% (IR)

Impact assessment

Contribution analysis

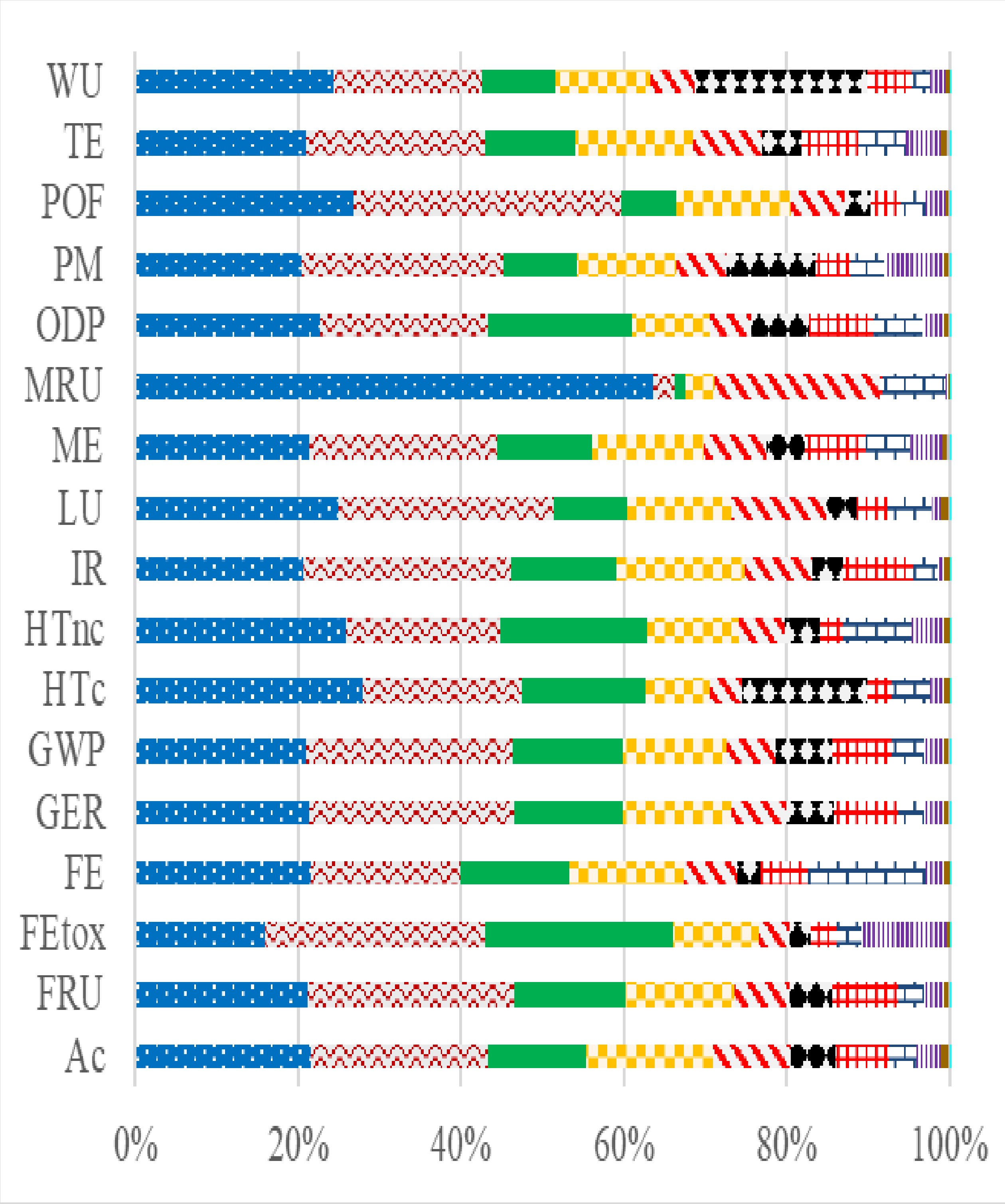


PWB: 39%(HTc) - 99.98% (WU)

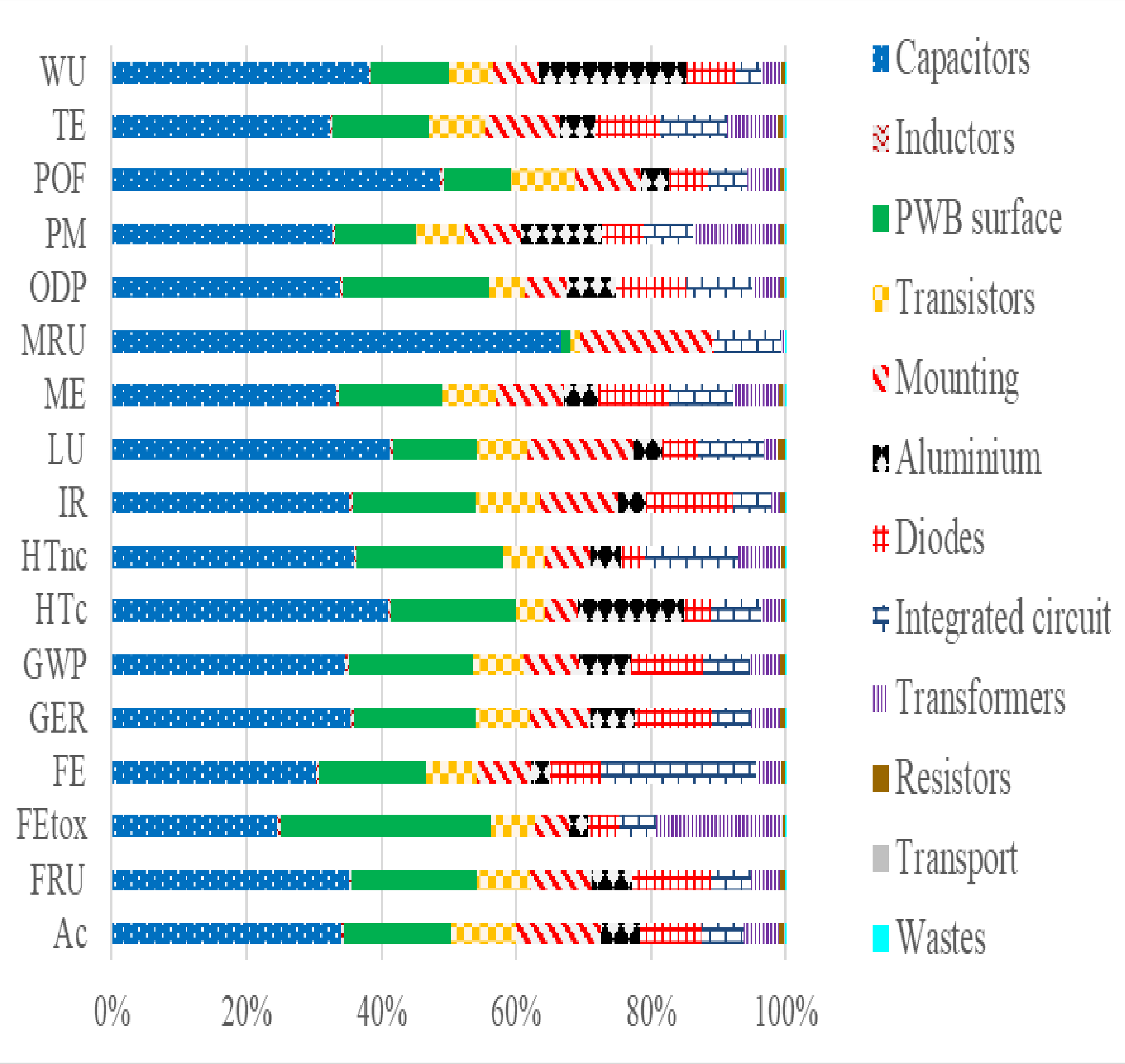
Impact assessment

Contribution analysis

AC-PSU



DC-PSU



Capacitors incidence:
AC: 16% - 64%
DC: 25% - 67%

Inductors incidence:
AC: 2% - 33%
DC: < 1%

PWB surface incidence:
AC: 2% - 23%
DC: 2% - 31%

Other components incidence: no significant variations

Conclusions

- Assessment of the energy and environmental impacts of a PSU to demonstrate that **DC-DC loads can lead to a lower impact** than their AC counterpart (from 15% for HTc to 45% for IR).
- **PWB** is the main contributor of the PSU. Reducing PWB's sub-component improves energy and environmental performance of the entire device.

The contribution analysis on **the two PWB** indicated:

- **Capacitors and inductors** are the hot-spots for PWB in the **base case**;
- The removal of some inductors in the DC-PSU changed the contribution analysis and identified **capacitors and PWB surface** as the component with the highest burden.

Conclusions

Advancement with respect to the state-of-the art:

- it focuses on a specific electric load, allowing to develop a detailed analysis of a PSU and its components;
- it enriches the existing scientific literature with a new case study of LCAs applied to DC loads, for with there is a lack of primary data;
- the modelling of the PSU is based on primary data, studied at lab-scale through a detailed weighting process for obtaining a reliable mass balance;
- by identifying the environmental hot spots responsible of the higher impacts, it represents the starting point for defining eco-design strategies;

The results can be **the basis for further studies** that explore different DC loads.

The availability of **new DC loads datasets** will allow to perform complete evaluations of the environmental advantages of **DC microgrids** (including the devices that use the energy generated by the distributed energy systems).

LOV
LOWERING ORTIGIA'S VOLTAGE

Thank you for your attention!

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