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Life Cycle Assessment Tool Integrated to Process Monitoring, Design and Control Environment

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Introduction

Low Carbon Economy

- **Minimization** of greenhouse gas (GHG) **emissions** for industrial processing and power generation
- **Design** and **Simulation** of production process with **lower** carbon footprint.

Need of integrated **Life Cycle Assessment** tools for **Process Simulation, Design** and **Optimization**.

Introduction

LCA is defined by the ISO 14040 as the compilation and evaluation of the inputs, outputs and the **potential environmental impacts** of a product system throughout its **life cycle**.

- **Government Policy**
- **Decision-making Process**
- **Demonstrate** the process is **Green**
- Product **Marketing**

Introduction

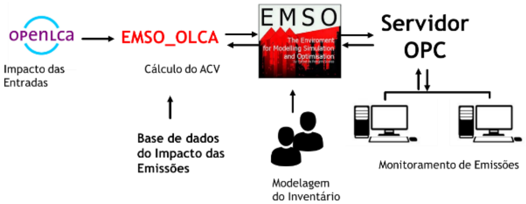
EMSO:

- **Free** for Academic use
- **Equation-Oriented** Simulator
- **Easy** to create new models: **Flexibility**
- **Fast:** lower computational time
- **Interface** with **Python**, C++, Matlab, Scilab, OPC, Excel, LibreOffice

OpenLCA:

- **Free, OpenSource**
- Several LCIA databases: **EcoInvent**, **Agri-footprint**,...
- **Atualization** of the impact assessment databases

EMSO_OLCA



Characteristics

- ✓ Flexibility
- ✓ Computational Speed (LCA of ethanol): 0.296 s
- ✓ Accuracy (LCA of ethanol): mean error of 0.0015%
- ✓ Integrated to **functionalities** of **EMSO**
- ✓ **Emissions impact** is accessed by **OpenLCA database**

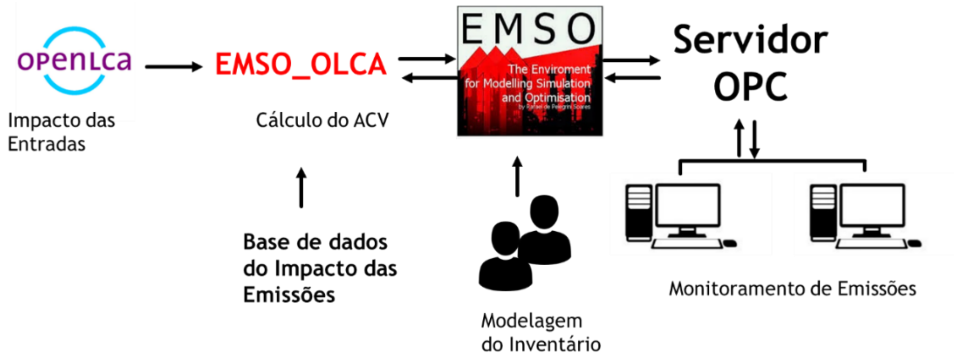
- ✓ **OpenLCA Impact Methodologies Available**:
  - ✓ 99 methodologies: IPCC, 2013; CML, 2001; ReCiPe, 2016; ...
  - ✓ 1479 Characterization Factors

- ✓ **OpenLCA** database update

EMSO_OLCA

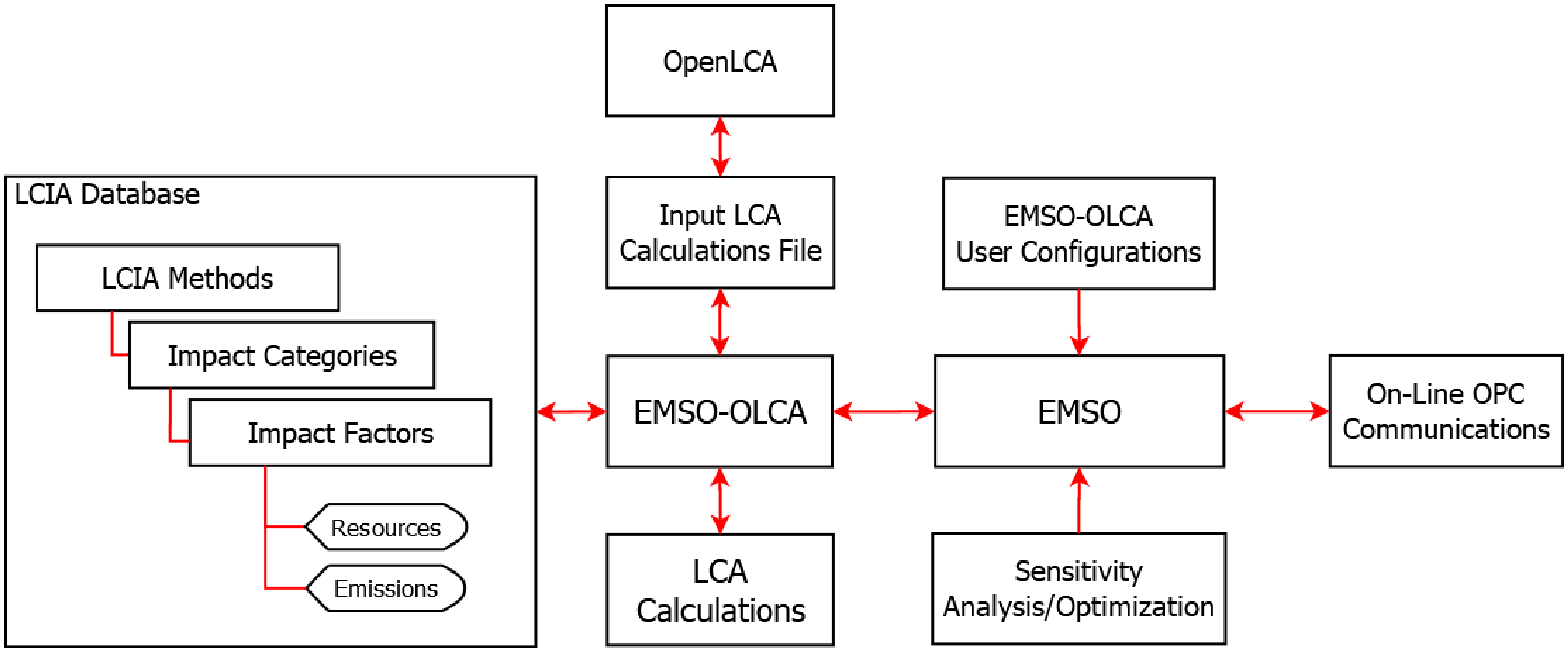
Applications:

- ✓ Identification of **bottom necks** and improvement opportunities
- ✓ Chemical Process **Routes** Selection
- ✓ **Process design** decisions: Eg. Different equipment configurations, process variables values
- ✓ Process **Monitoring**
- ✓ Process **Control**



EMSO_OLCA

EMSO_OLCA Framework



EMSO_OLCA Test

Ethanol Test Case

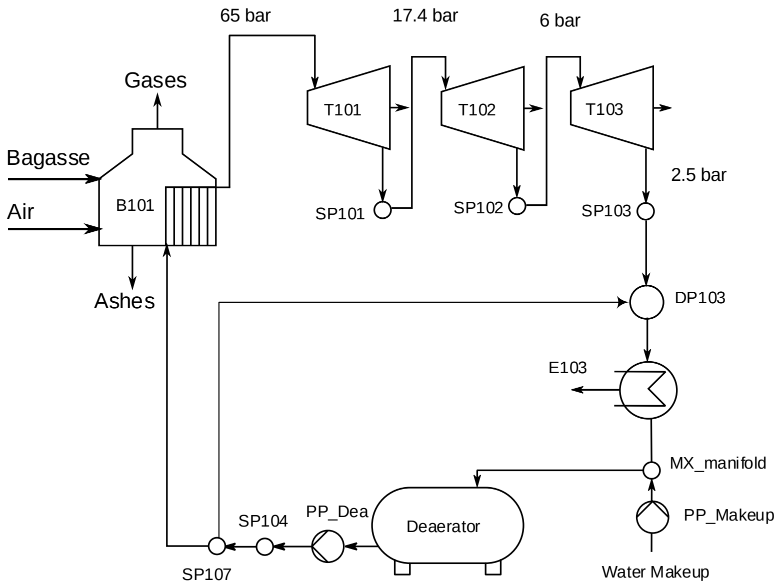
EcoInvent 3.8, ethanol production autonomous plant, BR, 1Kg

Impact category	Reference unit	OpenLCA Result	EMSO Result	% Error
Abiotic depletion	kg Sb eq	$4.2916 \cdot 10^{-6}$	$4.2962 \cdot 10^{-6}$	0.1083%
Abiotic depletion (fossil fuels)	MJ	3.2862	3.2862	-0.0001%
Acidification	kg SO2 eq	$1.3946 \cdot 10^{-2}$	$1.3946 \cdot 10^{-2}$	0.0001%
Eutrophication	kg PO4--- eq	$7.4082 \cdot 10^{-3}$	$7.4082 \cdot 10^{-3}$	-0.0001%
Fresh water aquatic ecotox.	kg 1,4-DB eq	$1.3882 \cdot 10^{-1}$	$1.3882 \cdot 10^{-1}$	0.0000%
Global warming (GWP100a)	kg CO2 eq	$6.5146 \cdot 10^{-2}$	$6.5140 \cdot 10^{-2}$	-0.0090%
Human toxicity	kg 1,4-DB eq	$2.5019 \cdot 10^{-1}$	$2.5019 \cdot 10^{-1}$	-0.0001%
Marine aquatic ecotoxicity	kg 1,4-DB eq	$2.5725 \cdot 10^{+2}$	$2.5726 \cdot 10^{+2}$	0.0000%
Ozone layer depletion (ODP)	kg CFC-11 eq	$1.9625 \cdot 10^{-8}$	$1.9639 \cdot 10^{-8}$	0.0686%
Photochemical oxidation	kg C2H4 eq	$1.6936 \cdot 10^{-3}$	$1.6938 \cdot 10^{-3}$	0.0128%
Terrestrial ecotoxicity	kg 1,4-DB eq	$1.0923 \cdot 10^{-3}$	$1.0924 \cdot 10^{-3}$	0.0071%

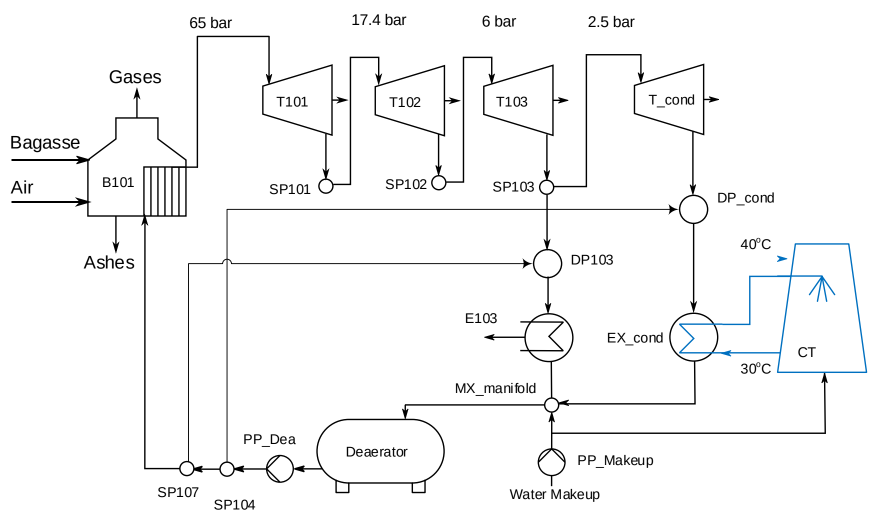
Mean Error 0.0015%

Cogeneration Study Case

Case Study 1



Case Study 2



Cogeneration Study Case
Inventory Results

Inventory	Unit	Scenario 1	Scenario 2	Δ%
Inputs				
Bagasse/Straw	t/h	38.04	129.06	339%
Water	t/h	7.46	479.56	6433%
Emissions				
VOC	kg/h	0.32	1.08	339%
CO	kg/h	5.06	17.18	339%
NO	kg/h	33.34	113.11	339%
Particulate M., < 2,5 um	kg/h	0.66	2.23	339%
Particulate M., < 10um	kg/h	0.74	2.53	339%
SO	kg/h	30.59	103.79	339%
BC	kg/h	0.09	0.31	339%
OC	kg/h	0.21	0.73	339%
CH_4	kg/h	5.12	17.38	339%
N_2O	kg/h	3.17	10.76	339%
CO_2, biogenic	t/h	61.56	208.87	339%
Products				
Vapor	MWh	113.50	113.50	100%
Bioeletricity, net	MWh	34.02	154.38	454%

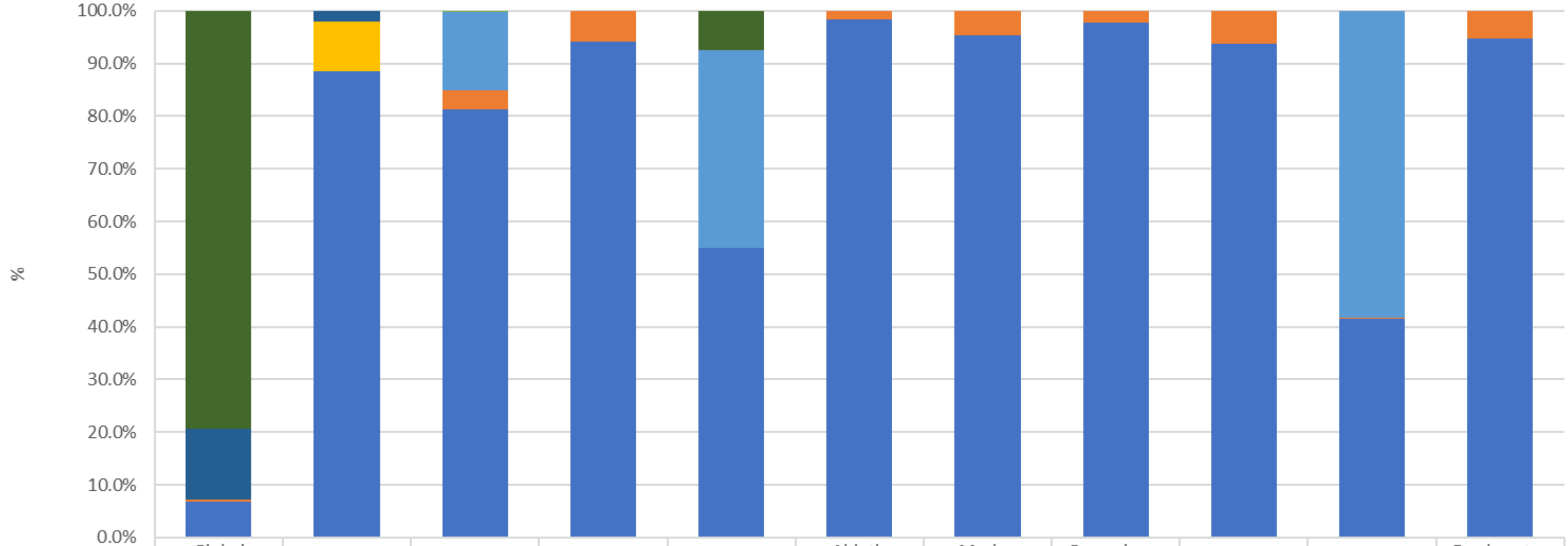
Cogeneration Study Case

LCA Results

Impact Category	Unit	Scenario 1	Scenario 2	Δ%
Global Warming (GWP100a)	kg CO_2 eq/MJ	$1.995 \cdot 10^{-3}$	$4.033 \cdot 10^{-3}$	202%
Photochemical oxidation	kg C_2H_4 eq/MJ	$2.761 \cdot 10^{-6}$	$5.285 \cdot 10^{-6}$	191%
Human toxicity	kg 1,4-DB eq/MJ	$5.087 \cdot 10^{-4}$	$1.571 \cdot 10^{-3}$	309%
Abiotic depletion	kg Sb eq/MJ	$7.270 \cdot 10^{-9}$	$2.776 \cdot 10^{-8}$	382%
Eutrophication	kg PO_4-eq/MJ	$2.172 \cdot 10^{-5}$	$4.120 \cdot 10^{-5}$	190%
Abiotic depletion (fossil fuels)	MJ/MJ	$5.979 \cdot 10^{-3}$	$1.448 \cdot 10^{-2}$	242%
Marine aquatic ecotoxicity	kg 1,4-DB eq/MJ	$4.470 \cdot 10^{-1}$	1.533E+00	343%
Ozone layer depletion (ODP)	kg CFC-11 – eq/MJ	$3.558 \cdot 10^{-11}$	9.244E-11	260%
Terrestrial ecotoxicity	kg 1,4-DB eq/MJ	$1.955 \cdot 10^{-6}$	7.737E-06	396%
Acidification	kg SO_2-eq/MJ	$5.381 \cdot 10^{-5}$	1.026E-04	191%
Fresh water aquatic ecotox.	kg 1,4-DB eq/MJ	$2.411 \cdot 10^{-4}$	8.787E-04	364%

Cogeneration Study Case

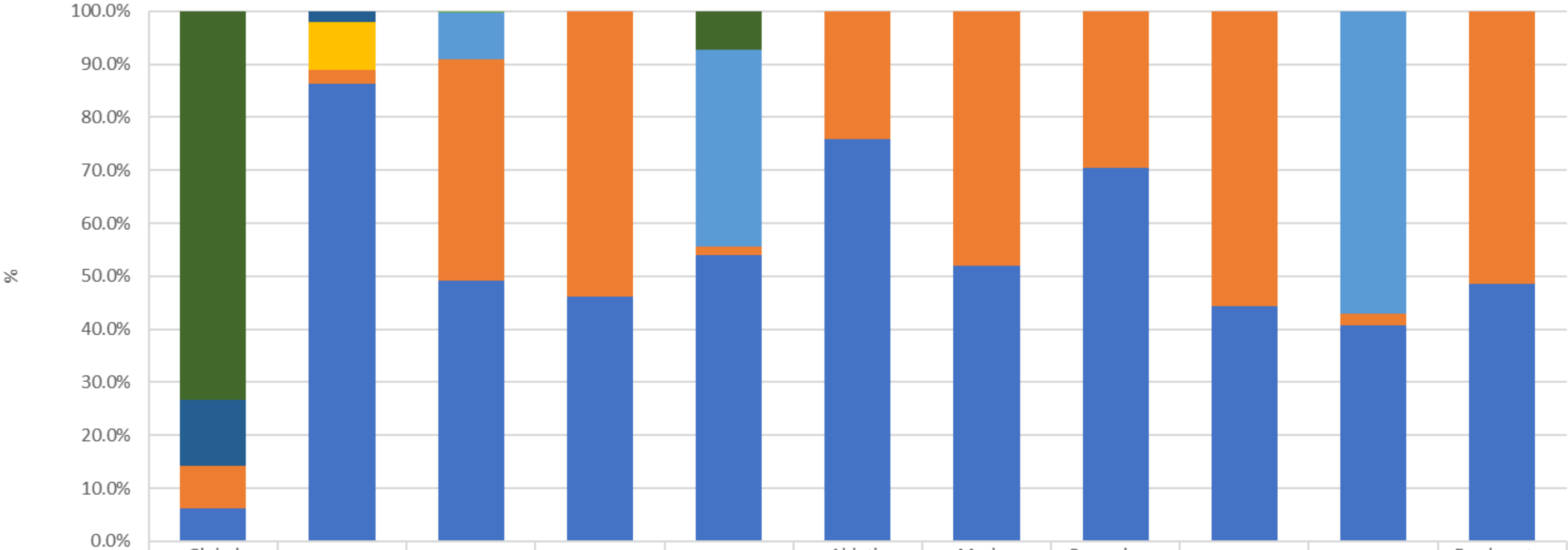
Contribution of Inputs and Emissions on Result – Scenario 1



	Global warming (GWP100a)	Photochemical oxidation	Human toxicity	Abiotic depletion	Eutrophication	Abiotic depletion (fossil fuels)	Marine aquatic ecotoxicity	Ozone layer depletion (ODP)	Terrestrial ecotoxicity	Acidification	Fresh water aquatic ecotox.
CO_2, Biogenic	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
N_2O	79.3%	0.0%	0.0%	0.0%	7.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CH_4	13.5%	2.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PM10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PM25	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NO	0.0%	0.0%	14.8%	0.0%	37.6%	0.0%	0.0%	0.0%	0.0%	58.3%	0.0%
CO	0.0%	9.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VOC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water	0.5%	0.1%	3.6%	5.8%	0.1%	1.6%	4.7%	2.2%	6.2%	0.1%	5.3%
Bagasse	6.7%	88.4%	81.4%	94.2%	54.9%	98.4%	95.3%	97.8%	93.8%	41.6%	94.7%

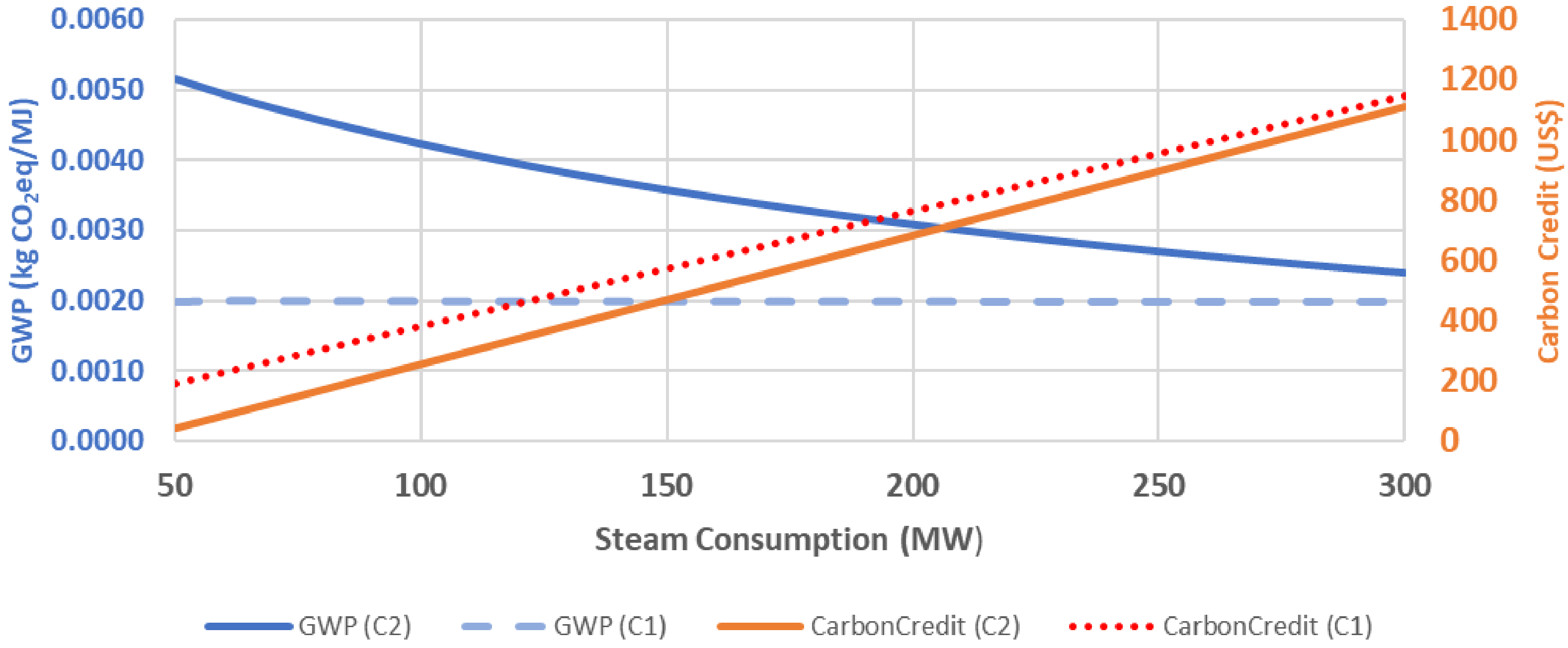
Cogeneration Study Case

Contribution of Inputs and Emissions on Result – Scenario 2

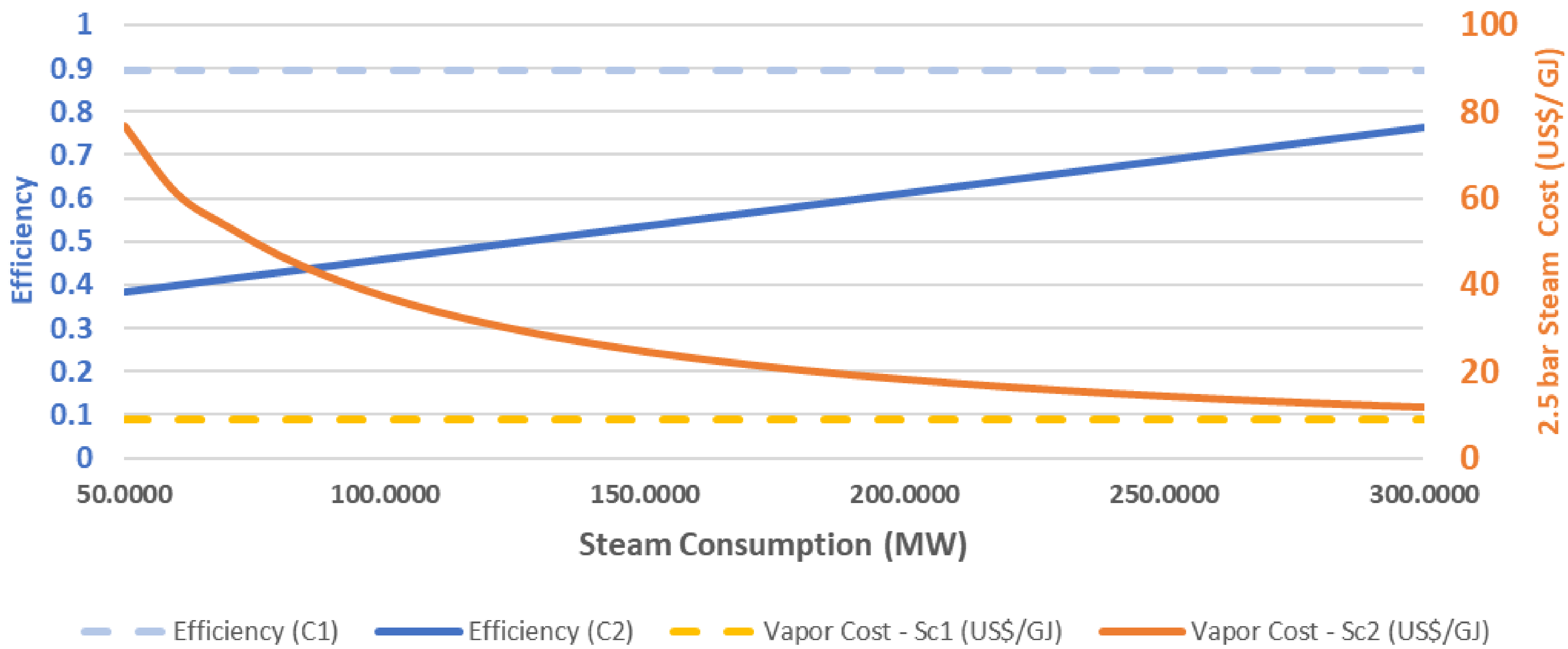


	Global warming (GWP100a)	Photochemical oxidation	Human toxicity	Abiotic depletion	Eutrophication	Abiotic depletion (fossil fuels)	Marine aquatic ecotoxicity	Ozone layer depletion (ODP)	Terrestrial ecotoxicity	Acidification	Fresh water aquatic ecotox.
CO2, Biogenic	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
N2O	73.3%	0.0%	0.0%	0.0%	7.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CH4	12.5%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PM10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PM25	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NO	0.0%	0.0%	9.0%	0.0%	37.0%	0.0%	0.0%	0.0%	0.0%	57.1%	0.0%
CO	0.0%	9.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VOC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water	8.0%	2.5%	41.7%	53.9%	1.6%	24.1%	48.1%	29.6%	55.7%	2.2%	51.5%
Bagasse	6.2%	86.4%	49.2%	46.1%	54.1%	75.9%	51.9%	70.4%	44.3%	40.7%	48.5%

Cogeneration Study Case
Case Study Results
Effect on GWP and Carbon Credit, varying Steam Consumption



Cogeneration Study Case
Case Study Results
Effect on Efficiency and Vapor Cost, varying Steam Consumption



Conclusions

- A platform for integration of OpenLCA and EMSO was implemented.
- Due to its framework, it presented flexibility, computational speed compatible with the use of simulators (0.296 s), Accuracy of the calculations (0.0015%) compared to OpenLCA.
- The integration of OpenLCA with EMSO allows the user to implement more complexes LCAs.
- As the communication is direct with the OpenLCA database, it minimize human errors on calculations, and guarantee that the database presents consistent data as it elaborated by OpenLCA;
- In the Cogeneration Study Case, the EMSO_OLCA showed robustness on calculations and was fully integrated with others EMSO entities as Case Study.
- In the Cogeneration Study Case, the EMSO_OLCA allowed to show which process configuration presented lower environmental impact and lower cost. In this case the reduction of environmental impact goes to the same direction as the economic ones.
- The Cogeneration Study also showed that if the steam generated is not directly used in the process, it is not worthy a condensation turbine even if it produces more electricity.