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ENERGY PRODUCTION FROM MICROALGAE BIOMASS: THE CARBON FOOTPRINT AND ENERGY BALANCE

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Academic Work

PRESENTATION STRUCTURE

- INTRODUCTION
- OBJECTIVES
- JUSTIFICATION
- METHOD
- RESULTS
- DISCUSSION
- CONCLUSION

INTRODUCTION

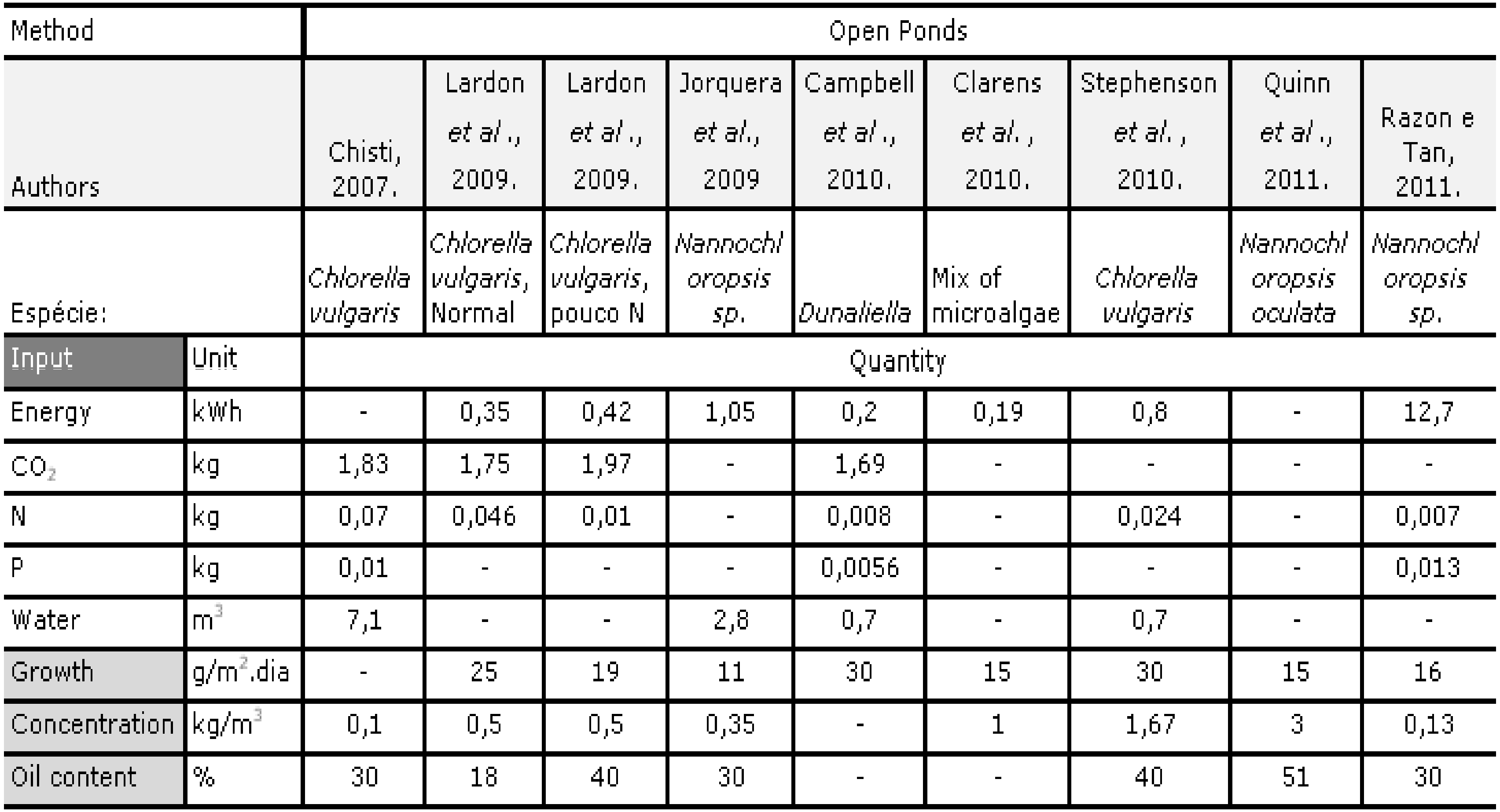
- Climate Change
- Increasing global energy demand
- Fossil vs. Renewable fuel
- Microalgae as a potential source
- Life Cycle Assessment

OBJECTIVES

- This paper intends to assess qualitatively the microalgae bioenergy production including an examination of some of the latest discoveries.
- A case study on microalgae biomass combustion was simulated to produce heat and compares the use of different electricity sources with respect to Greenhouse Gas (GHG) emissions and Net Energy Ratio (NER). Some fossil sources were used as reference.

2 MICROALGAE TO BIOENERGY

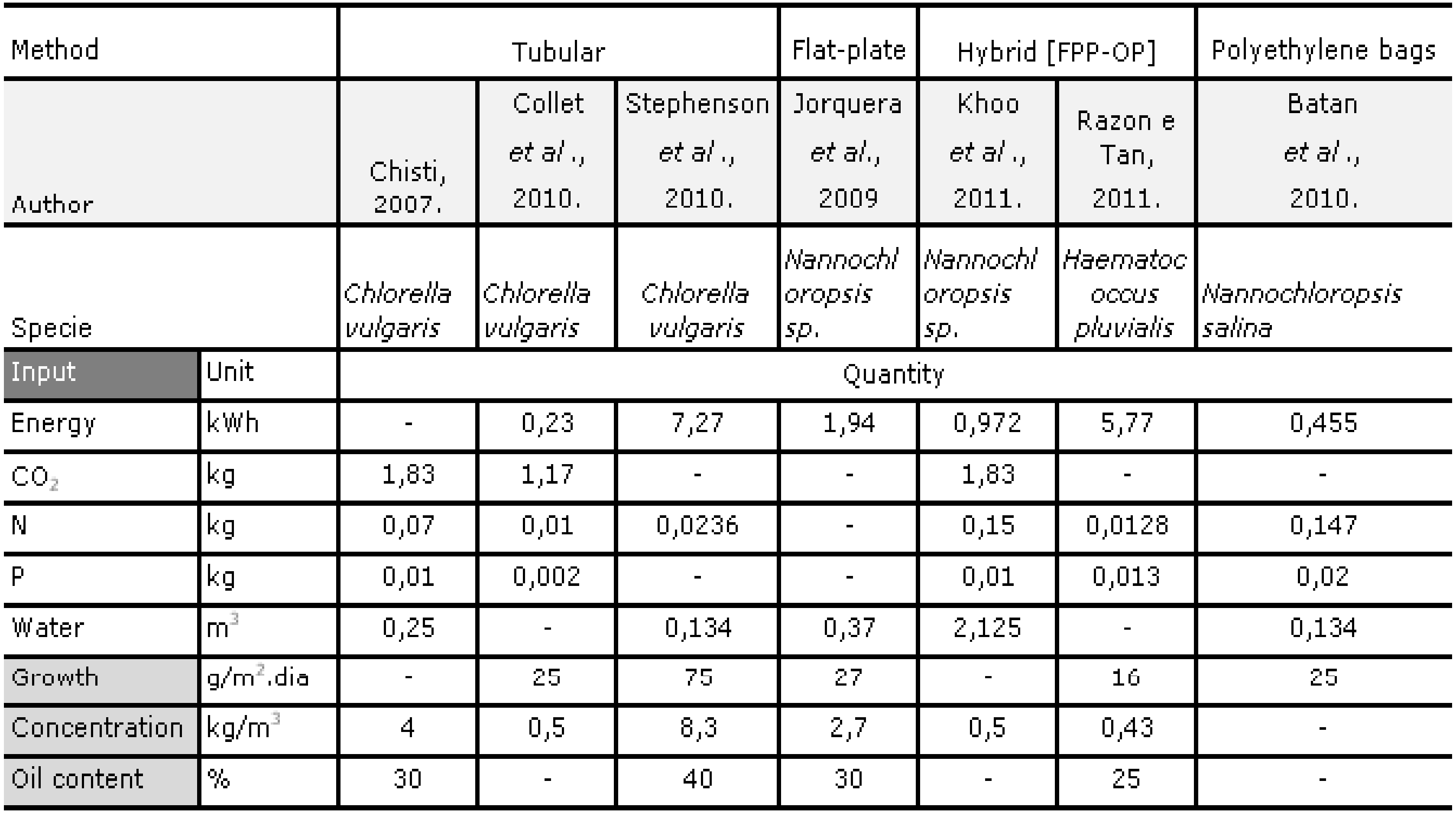
2.1 Cultivation data. Table 1 – Microalgae cultivation inventory in Open-ponds per kilogram of dry matter.



Method		Open Ponds								
Authors		Chisti, 2007.	Lardon *et al*., 2009.	Lardon *et al*., 2009.	Jorquera *et al*., 2009	Campbell *et al*., 2010.	Clarens *et al*., 2010.	Stephenson *et al*., 2010.	Quinn *et al*., 2011.	Razon e Tan, 2011.
Espécie:		*Chlorella vulgaris*	*Chlorella vulgaris*, Normal	*Chlorella vulgaris*, pouco N	*Nannochloropsis sp.*	*Dunaliella*	Mix of microalgae	*Chlorella vulgaris*	*Nannochloropsis oculata*	*Nannochloropsis sp.*
Input	Unit	Quantity								
Energy	kWh	-	0,35	0,42	1,05	0,2	0,19	0,8	-	12,7
CO_2	kg	1,83	1,75	1,97	-	1,69	-	-	-	-
N	kg	0,07	0,046	0,01	-	0,008	-	0,024	-	0,007
P	kg	0,01	-	-	-	0,0056	-	-	-	0,013
Water	m^3	7,1	-	-	2,8	0,7	-	0,7	-	-
Growth	g/m^2.dia	-	25	19	11	30	15	30	15	16
Concentration	kg/m^3	0,1	0,5	0,5	0,35	-	1	1,67	3	0,13
Oil content	%	30	18	40	30	-	-	40	51	30

2 MICROALGAE TO BIOENERGY

Table 2 – Microalgae cultivation inventory in Photo-bioreactors per kilogram of dry matter.



Method		Tubular			Flat-plate	Hybrid [FPP-OP]		Polyethylene bags
Author		Chisti, 2007.	Collet *et al.*, 2010.	Stephenson *et al.*, 2010.	Jorquera *et al.*, 2009	Khoo *et al.*, 2011.	Razon e Tan, 2011.	Batan *et al.*, 2010.
Specie		*Chlorella vulgaris*	*Chlorella vulgaris*	*Chlorella vulgaris*	*Nannochloropsis sp.*	*Nannochloropsis sp.*	*Haematococcus pluvialis*	*Nannochloropsis salina*
Input	Unit	Quantity						
Energy	kWh	-	0,23	7,27	1,94	0,972	5,77	0,455
CO_2	kg	1,83	1,17	-	-	1,83	-	-
N	kg	0,07	0,01	0,0236	-	0,15	0,0128	0,147
P	kg	0,01	0,002	-	-	0,01	0,013	0,02
Water	m^3	0,25	-	0,134	0,37	2,125	-	0,134
Growth	$g/m^2.dia$	-	25	75	27	-	16	25
Concentration	kg/m^3	4	0,5	8,3	2,7	0,5	0,43	-
Oil content	%	30	-	40	30	-	25	-

2 MICROALGAE TO BIOENERGY

2.2 Scaling-up. Table 3 – Microalgae to biofuel obstacles for commercial scale implementation.

Cultivation	Opportunities	Challenges
CO_2	From industry[1]	Land shortage[2]
Nutrients	Waste Water	Not well studied[3]
Water	Recirculation	Not well established[4]
Infrastructure and Operation	More control of the processes	Higher costs and energy intensive[5]
Sun/light	Arid areas	Far from resources and users
Temperature	Mild temperatures	Protected areas or temperature control in arid areas[6]

Sources: CAMPBELL *et al*., 2010[1]; PATE *et al*., 2011[2]; PARK *et al*., 2011 & CHRISTENSON e SIMS 2011[3]; YANG *et al*., 2011[4]; NORSKER *et al*., 2011[5]; NREL, 1998[6].

2 MICROALGAE TO BIOENERGY

2.2 Scaling-up. Table 3 – Microalgae to biofuel obstacles for commercial scale implementation.

Cultivation	Opportunities	Challenges
Specie	Wild types of algae	Domestication[8]
Oil productivity	Nitrogen starvation[10]	Slow down growth
Contamination	Lab microalgae are weak in the field	Allow a native contaminant[6]
Harversting	Many technologies	Specific to the specie, medium and required downstream process[7]
Lipid extraction	Promising technologies being developed	Dependent on microalgae specie and intended products[8]
Biomass	Convert into many forms of biofuels	In development[9]

Sources: UDUMAN *et al*., 2010 & MATA *et al*., 2010[7]; RAWAT *et al*., 2011 & BENEMANN 2010[8]; SINGH e OLSEN, 2011[9]; LARDON *et al*., 2009[10].

2 MICROALGAE TO BIOENERGY

Table 4 – Comparison of energy balance results of microalgae biofuel production over the life cycle.

Studies	Routes	Positive	Negative
Lardon et al. (2009)	Biodiesel production from microalgae	X	
Clarens et al (2010)	Biomass production from microalgae	X	
Liu et al. (2009)	Methanol production from microalgae	X	
Scott et al. (2010)	Biodiesel production from microalgae		X
Jorquera et al. (2010)	Biomass production using different methods	X	X
Liu et al. (2011)	Biodiesel produced from six microalgae (raceway) models	X	X
Razon and Tan (2011)	Biodiesel and methane produced from microalgae		X
Clarens et al. (2011)	Biomass burned to produce electricity	**X**	

METHOD

Evaluated the NER and GHG emissions from the production of *Nannochloropsis sp.* biomass using SimaPro 7.3 ™ software in the following scenarios:

OP1 - algal biomass, open pond, residual CO_2 and conventional fertilizers.

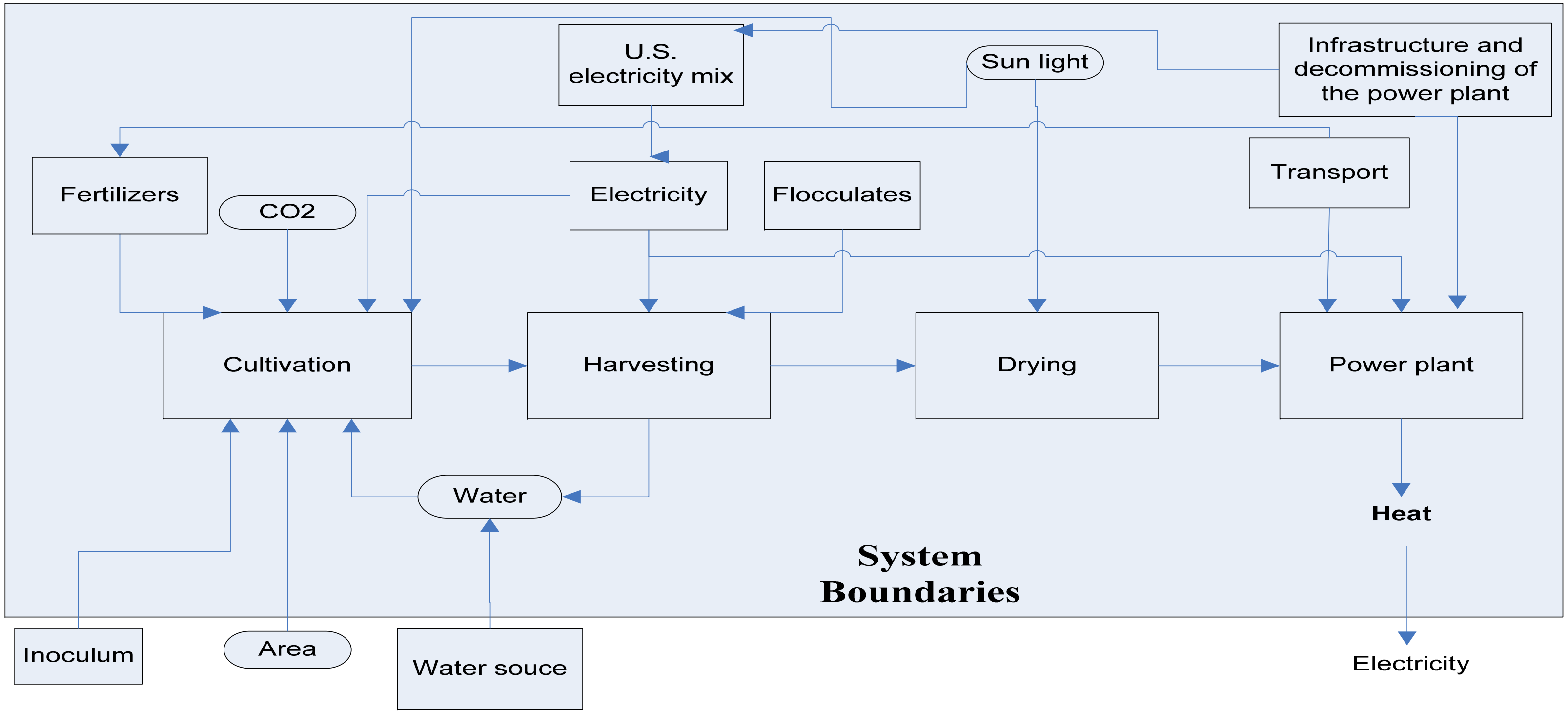
OP2 - algal biomass, open pond, residual CO_2 and wastewater.

FPP1 - algal biomass, flat plate, residual CO_2 and conventional fertilizers.

FPP2 - algal biomass, flat plate, residual CO_2 and wastewater.

METHOD

Scope. Figure 1 – Thermal energy production chain from microalgae biomass.



METHOD

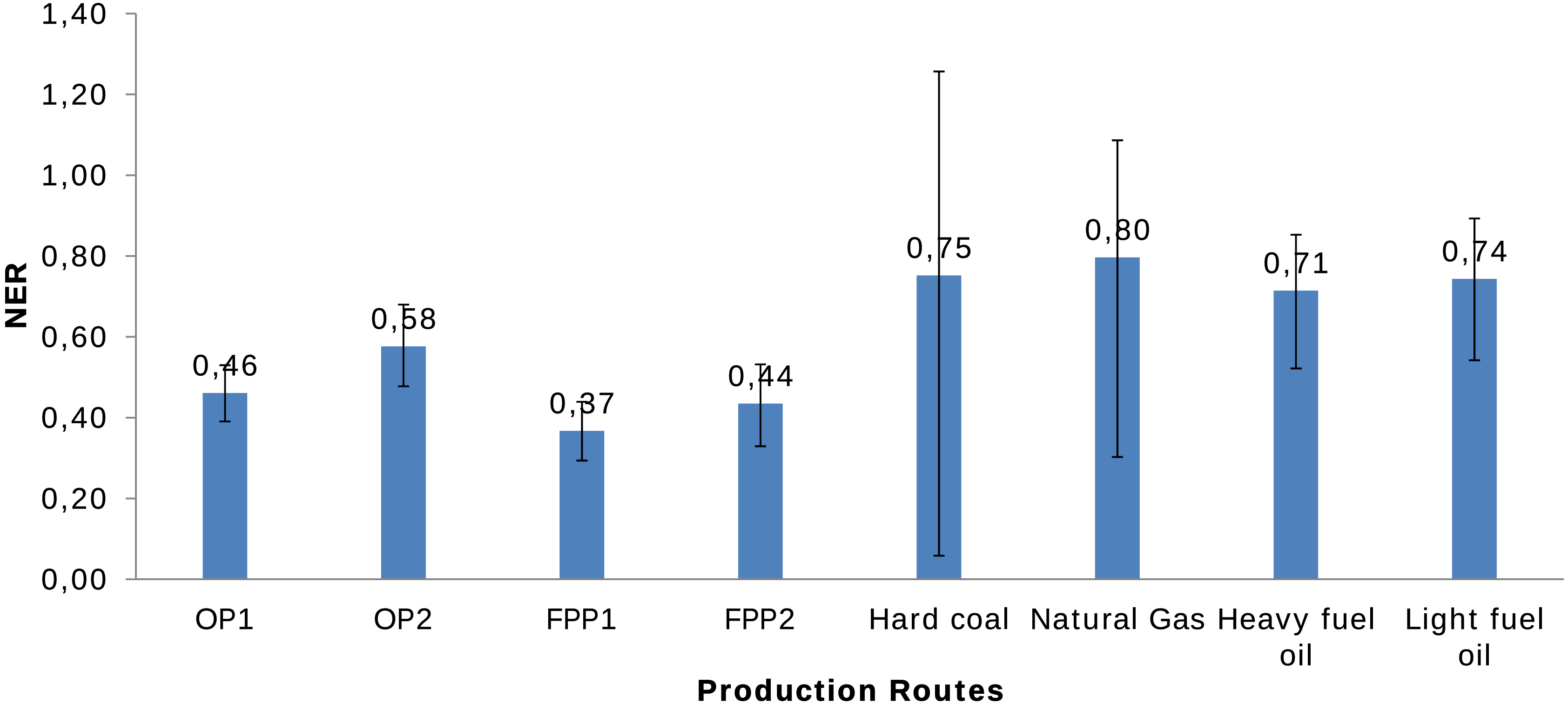
3.2 Inventory Analysis. Tabela 5 – Microalgae biomass from *Nannochloropsis sp.* production inventory per kilogram of dry matter in Open-ponds (OP) and Flat-plate photobioreactor (FPP).

Inputs	OP	FPP	Unit	Source
CULTIVATION				
Nitrogen (N)	**0,07**	**0,07**	**kg/kg**	Calculated
Phosphorus (P)	**0,01**	**0,01**	**kg/kg**	Calculated
Potassium (K)	**0,01**	**0,01**	**kg/kg**	Calculated
Fertilizers transportation	**0,02**	**0,02**	**t.km**	Estimated
Carbon dioxide (CO_2)	**1,83**	**1,83**	**kg/kg**	Chisti 2007
Water	**2857,14**	**370,37**	**kg/kg**	Jorquera et al. 2009
Electricity	**1,05**	**1,94**	**kWh/kg**	Jorquera et al. 2009
Microalgae + Water	**2858,14**	**371,37**	**kg/kg**	
FLOCULATION				
Aluminum Sulfate $Al2(SO_4)_3$	**1,3**	**1,3**	**kg/kg**	Razon and Tan 2011
Hydrochloric Acid HCL (15%)	**0,3**	**0,3**	**kg/kg**	Razon and Tan 2011
Microalgae + moisture	**8**	**1,04**	**kg/kg**	
CENTRIFUGATION				
Electricity	**0,06**	**0,001**	**kWh/kg Water**	Brentner et al. 2011

RESULTS

4.2 Net Energy Ratio. Figure 2 – Energy balance of 20 Mega Joules (LHV) from *Nannochloropsis sp.* at OP1, OP2, FPP1 and FPP2 and the fossil options.

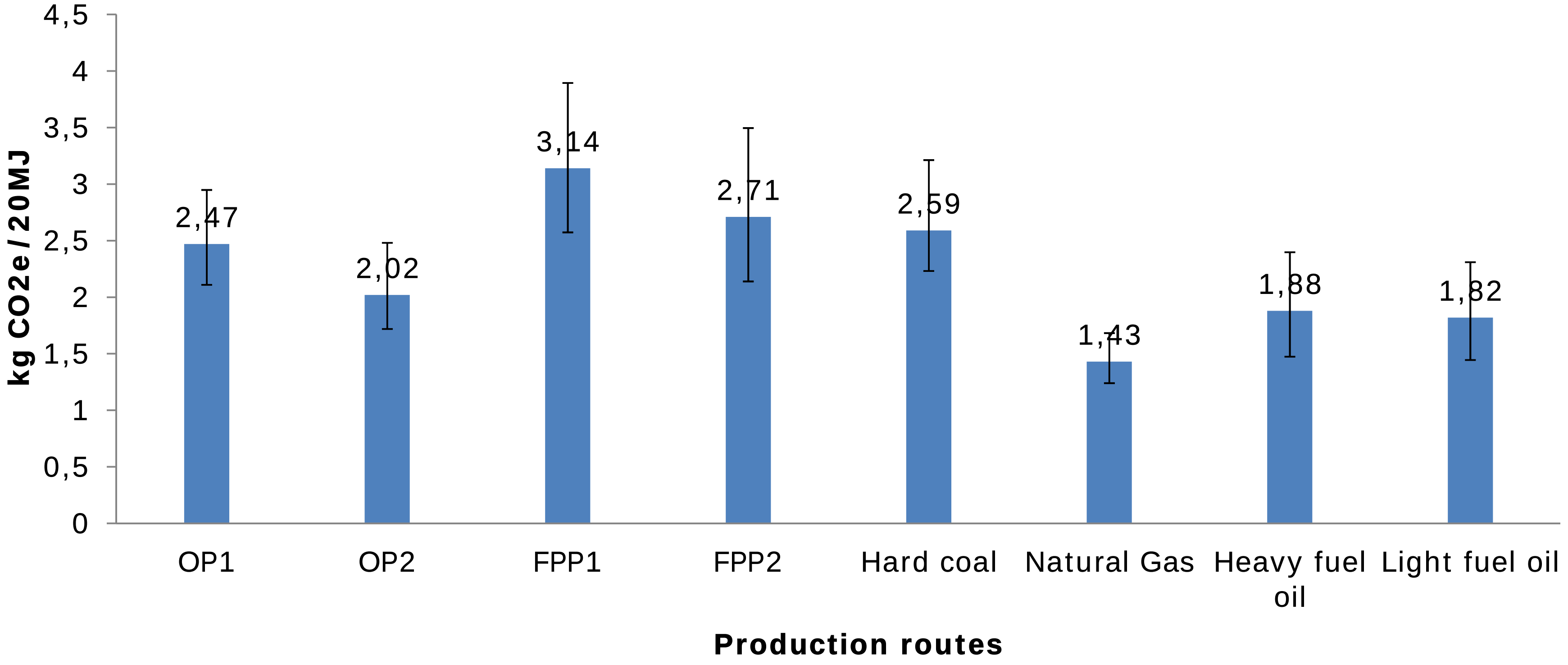
NER = E Out / Σ E In



Source: Cumulative Energy Demand (CED) method from Ecoinvent v2.2 (2013).

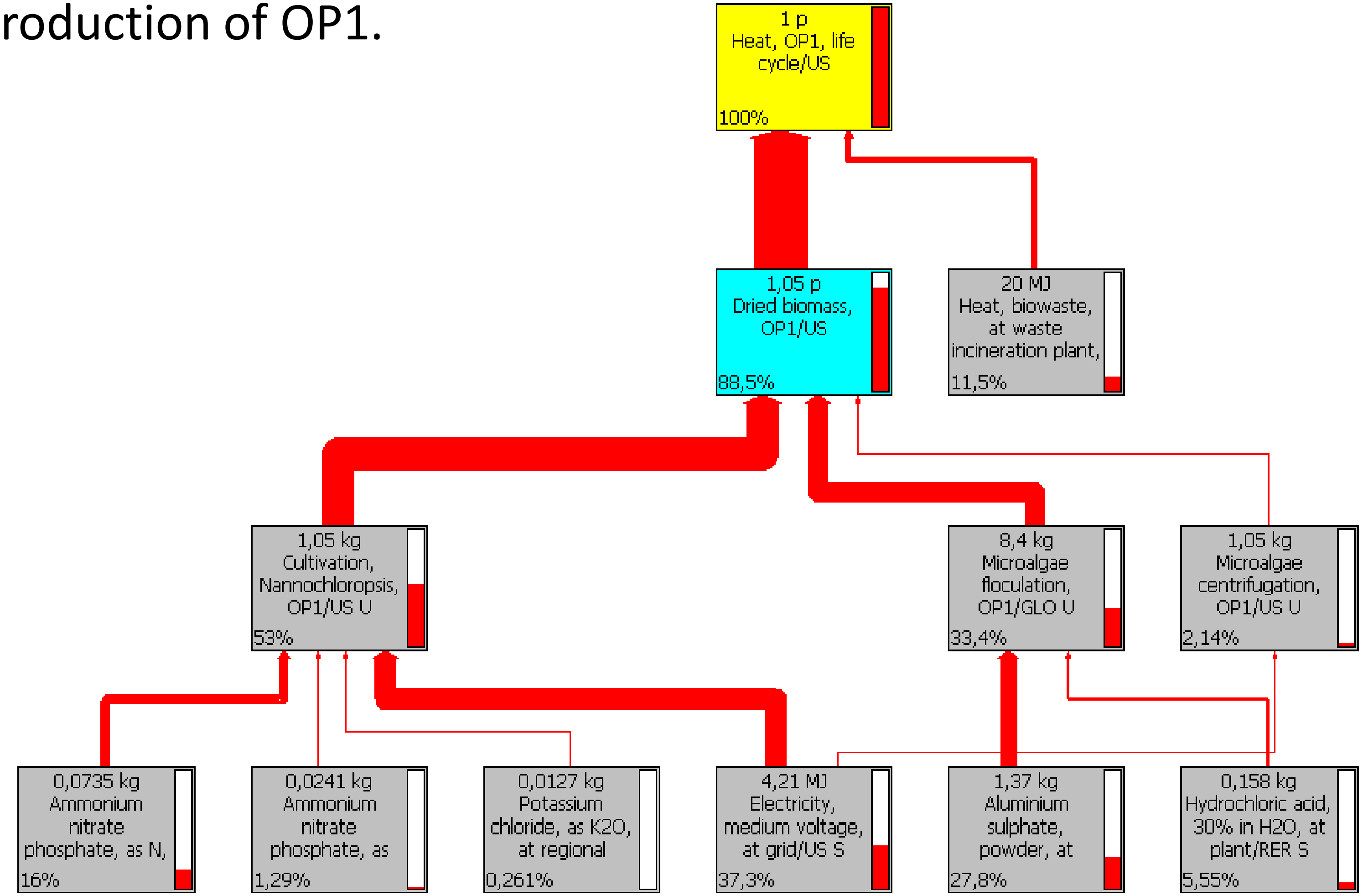
RESULS

4.3 GHG emissions Figure 3 – GHG emissions from OP1, OP2, FPP1, FPP2 and some fossil options referred to the production of 20 MJ (LHV) of thermal energy from combustion at the power plant.



RESULTS

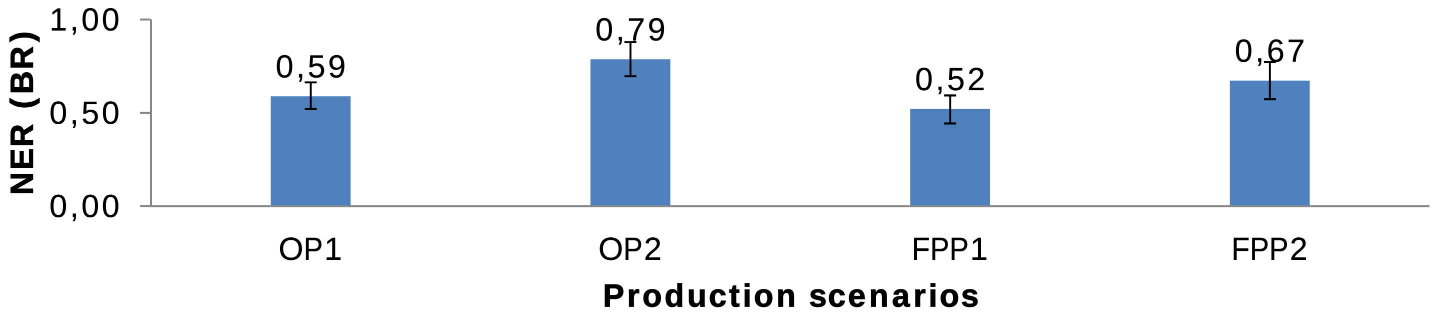
Figure 4 – Relative GHG emissions per processes from thermal energy production of OP1.

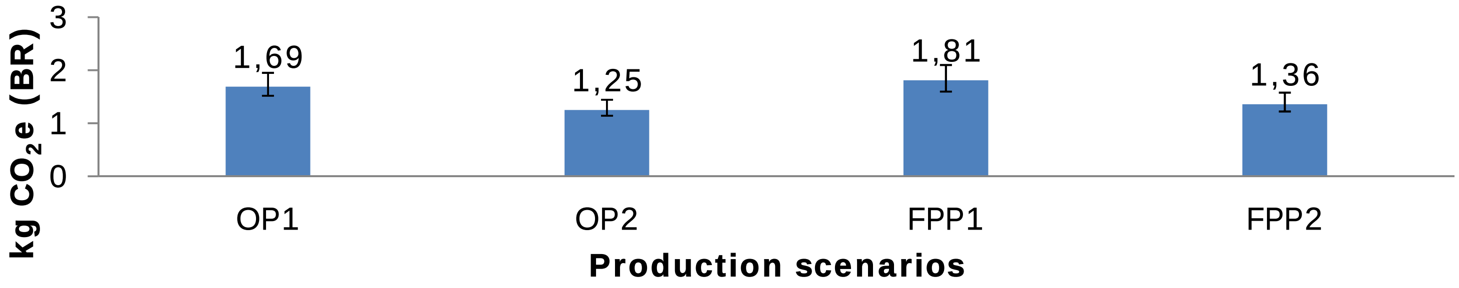


Source: SimaPro 7.3 ®.

RESULTS

Using the Brazilian electricity matrix.





DISCUSSION

- The substitution of commercial fertilizers by effluent brought an expressive gain in NER of 25-30%.
- Around 80% of the GHG emissions using fossil sources comes from combustion.
- Microalgae GHG emissions were higher than for fossil using the United States electricity grid but lower using the Brazilian one. It means, a cleaner matrix stimulates it to keep clean.
- Scenarios OP1, OP2, FPP1 and FPP2 increased 28, 36, 42 and 55% on their NER and decreased 32, 38, 42 and 50% on their GHG emissions respectively.

CONCLUSION

Even though the fossil options show slightly better yields compared to microalgae in the two categories analyzed, the fossil energy technology is mature and has less space for improvements, while microalgae is in its infancy and has many technological solutions being developed.

Microalgae favor industrial ecology practices.

Source: Franc, CleanTick 2011

CLEAN TECHNOLOGY NETWORK

TECLIM

Thank you for your kind attention!

ACKNOWLEDGEMENTS

CAPES

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