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Energy Efficiency Assessment of the Brazilian Pre-salt Petroleum

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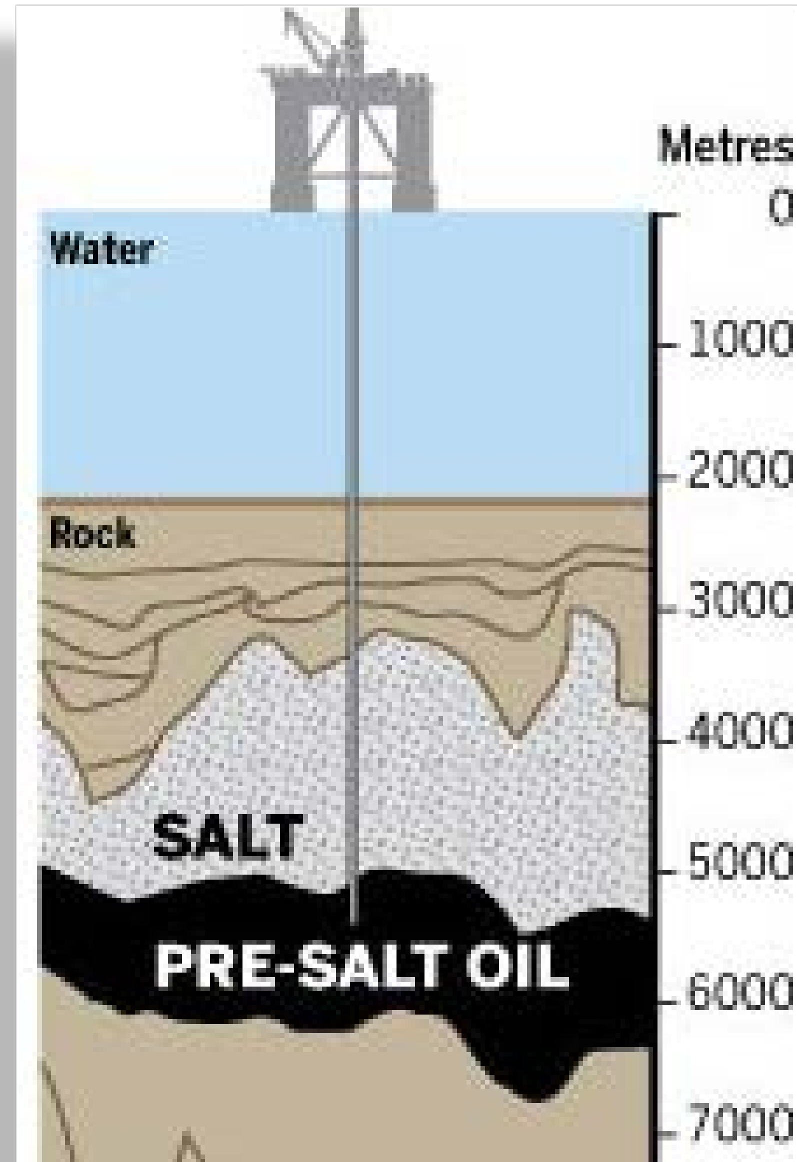
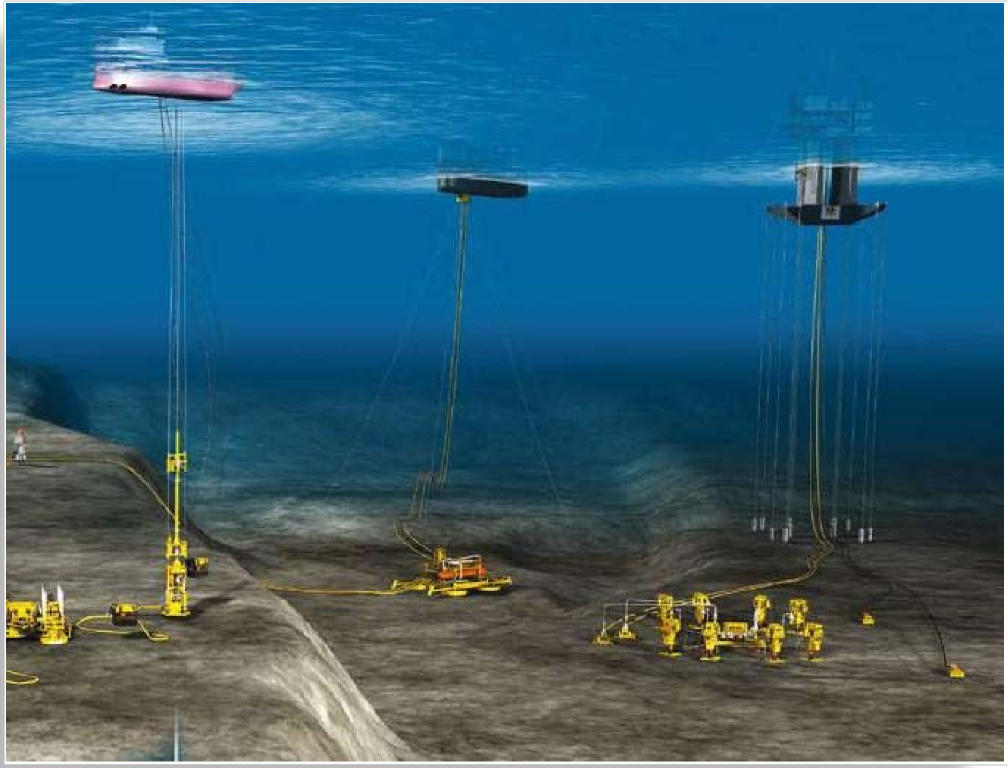
Introduction

- Petroleum will be responsible for about 30% of total world energy demand in 2050
- For the Brazilian case, petroleum will be responsible for about 40% of its energy demand in the same year
- Petroleum will continue to play an important rule on energy issues
- The recent discoveries of Brazilian pre-salt petroleum reserves could increase 5 times the current petroleum & gas Brazilian reserves



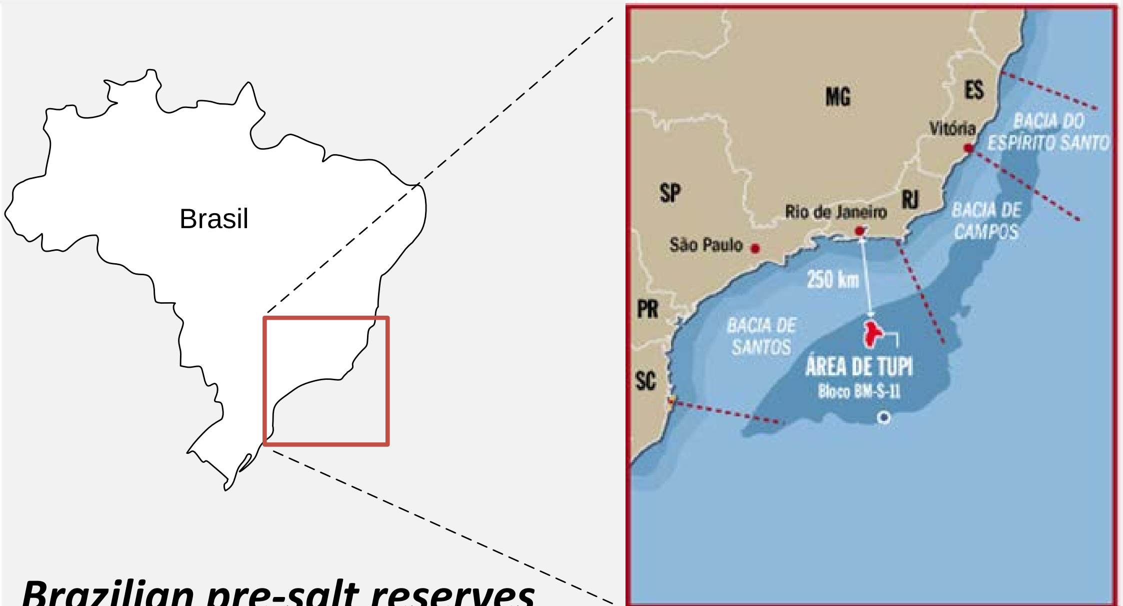
Introduction

- The demand of huge amount of energy to obtain pre-salt oil raises doubts about its net energy contribution to society

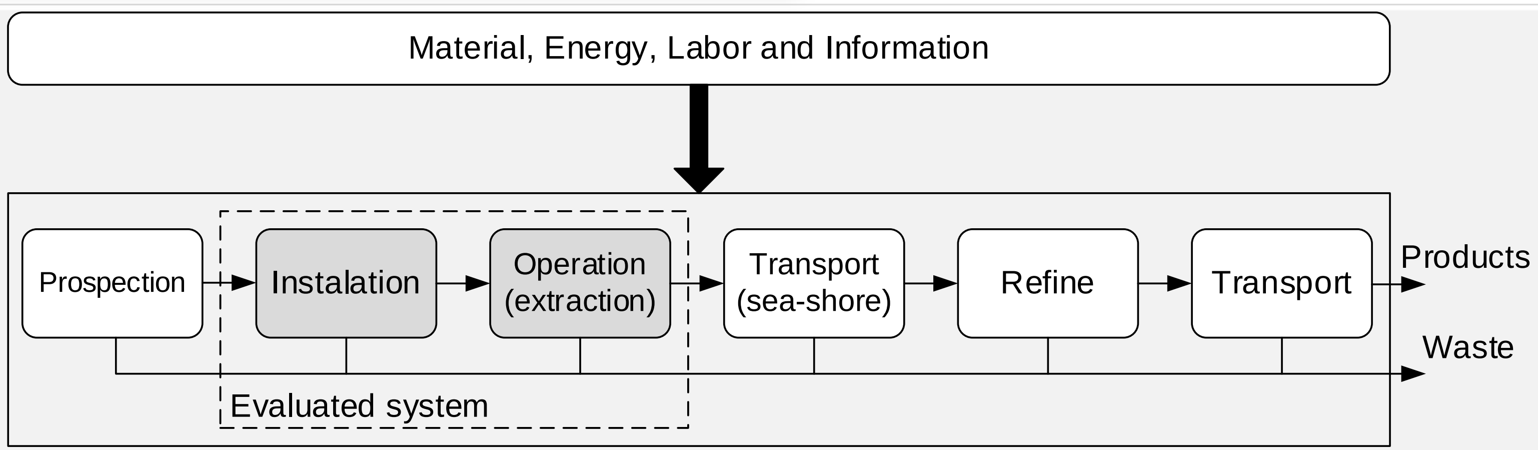


Does the Brazilian offshore pre-salt oil extraction provides net fossil-energy to society?

Methods: case study boundaries

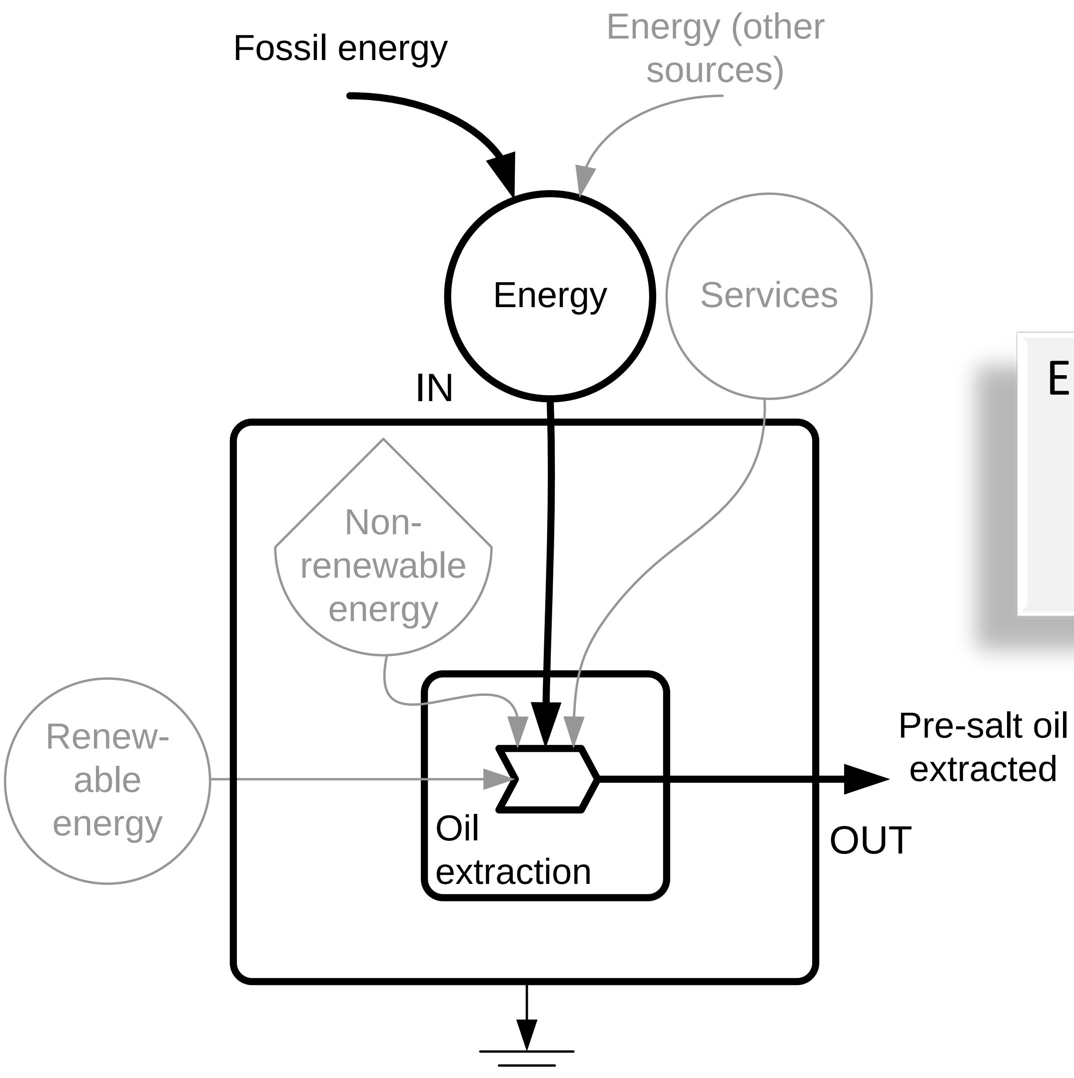


Brazilian pre-salt reserves



System boundaries

Methods: embodied energy analysis

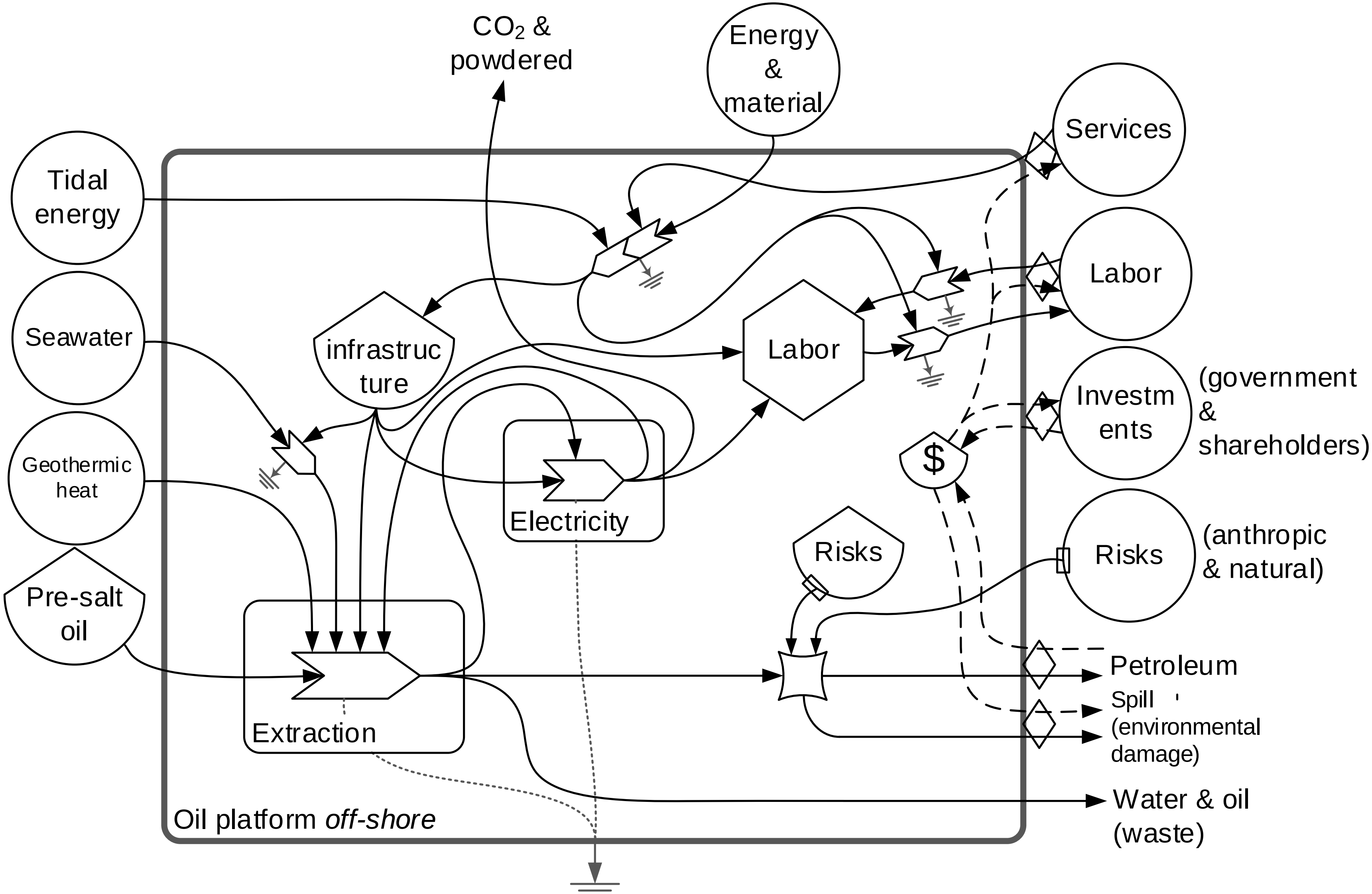


Energy Return on Investment (EROI)

$$EROI = \frac{\text{energy OUT}}{\text{energy IN}}$$

Slesser, 1974, Energy analysis workshop on methodology and conventions. Stockolm, Sweden, IFIAS, 89p.

Results & Discussion



Energy diagram of the Brazilian offshore pre-salt oil extraction

Results & Discussion

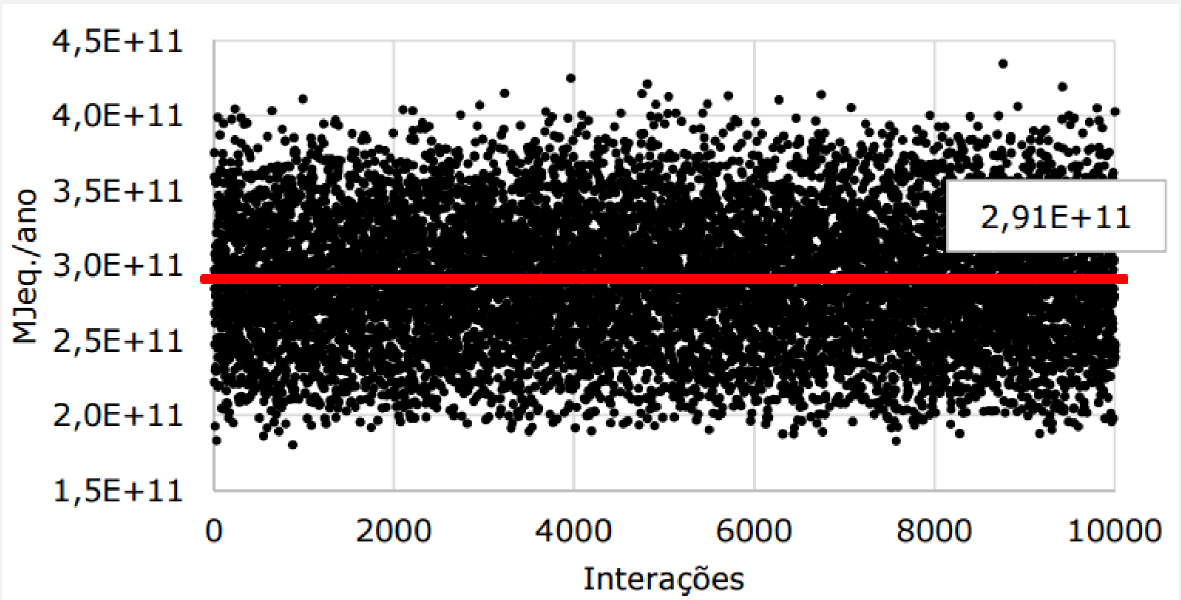
Uncertainty analysis through Monte Carlo simulation (10,000 interactions; log-normal PDF)

Note	Item	Minimum quantity	Maximum quantity	Unit	Material	Minimum service life (years)	Maximum service life (years)	Minimum embodied energy factor	Maximum embodied energy factor	Unit
1	Platform	3.48E+06	9.08E+06	ton	Steel	20	30	3.25	20.69	MJeq./kg
2	Drilling rig	3.86E+06	6.28E+06	ton	Steel	10	15	3.25	20.69	MJeq./kg
3	Anchorage cables	6.92E+06	1.04E+07	ton	Synthetic fiber (50%)	30	40	50.31	88.21	MJeq./kg
				ton	Polyester (50%)	30	40	50.32	88.21	MJeq./kg
4	Oil tanker	1.65E+07	2.64E+07	ton	Steel	30	40	3.25	20.69	MJeq./kg
5	Support boats	7.72E+05	1.87E+06	ton	Steel	30	40	3.25	20.69	MJeq./kg
6	Flexible pipes	9.82E+06	1.12E+07	ton	Steel (20%)	10	20	3.25	20.69	MJeq./kg
				ton	Stainless steel (20%)	10	20	49.94	49.94	MJeq./kg
				ton	Polymer (60%)	10	20	69.72	69.72	MJeq./kg
7	Risers	4.42E+06	4.42E+06	ton	Steel (20%)	10	20	3.25	20.69	MJeq./kg
				ton	Stainless steel (20%)	10	20	49.94	49.94	MJeq./kg
				ton	Polymer (60%)	10	20	69.72	69.72	MJeq./kg
8	Christmas tree (oil well)	1.73E+05	3.90E+05	ton	Steel	10	15	3.25	20.69	MJeq./kg
9	Labor	2.38E+08	6.22E+08	hours/yr	-	-	-	-	-	-
10	Diesel	1.08E+17	1.44E+17	J/yr	Diesel	-	-	1.34	1.34	MJeq./MJ

Results & Discussion

Indicator	Value
Average	2.91E+11
Standard deviation (σ)	4.33E+10
Confidence interval (95%) = μ ± 1.96 σ	1.81E+11 a 4.35E+11

Monte Carlo simulation result (in $MJ_{eq.}$/yr) for fossil energy embodied in the pre-salt oil extraction



Monte Carlo simulation graphical result

Results & Discussion: calculation summary

2.91 E11 $MJ_{eq.}$/yr
(fossil energy demanded by system)

51.0 E11 MJ_{oil}/yr
(annual average for oil extracted)

$$EROI = \frac{Output}{Input} = \frac{51.0\text{ E11 } MJ_{oil}/yr}{2.91\text{ E11 } MJ_{eq.}/yr} = 17.5$$

Resource	Year	Country	EROI (X:1)[1]	Reference
Fossil fuels (Oil and Gas)				
Oil and gas production	1999	Global	35	Gagnon, 2009
Oil and gas production	2006	Global	18	Gagnon, 2009
Oil and gas (Domestic)	1970	US	30	Cleveland et al. 1984, Hall et al. 1986
Discoveries	1970	US	8	Cleveland et al. 1984, Hall et al. 1986
Production	1970	US	20	Cleveland et al. 1984, Hall et al. 1986
Oil and gas (Domestic)	2007	US	11	Guilford et al. 2011
Oil and gas (Imported)	2007	US	12	Guilford et al. 2011
Oil and gas production	1970	Canada	65	Freise, 2011
Oil and gas production	2010	Canada	15	Freise, 2011
Oil, gas & tar sand production	2010	Canada	11	Poisson and Hall, in press
Oil and gas production	2008	Norway	40	Grandell, 2011
Oil production	2008	Norway	21	Grandell, 2011
Oil and gas production	2009	Mexico	45	Ramirez, in preparation
Oil and gas production	2010	China	10	Hu et al. 2013
Fossil fuels (Other)				
Natural Gas	2005	US	67	Sell et al. 2011
Natural Gas	1993	Canada	38	Freise, 2011
Natural Gas	2000	Canada	26	Freise, 2011
Natural Gas	2009	Canada	20	Freise, 2011
Coal (mine-mouth)	1950	US	80	Cleveland et al. 1984
Coal (mine-mouth)	2000	US	80	Hall and Day, 2009
Coal (mine-mouth)	2007	US	60	Balogh et al. unpublished
Coal (mine-mouth)	1995	China	35	Hu et al. 2013
Coal (mine-mouth)	2010	China	27	Hu et al. 2013
Other non-renewables				
Nuclear	n/a	US	5 to 15	Hall and Day, 2009, Lenzen, 2008
Renewables[2]				
Hydropower	n/a	n/a	>100	Cleveland et al. 1984
Wind turbine	n/a	n/a	18	Kubiszewski et al. 2010
Geothermal	n/a	n/a	n/a	Gupta and Hall, 2011
Wave energy	n/a	n/a	n/a	Gupta and Hall, 2011
Solar collectors[2]				
Flat plate	n/a	n/a	1.9	Cleveland et al. 1984
Concentrating collector	n/a	n/a	1.6	Cleveland et al. 1984
Photovoltaic	n/a	n/a	6 to 12	Kubiszewski et al. 2009
Passive solar	n/a	n/a	n/a	Cleveland et al. 1984
Biomass				
Ethanol (sugarcane)	n/a	n/a	0.8 to 10	Goldemberg, 2007
Corn-based ethanol	n/a	US	0.8 to 1.6	Patzek, 2004, Farrell et al. 2006
Biodiesel	n/a	US	1.3	Pimentel and Patzek, 2005

17.5

Hall, C.A.S., Lambert, J.G., Balogh, S.B., 2014. EROI of different fuels and the implications for society. Energy Policy 64, 141-152.

Conclusions

- The Brazilian offshore pre-salt oil extraction demands about 2.91 E11 MJeq./yr of fossil energy to operate;
- This energy demand results in an EROI of 17.5;

  (for 1J of fossil energy invested results in 17.5J of oil)
- EROI performance can be considered as good or positive when compared to similar energy sources as found in literature; but renewable energy sources as windturbines deserves attention because its EROI is also similar to the fossil fuels

Thank you!

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