

Calculating the environmental cost of the nuclear power plants Angra 1, 2 and 3 using the program SIMPACTS

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Abstract – Environmental impact, converted into economic terms, is an environmental cost. For this calculation, computational programs such as the Simplified Approach of Estimating Impacts of Electricity Generation (SIMPACTS) are used. SIMPACTS is a code that estimates and quantifies the costs of both, environmental and health damage, caused by different electricity generation technologies. The aim of this work is the calculation of the environmental cost of the nuclear power plants Angra 1, 2 and 3. The results were compared with data provided in the program of the Serra da Mesa hydroelectric power plant. The results have demonstrated that a nuclear reactor has lower impacts associated and consequently lower environmental cost than a hydropower plant of similar capacity. Therefore, nuclear reactors are attractive sources of power generation with low environmental impacts.

Keywords – Best practices, Costs, Decision making, Environmental economics, Nuclear power generation.

I. INTRODUCTION

The energy model of most countries is based on the consumption of fossil fuels, such as petroleum, natural gas, and coal. However, the problem with this model is that these fuels are not renewable sources of energy and, thus, their use is limited in the long, medium, and short run. Furthermore, fossil fuels are highly harmful to the environment, leading to atmospheric pollution, which directly affects the health of living beings.

The main alternative energy sources are: wind, solar, biomass power, and nuclear energy. The operation of Angra 1, 2 and recently Angra 3 – located in Angra dos Reis – has contributed to the growth of nuclear energy in Brazil [1].

Alternative energy sources including nuclear energy are advantageous regarding externalities. Externality is a term used to describe the collateral effects of the production of goods and services on individuals who are not directly related to such activities [2]. Thus, externalities refer to the consequences of a decision on those who did not take part in its discussion. The effects of externalities can be both positive and negative, which can generate either higher costs or benefits to society. The amount of pollution produced by the use of fossil fuels affects external agents, which are not necessarily beneficial, but are rather harmful, leading to negative externalities.

Externalities can be identified by what is known as environmental cost, and they also have some relation to it. Environmental cost is a negative externality, which is in some way harmful to the environment and, in economic terms, is comparable to other costs associated with actions and endeavors [2].

The International Atomic Energy Agency (IAEA) developed a program to calculate the environmental cost of electricity plants, known as SIMPACTS (Simplified Approach of Estimating Impacts of Electricity Generation) [3]. This program is the main focus of this study, and will be described in this article.

The aim of this study is to use SIMPACTS to calculate the environmental cost of the plants Angra 1, 2, and 3 during routine operation and to compare the results with data of the facilities given in the program.

II. MATERIAIS AND METHODS

SIMPACTS consists of separate modules for estimating the impacts on human health, agricultural crops and buildings resulting from routine atmospheric emissions of pollutants from energy facilities. The program estimates physical damage and external costs. The most significant aspect of this program is its simplicity, as it has been designed for

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use on a Personal Computer (PC) with a minimum of input data [3].

There are three modules in SIMPACTS: AIRPACTS, used for quantifying the impacts and costs of damage due to atmospheric emissions; NUKPACTS, used for assessing the collective doses and health effects from routine operation of nuclear facilities, and the external cost due to waste disposal and accidents; and HYDROPACTS, used for calculating the damage costs of hydropower dams, resulting from resettling people due to floods and lost use land [3].

Only the HYDROPACTS and NUKPACTS modules were used in this study.

III – THEORY/CALCULATION

This chapter will present data in SIMPACTS to calculate the environmental cost of the nuclear power plants Angra 1, 2, and 3. In order to provide parameters to compare the cost of Angra 1, 2, and 3 with the cost of other energy sources, the cost of a hydroelectric power plant with electricity output similar to Angra 2 (Serra da Mesa) was also considered.

A. Angra 2 e 3

The reactors of Angra 2 and 3 are similar: 1350 and 1405 MW, respectively. Therefore, for academic purposes, the data related to Angra 2 and Angra 3 will be the same, and will be presented together in Table 1.

Table 1. SIMPACTS data for Angra 2 and 3.

DISPERSION AND RECEPTION	
Population and dispersion parameters	Regional: 365. 23 people per km ² (State of Rio de Janeiro) Local: 246. 02 people per km ² (Cities of Angra dos Reis and Parati)
Urban and rural distribution	96. 71% (urban) 3.29% (rural)
Yearly average wind speed	15 knots
Effective release height	492 ft
Yearly average breathing rate among adults	7500 m ³ /year
EMISSIONS AND METEOROLOGY	
Radionuclides release rate	Bq/s
H-3	8.1E+05
C-14	0
Co-58	0. 66
Co-60	0. 19
Kr-85	2. 55
I-131	2.81E+02
I-133	1.4E+03
Xe-133	1.7E+03
Cs-134	5.85
Cs-137	1.7E+01
Frequency of stability among the Pasquill stability classes (A, B, C, D, E, F)	A 10.60% B 7.48% C 7.20% D 24.16% E 34.16% F 15.24% G 1.15%
FOOD CONSUMPTION	
Average consumption rate for the following foods: beef, pork, poultry, lamb, grains, vegetables, tubers, fresh, and other types of milk	Kg/person/year Beef: 46,7 Pork: 14,5 Poultry: 44

	Lamb: 0,5 Grains: 135 Rice: 43 Corn: 12 Wheat: 80 Vegetables: 27,08 Milk: 161liters
Edible fraction for each of the above	100.00%
HEALTH EFFECTS AND VALUATION	
Possible risks for health effects	Cases per Sv per capita
Effects – fatal cancer, non-fatal cancer, severe hereditary effects	Fatal cancer: 5 (0.05%) Non-fatal cancer: 1 (0.01%) Hereditary effect: 1,3 (0.013%) INCA (2012)
Unitary economic values per fatal case of cancer	Fatal cancer: VOSL 3.30E+0.5; VLYL 2.48E+0.5 Non-fatal cancer: 1.10E+0,5 Severe hereditary effects: 3.30E+0,5
Purchasing power parity	US\$7330.00

B. Angra 1

The Angra 1 nuclear power plant is less powerful (657 MW), for this reason exhibit a variation regarding the emission and meteorology data. This data is displayed below.

Table 2. SIMPACTS data for Angra 1.

DISPERSION AND RECEPTION	
Population and dispersion parameters	Regional: 365. 23 people per km ² (State of Rio de Janeiro) Local: 246. 02 people per km ² (Angra dos Reis and Parati)
Urban and rural distribution	96. 71% (urban) 3.29% (rural)
Yearly average wind speed	15 knots
Effective release height	146 ft
Yearly average breathing rate among adults	7500 m ³ /year
EMISSIONS AND METEOROLOGY	
Radionuclides release rate H-3 C-14 Co-58 Co-60 Kr-85 I-131 I-133 Xe-133 Cs-134 Cs-137	Bq/s 7,65E+04 1,41 1,03 1,09E+05
Frequency of stability among the Pasquill stability classes (A, B, C, D, E, F)	A 10,60% B 7,48% C 7,20% D 24,16% E 34,16% F 15,24% G 1,15%

FOOD CONSUMPTION	
Average consumption rate for the following foods: beef, pork, poultry, lamb, grains, vegetables, tubers, fresh, and other types of milk	Kg/person/year Beef: 46,7 Pork: 14,5 Poultry: 44 Lamb: 0,5 Grains: 135 Rice: 43 Corn: 12 Wheat: 80 Vegetables: 27,08 Milk: 161liters
Edible fraction for each of the above	100.00%
HEALTH EFFECTS AND VALUATION	
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Unitary economic values per fatal case of cancer	Fatal cancer: VOSL 3.30E+0.5; VLYL 2.48E+0.5 Non-fatal cancer: 1.10E+0,5 Severe hereditary effects: 3.30E+0,5
Purchasing power parity (PPP)	US\$7330.00

C. Serra da Mesa hydroelectric power plant

The environmental cost of Serra da Mesa hydroelectric power plant was calculated in order to establish a comparison with other energy resources. The plant is located in the State of Goiás, and its power output is similar to Angra 2 and 3.

Table 3. SIMPACTS data for hydroelectric power plants

DAM CHARACTERISTICS		
Name of location	Serra da Mesa	
Location and description	Located in Goiás, Brazil. Latitude -13.833749 and Longitude -48.302809	
Dam height (H_D)	492ft	
Nominal net head	412ft	
Additional net head correction (Δ_H)	-79ft	
Plant capacity (P)	1.275 MW	
Average plant capacity factor (CF)	58%	
Turbine flow (Q_w) between all turbines	668,0 m ³ /s	
LOCATION CHARACTERISTICS		
Characteristics	Unitary value	Comments
Region ID	1 or 2	1 (tropical) and 2 (boreal)
Terrain index	4	4 is the value given by the program for the region within Brazil. The value equals 5.65E-05
Type of terrain	1	Value given by the program describing canyons, ravines, and

		steep mountains.
Average terrain inclination		
Average river inclination		
Reservoir Flood area		The model will estimate the value if it is unknown
Average rate of failure	1,00E-04	
Average accident warning time	1.5 hours	

POPULATION CHARACTERISTICS AND TERRAIN USAGE

Population density	
Close to the river basin	6 people/km ²
People in situations of risk during accidents	50.000 people
Percentage of resettled inhabitants	50%
Land cover: forests	89%
Land cover: agricultural purposes	10%
Land cover: others	1%

LOSS OF PRODUCTION: AGRICULTURE AND HUSBANDRY

Characteristics	Unitary value (tons/year)	Market price (US\$/ton)
Sugar cane	3712	8.5
Corn	3710	79
Soybean	1684	175
Beans	117	40
Rice	491	105
Cassava	912	115
Coffee beans	12	1080
Pineapples	58	498
Bananas	198	436
Watermelon	388	163
Mangoes	1	205
Passion fruit	16	535
		Market price (US\$/unit)
Beef	49.403,0	259
Poultry	26.673,0	0,5
Eggs	65.850,0	0,4
Milk	4.284.897,0	0,2

EMISSION CHARACTERISTICS

Emissions	Ton/km ² /year
Low CH ₄ emissions	
High CH ₄ emissions	
Medium CH ₄ emissions	18,7
Low CO ₂ emissions	
High CO ₂ emissions	
Medium CO ₂ emissions	1.450,0
Methane GWP	21,0
Cost of carbon	US\$ 20,0 per ton of carbon

COST CHARACTERISTICS

Country's GNP	5.300 US\$ ₂₀₀₀ per capita
Country's PPP GNP	7.300 US\$ ₂₀₀₀ per capita
Cost of forest	2.000 US\$ ₂₀₀₀ per hectare
Cost of agricultural land	2.500 US\$ ₂₀₀₀ per hectare
Cost of other types of land	1.000 US\$ ₂₀₀₀ per hectare
Internal land cost fraction	0.50
Economic life project	50 years
Interest rate of increased cost	0%

IV – RESULTS AND DISCUSSION

A. Angra 2 e 3

Both local and regional level impacts have been considered. Thus, the total cost corresponds to the sum of the costs in a local and regional level, which includes: fatal cancer as seen on VOSL (Value of Statistic Life) and VLYL (Value of a Life Year Lost), non-fatal cancer, and severe hereditary effects. The value of the total cost of health effects caused by the release of radionuclides by the reactors of Angra 2 and 3 was of US\$ 2,790 in the year of 2000.

In a regional level, the impacts and costs associated with those effects are significant, as the majority of them are connected to fatal cancer as demonstrated by the VOSL. Figure 1 demonstrates the environmental cost of the reactors of Angra 2 and 3.

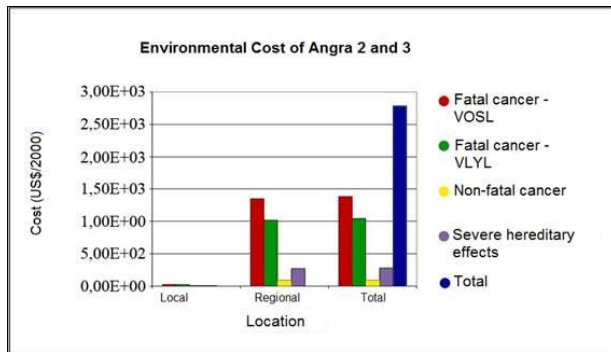


Fig 1. Environmental cost of Angra 2 and 3.

B. Angra 1

Figure 2 shows environmental cost of the reactor Angra: US\$ 17.8 in 2000.

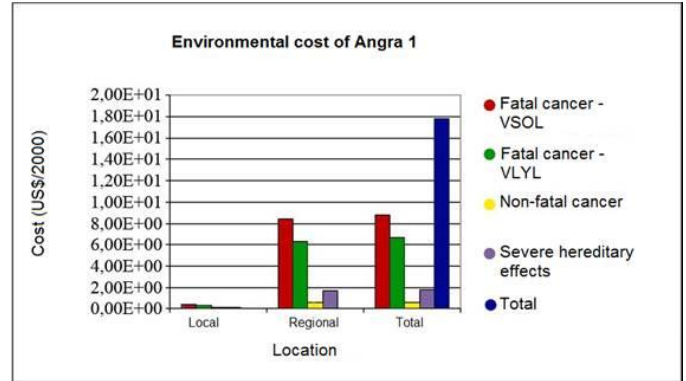


Fig 2. Environmental cost of Angra 1.

C. Serra da Mesa

Figure 3 shows the results of the environmental cost of Serra da Mesa. To compare the results of HIDROPACTS with the NUKPACTS, the unity of the end result should be in US\$ per year. The value of the environmental cost for Serra da Mesa is 3.82 US\$ / MWh. For one year the value is US \$ 33463.2 / MW. Finally, the value above multiplied by the installed capacity of hydropower (1275 MW) and its average capacity factor (0.58) shows that the environmental cost associated with this facility is US\$ 24,746,036.4 per year.

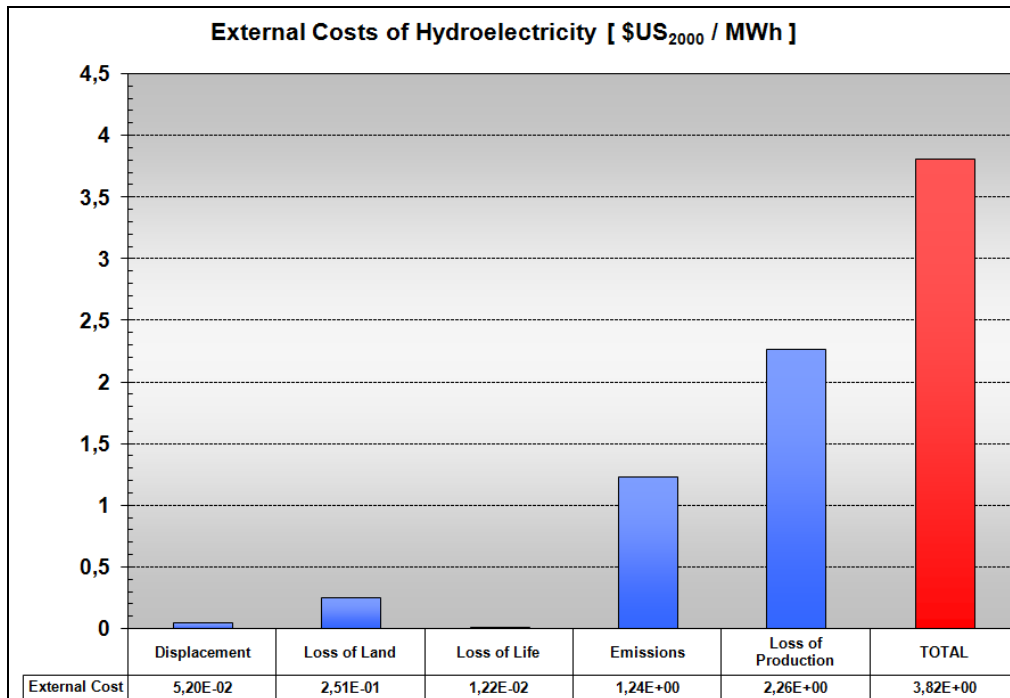


Fig 3. Environmental cost of Serra da Mesa.

V – CONCLUSION

The results have demonstrated that a nuclear reactor has lower impacts associated and lower environmental cost than a hydropower plant of similar capacity.

That may be explained by the fact that a hydroelectric power plant can be associated with a number of social impacts, such as resettling and displacement, as well as the loss of productive land, leading to higher associated costs.

VI - ACKNOWLEDGMENT

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VIII – BIOGRAPHIES



Francine Menzel was born in São Paulo, Brazil, on March 14, 1988. She earned a bachelor's degree in Environmental Management from the University of São Paulo (2010) and a master's degree in Nuclear Technology from the Instituto de Pesquisas Energéticas e Nucleares (2014). She has experience in Environmental Science, focusing on the following subjects: energy, alternative sources, sustainability, economic viability, environmental cost and licensing of nuclear reactors.



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