YASUNIZATION OF THE EARTH: FROM THE CASE OF AMAZON BASIN TOWARDS A WORLD ATLAS OF UNBURNABLE CARBON

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ABSTRACT

Climate change represents the greatest challenge for current and future generations as part of the paradigmatic metaphor of sustainability. This is more and more claimed in the political, social and scientific spheres, such as in the article published by McGlade and Ekins in Nature in January 2015 [1], where they argue that implementation of effective climate policies would require that around 80% of coal, 50% of gas and 30% of oil reserves remain untapped. Despite these scientific efforts of quantification of unburnable carbon, criteria for choosing spatially which reserves must remain underground have not been addressed in relation to implementation of effective policies for avoiding emissions. For instance in western Amazon, one of the most cultural and biological diverse area in the world [2], shows that oil and gas blocks cover 733414 km^2 and are in expansion since 2008, aside from 35 confirmed or suspected untapped hydrocarbon discoveries along the area.

In this work, we present a new starting research project that aims: 1) to map, at global scale, on-shore hydrocarbon reserves which overlap and/or impact on biologically and culturally high sensitive areas; 2) identify unburnable carbon areas. Methodology involves the structuring of an open source GeoDatabase collecting all the ecological, anthropic, productive, economic and infrastructural data; the performing of an integrated spatially explicit Multicriteria Analysis in Geographical Information System environment.

We focus on the analysis carried out in the countries that are part of Amazon basin, showing the data collection, validation, systematization, and GIS analysis processes. The first results indicate several overlaps between hydrocarbon production sectors and very high ecological and cultural areas, highlighting the role that tropical forest ecosystem services may play in exchange of unburnable oil.

Keywords: *Yasunisation, oil and gas, biodiversity, Amazon, conservation*

INTRODUCTION

For the period 2011-2050 cumulative carbon dioxide emissions, to stay under the limits of 2° C above the average global temperature of pre-industrial times, must remain between 870 to 1.240 Gt of CO2. To reach this objective, McGlade and Ekins [1], estimate that more than 80% of coal, 50% of gas and 30% of oil reserves must remain underground.

Besides the climate change challenge, impacts on health, water and biodiversity in conventional and unconventional fossil fuel operations in different geographical contexts are widely reported in scientific literature, as well as policies and interventions to try to reduce or mitigate them [2; 3; 4; 5; 6; 7; 8; 9; 10; 11; 12; 13].

One experiment internationally discussed policy, for oil and gas activities impacts mitigation and reduction, is to leave hydrocarbon reserves underground. Nowadays in the world, there has been only one empirical experimentation about it: the Yasuni ITT Initiative implemented in Ecuador in the period 2006-2013 to avoid the exploitation of ITT oil block (Ishpingo, Tambococha, Tiputini) partially located into the Yasuni National Park. Considering the scarce results in terms of accumulated funds, the government abandoned the Initiative. However civil society and the scientific community

still support the initiative, coining the neologism "Yasunization" to describe either past experience or the need to maintain oil underground to reduce carbon emissions, thereby granting climate justice, human rights and biodiversity conservation, through citizen involvement.

However, from the state of art of research, a key scientific topic remain unexplored: general targets for leaving carbon reserves underground at international or national level are not supported by spatially explicit location for the untapped fossil fuel reserves. To respond to these practical aspects, in 2016 we started a research project, in current development, called "Yasunization of earth: a World Atlas of Unburnable carbon. Cartography and GIS tools to implement inclusive spatial explicit policies for climate and biodiversity protection and human rights enforcement (Yasunization of earth)", framed around two key goals: 1) to map, at global scale, on-shore hydrocarbon reserves which overlap/impact biologically and culturally high sensitive areas; 2) identify unburnable carbon areas. All the available ecological, anthropic, productive, economic and infrastructural data is being structured in an open source GeoDatabase; methodology is based on an integrated spatially explicit Multicriteria Analysis performed in Geographical Information System (GIS) environment.

Hence, in this paper we present the analysis carried out concerning the spatial dimension of hydrocarbon production and relationship with biological and cultural diverse areas in the Amazon region of Colombia, Brazil and Bolivia (see figure 1).

Extractive activities have great importance for all the countries we are taking into consideration.

In Colombia, fossil hydrocarbons are the main sources for the economy. Oil was discovered by the troops commanded by the Spanish explorer Gonzalo Jimenez de Quesada in the XVI century [14]. However, we have to wait until 1918 for the first production of well with Bohorquez, De Mares and Barco [15]. In 2015 Colombia produced 1 million b/d of petroleum and other liquids and according to the U.S. Energy Information Administration, oil consumption accounted for 37% of the total energy consumption in the country, whereas natural gas reached 25% [16]. The Colombia's top export destination is United States with 370.000 barrels per day (b/d) of crude oil followed by Panama [16].

In Bolivia the discovery of hydrocarbons dates back to the XX century [17]. The entrepreneur Luis Lavandez drilled the first well in 1913 [18]. Extraction activities in Bolivia represent 8% of the GDP of the entire country. Nevertheless, The Oil and Gas Journal places Bolivia among the countries with the smallest reserves of the world with 210 million barrels of crude oil reserves produced in January 2015[19]. The Bolivian government has declared that only 10% of the reservoir has been discovered, therefore an increase of exploration will be put into action in order to increase these reserves. Thus, the Yacimientos Petrolíferos Fiscales Bolivianos (YPFB), a company founded in 1936 with the aim of improving land management and internal marketing and controlling the production of hydrocarbons [18], asked for the perforation of 17 new exploration wells between 2015 and 2016. In 2015 the YPFB and other foreign companies planned to invest 12.17 billion dollars to improve natural gas reserves up to 1.5 billion m3 [19]. Actually oil production in Bolivia is concentrated in four departments: Tarija, Santa Cruz, Cochabamba and Chuquisaca [20]. In 2014, the U.S. Energy Information Administration has estimated a production of petroleum and other liquids of 67.000 b/d [19].

In Brazil oil drilling started in 1897 in Bofete (San Paolo) with only 2 barrels of oil extracted [21]. One of the most important oil company in Brazil is Petrobras, a company founded in 1953 for the onshore and offshore exploration and the exploitation through the system of ducts [22]. Brazil is the 8th-largest total energy consumer and the 9th-largest liquid fuels producer in the world. In 2014, Brazil produced 2.95 million barrels per day (b/d), representing a 9.5% increase compared to the previous year. Approximately 9% of the total oil production in Brazil is onshore. In 2014 the consumption of hydrocarbons was highest than productivity with 3.2 million b/d [23].

As seen extractive activity are very important for the economy of these countries, but it could also trigger and drive to important environmental impacts as it is documented in Diantini (2016) [24]. Usually governments allow exploration and exploitation of oil & gas through the concession of areas (after defining a cadastre of oil blocks) to governmental, national or international companies. The succession of oil operation between concession leasing to exploitation, see first of all companies verify the presence of hydrocarbons. Exploratory activities are allowed inside exploration blocks and included geological, geophysical, geochemical, seismic surveys and drilling of exploratory wells [25]. Particularly, seismic survey, (the production of waves for geophysical prospection of underground properties of earth through controlled explosion along lines [26]), represent a first source of impacts on ecosystems in different ways. In forest ecosystems it is necessary to deforest to create seismic lines, causing habitat loss and fragmentation of large extension of territory (for example, in Ecuador 540 km^2 were deforested for seismic prospecting [27]. Moreover the noise of seismic survey makes animals get away or change their nutritional and reproductive behavior [27]. Once exploration activities have established the presence of hydrocarbons, companies enter in the exploitation phase of reserves in specific areas, so blocks are renamed "production blocks" or "oil fields" [28]. During the hydrocarbon production, environmental impacts on water bodies are relevant both in terms of water contamination and water withdrawal [29]. Pipelines, usually built and used to bring out the product to the processing centers, are another important source of impacts, because the lack of maintenance may evolve in oil spill [30]. In Niger Delta for example there are on average 600 oil spills per annum [31]. Furthermore there are other environmental impacts like air pollution due to flare stacks and vehicle emission with radiation of carbon monoxide and nitrogen oxides [32].

All these potentially impacting activities, along with the territorial control given to oil companies through the concession of areas, are particularly dangerous in sensitive areas with high presence of valuable biological and cultural features, as is the Amazon region.

The general aim of this study is to explore the hydrocarbon dimension of the Amazon of these three countries and the spatial relationships with high biological and cultural diversity areas. Specific aims are: a) to map and assess the total oil and gas footprint using the presence of wells, blocks, seismic, and pipelines in Amazonas as indicators; b) to map and assess the spatial relationships and the overlap between oil and gas activities and Amazon protected and indigenous areas.

METHODS

Study Area

In figure 1 it is shown the geographic context of the research, highlighting the Amazon limits and the study area limits (Amazon regions of Bolivia, Colombia and Brazil), and the main roads, indigenous and protected areas. We used as limits for the whole Amazon the "Amazon ecoregion" provided by WWF. We started the data collection and analysis for the Yasunisation project in the Amazon because it is one of the most important area in the world in terms of biological and cultural diversity [2] related to tropical forests. Moreover Amazon is a key region for the provision of ecosystem services worldwide, mainly water availability and carbon sequestration, ecosystem process recognized internationally as fundamental in the climate change challenge. This biogeography region is under several conservation interests also due to is high richness in biological taxa, mostly insects, amphibians, birds, and mammals [33] but also in plants with around 30000 known endemics species [34]. The Amazon is also home to many cultures and indigenous groups, among others different ethnicities that chose to stay in voluntary isolation or others uncontacted yet [10; 35]. This complex system is even more made complex and fragile by the relationships, interactions and overlaps with current pressure and future threats impacting on it, such as migratory and industrial agricultural

expansion, grazing, dams and infrastructural projects, and in these last years more and more extractive interests focused on minerals and oil and gas [36; 37].

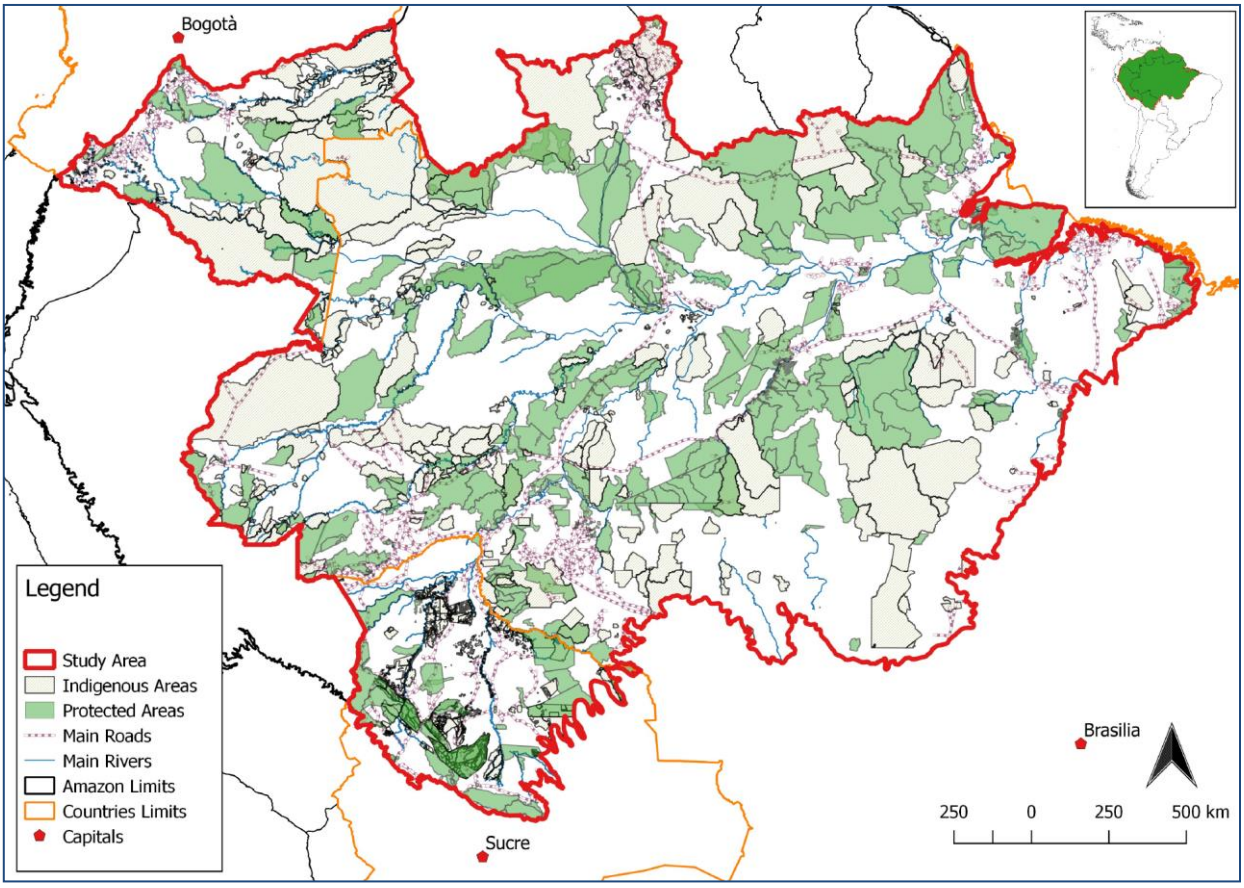

Fig. 1. Geographical framework of the study area. The map shows Amazon and study area limits, indigenous areas, protected areas, main roads and rivers.

GIS data collection and analysis

The most challenging part of the study was the data mining. This research took place in each country in consultation, using the national geoportals, national web pages providing geographical data, and information provided by the oil companies themselves, or NGOs and other organizations caring for issues related to ecosystem conservation, human right, indigenous self-determination and socio-environmental conflicts of the Amazon region.

For each country, vector files (basically shapefile format or kml) and georeferenced raster dataset have been researched. When direct access to these types of data it was not possible, pdf maps, geo-referenced and digitized, and statistical excel databases have been used. The main collected data were: a) administrative data (such as borders, administrative units, capital cities, etc.); b) human/cultural related aspects (such as road networks, urban areas, infrastructures, indigenous territories, poverty, land use, etc.); c) environmental features (rivers, Digital Elevation Model, ecosystems, land cover, etc.); d) conservation and biodiversity layers (protected areas, UNESCO sites, etc.), from national and international sources, such as International Union for Conservation of Nature (IUCN) portal; e) oil and gas activities, such as wells, pipelines, seismic, blocks divided into promotion, exploration and productive phases.

Once all the collected data have been selected and stored, it was possible to proceed with the creation of metadata. After this long operation, all the collected data were compared and placed in a

geodatabase in a unique geographical referenced system for each country, ready to be analyzed in GIS.

It was used the QGIS open source software, very powerful and versatile. It has allowed to perform the spatial analysis, basically in two ways/steps: 1) all data collected were clipped on the study area and spatial geometrics were calculated, such as the amount of features for point data (wells), area in km^2 for polygon features, such as protected areas, blocks, indigenous territories, etc., length in km for linear seismic; 2) we carried out a spatial overlay operation with the command "intersect", which made possible to highlight where oil and gas activities, indigenous and protected areas share the same zone and calculate the related geometries. All analysis were then presented with maps and tables showing the spatial relationships and absolute and relative frequencies of each feature for the Amazon of each country, the total of Amazon territory in the study area and related to the total area of each country. Using this tool, not only is possible to understand where, but also how oil extraction mostly affects the Amazon ecosystem.

RESULTS AND DISCUSSION

In the table below (table 1) and in figure 1 it is possible to see the GIS analysis results referring to the Amazon area of Bolivia, Colombia and Brazil. In particular, we calculated the extension of the Amazon area of the three countries, and these values were compared to the overall Amazon region, and to the area occupied by each country. It was also calculated the area and the percentage of protected areas and indigenous lands placed in the Amazon region for each country.

Table 1. GIS analysis of the study area and percentage of Amazon, protected and indigenous areas for each country and for the study area.

Features	Bolivia	Brazil	Colombia	Total study area
Amazon area (Km^2)	457622.63	4075136.60	505913.72	5038672.95
% of Amazon on total study area	9.08%	80.88%	10.04%	100%
% of Amazon on total Amazon area	6.75%	60.07%	7.46%	74.27%
% of Amazon area on total area of each Country	41.77%	46.35%	43.85%	45.64%
Protected areas in Amazon (Km^2)	150791.54	2190596.00	97028.70	2438415.70
% of Protected areas on Amazon area	32.95%	53.76%	19.18%	48.39%
Indigenous areas (Km^2)	86817.85	1028028.29	260176.53	1375022.67
% of indigenous areas on Amazon area	18.97%	25.23%	51.43%	27.29%

The three countries considered for this study contain nearly 75% of the entire Amazon region. Especially in Bolivia, Brazil and Colombia are respectively 457622.63, 4075136.6 and 505913.72 km^2 of the Amazon area, which in all three cases corresponds to less than a half of the area of each country. Most of the part of the Amazon area considered in this study is part of Brazil (80.88%), while the other two countries take around 10% each.

For what concerns Amazon protected areas, they cover 45.64% of the entire study area. Brazil in particular, with its 2190596.0 Km^2 is the country that has the larger surface of protected areas, corresponding to 53.76% of its Amazon region.

The indigenous lands within the study area occupy 1375022.67 Km^2. It is possible to see that in Colombia the percentage within its Amazon region is much higher than the other countries. In fact

this area reaches 51.43%, while in Bolivia and Brazil the percentage is 18.97% and 25.23% respectively.

GIS analysis concerning oil and gas activities related to Amazon and its cultural and biological aspects is presented in table n. 2 and spatially represented in figure 5 and 6.

As it can be seen in table n. 2, the 8% of the analyzed Amazon area is subjected to oil and gas interests and activities, considering the total covered area by blocks. This aspect vary between the different countries because, while in Colombia and Bolivia blocks occupy more than 30% of their Amazon area, Brazil, that has the 81% of whole considered Amazon, is interested for only 1.70%. This values only refer to the blocks extension in the study area, but it is also necessary to take into account the impact caused by seismic surveys and the presence of pipelines and wells. In the Amazon region examined there are 2170 hydrocarbon wells, which 757 of them are located in Bolivia, 788 in Colombia and 625 in Brazil. However, by comparing the amount of wells in the Amazon area of each country to the amount of wells in every country, it is evident that Bolivia presents a very high number (31.53%) compared to Colombia and Brazil, where most of the wells are located outside the area taken into consideration.

For what concerns the areas occupied by different kind of blocks (Figure 2), it is possible to observe that promotion blocks occupy the largest surface of Amazon: 262702.04 km^2, corresponding to 5.21% of the total area occupied by the different blocks.

It can be noticed that the exploration activities are so important in the Amazon territory in each country for a total of 139458.52 km^2, while extractive activities, which correspond to the production blocks, occupy an area of 4492.55 km^2 (0.09% of the Amazon area of the three countries).

It can be noticed that seismic surveys are widely present in the Amazon territory of the three countries under consideration and the lines resulting from the investigation are extended for a total of 104097.85 km. In particular it's possible to observe that 7661,84 km of seismic lines intersect many protected areas; in particular, this can be observed in the territory of Bolivia, whose protected areas are intersected by 6512,36 km of seismic.

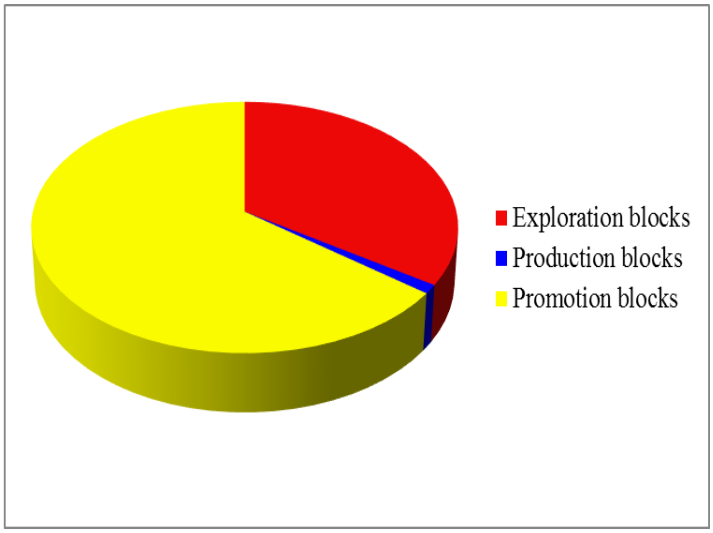

Fig. 2. Relationships between different kinds of hydrocarbons blocks for the study area.

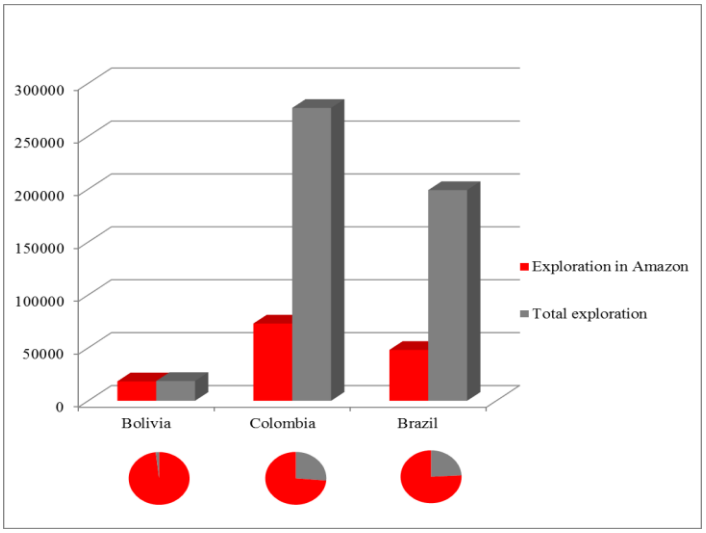

Fig. 3. For each country it is highlighted the relationships between the exploration blocks of the entire country and those of the respective Amazon region.

Total linear kilometers of pipelines in the Amazon region of the three countries are 4428.91. 38022.38 km^2 of protected areas are overlapped with oil and gas activities: there are differences among countries: Colombia 130.34 km^2, Brazil 336.08 km^2, in opposition Bolivia have the largest area: 37555.96 km^2 of protected areas under oil operations. Bolivia allows the exploration and exploitation of gas and oil within protected areas.

The overlap between indigenous territories and oil activities (figure 4) amounts to 80599.71 km^2; there is no overlap in Brazil, while in Colombia and Bolivia, it reaches respectively 48998.58 and 31601.13 km^2.

The spatial aspect of these considerations is clearly visible in figure 5 and 6. Map represented in figure 5 shows the presence and relationships of linear hydrocarbon features (seismic and pipelines) with protected and indigenous areas, while map in figure 6 the polygonal (blocks divided into promotion, exploration and production type) and point (wells) one.

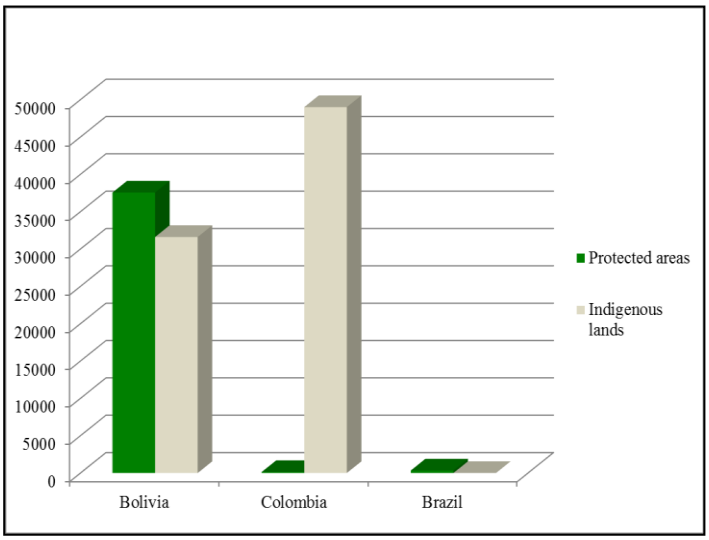

Fig 4. For each country have highlighted the overlap of oil activity with protected areas and indigenous lands**.**

Table 2. GIS analysis of oil activities in Amazon and relationships with protected and indigenous areas. (a) The Brazil seismic is underestimated, because not all seismic lines were available as spatial data. (b) Most part of overlap is between borders areas.

Features	Bolivia Amazon			Brazil Amazon			Colombia Amazon			Total Study Area	
	Total	% on Amazon	% of feature in Amazon on feature in Country	Total	Relative Frequency	% of feature in Amazon on feature in Country	Total	Relative Frequency	% of feature in Amazon on feature in Country	Total	% on study area
Wells (num.)	757		31.52%	625		2.95%	788		3.89%	2170	
Exploration blocks (km^2)	18373.15	4.01%	98.22%	48088.04	1.18%	24.15%	72997.33	14.43%	26.37%	139458.52	2.77%
Production blocks (km^2)	1165.70	0.25%	15.30%	1054.29	0.03%	13.92%	2272.56	0.45%	10.31%	4492.55	0.09%
Promotion blocks (km^2)	137319.15	30.01%	51.85%	19959.97	0.49%	23.87%	105422.92	20.84%	35.22%	262702.04	5.21%
Total blocks (km^2)	156858.00	34.28%	53.88%	62102.42	1.70%	23.80%	180692.82	35.72%	30.21%	399653.24	7.93%
Seismic (km)	24713.00		28.92%	45385.36		36.16%	33999.49		8.47%	104097.85	
Seismic in protected areas (km)	6512.36		35.16%	524.03(a)		95.20%	625.45		5.94%	7661.84	
Pipelines (km)	683.71		11.53%	3420.80		28.40%	324.40		2.36%	4428.91	
Protected areas within blocks (km^2)	37555.96	24.91%	82.35%	336.08	0.02%	0.01%	130.34 (b)	0.13%	1.40%	38022.38	0.75%
Indigenous lands within blocks(km^2)	31601.13	36.40%	47.70%	0	0%	0%	48998.58	18.83%	60.62%	80599.71	1.60%

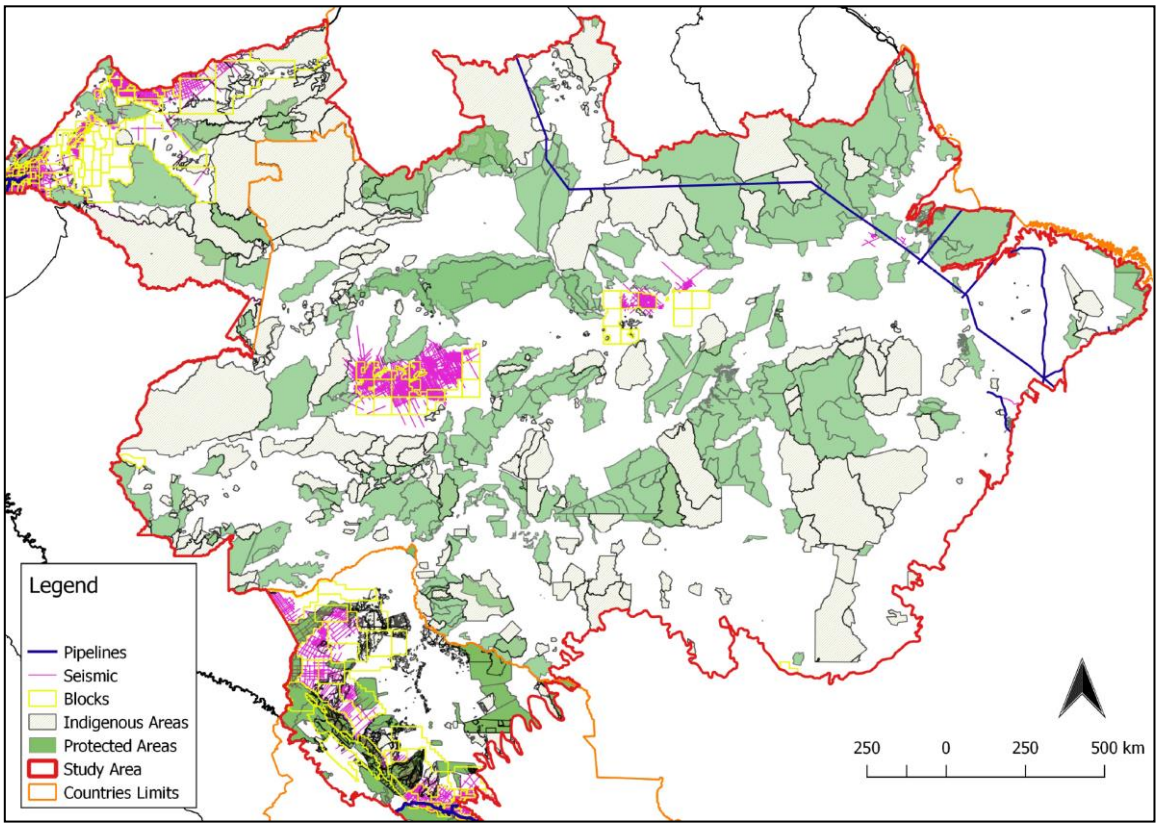

Fig. 5. The map shows the state of hydrocarbon blocks, pipelines, seismic, protected areas and indigenous lands within the area of study.

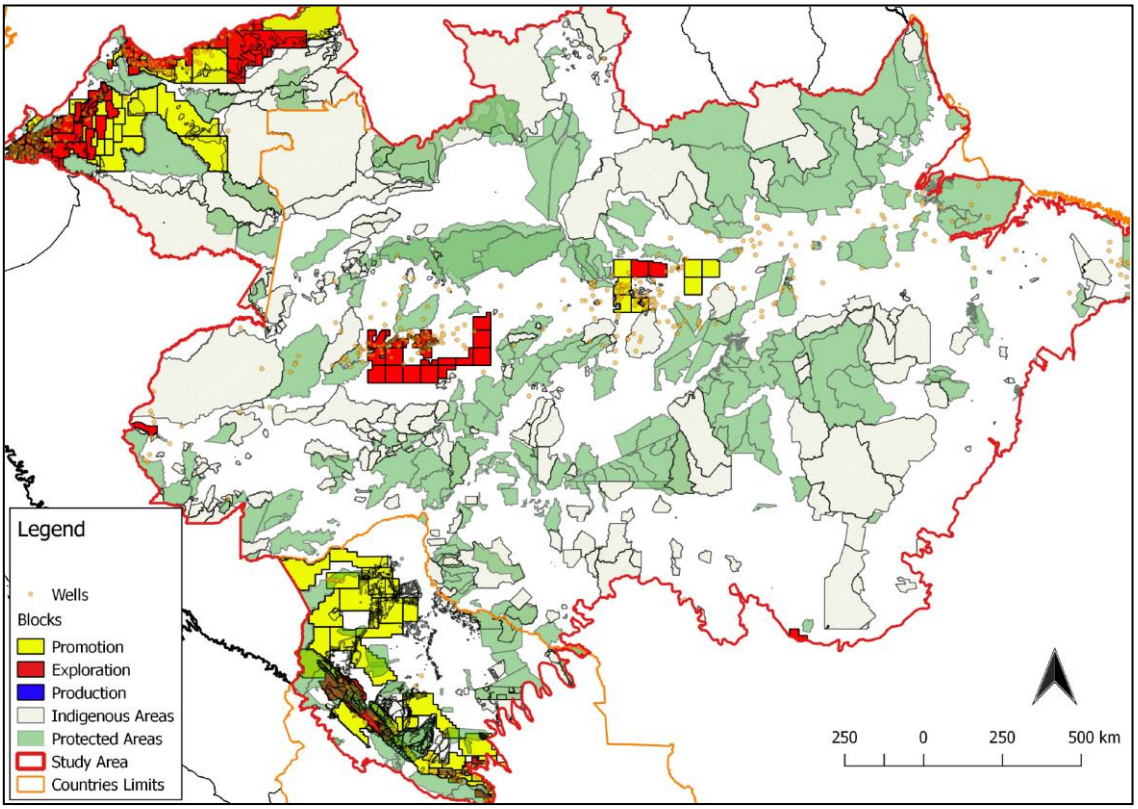

Fig. 6. The map shows the overlap of hydrocarbon blocks divided in wells, protected areas and indigenous lands within the study area.

CONCLUSIONS

In this study we presented a new research project, the "Yasunization of earth: a world atlas of unburnable Carbon. Cartography and GIS tools to implement inclusive spatial explicit policies for climate and biodiversity protection and human rights enforcement (Yasunization of earth)", which aims to make spatially explicit where hydrocarbon should be untapped, using criteria based on impacts and relationships with high biological, cultural and ecosystem services providing areas. This is particularly urgent in the Amazon, a globally recognized key "ecoregion" increasingly subjected to pressures and projects related to the extraction of non-renewable resources, such as oil and gas. This analysis allow either a regional outlook and a country comparison. In Bolivia and Colombia Amazon areas more than 34% of their territory is covered by oil and gas blocks. Overlays between oil and gas activities (protected and indigenous areas within blocks and seismic in blocks) is another relevant aspect highlighting interactions and trade-offs between the resources exploitation, natural conservation and human rights. Although there are good examples in Brazil and Colombia of regulations prohibiting the development of hydrocarbon activities in certain protected areas (but not for indigenous areas), for Bolivia the situation is different because these activities are authorized by law. From the GIS analysis carried out in the study area, it has emerged the necessity and urgency of scientific investigations in order to define policies and criteria for a more sustainable development of extractive activities.

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SPATIAL DATASET SOURCES

ArcGis Online

Agencia nacional de Hidrocarburos (ANH)

Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP)

DivaGIS

Fundação Nacional do Índio (FUNAI)

Instituto Nacional de Reforma Agraria – INRA)

Ministèiro do Meio Ambiente (Brazil)

Office for the Coordination of Humanitarian Affairs (OCHA)

Protected Planet: The World Database on Protected Areas (WDPA)

WWF

Yacimientos Petrolíferos Fiscales Bolivianos (YPFB)