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IMPACT ANALYSIS OF SHALE GAS EXPLOITATION

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Abstract: Shale gas is a type of unconventional gas exploited by the fracking process that has been widely diffused in the United States of America. This example has also led several countries to equate the possibility of exploring gas in non-conventional reservoirs, following the release of the world ranking of technically recoverable reserves in 2013 from the U.S. Energy Information Administration. Fracking is the combination of two complex processes: hydraulic fracturing and horizontal drilling and it can raise important environmental and social concerns. Currently, the methodologies used to assess impacts, when choosing a new energy source, tend to deal independently with the variables that make up these impacts. However, these variables are interrelated and will interact with each other. A systemic analysis is then required to deal with these complex relations. The purpose of this paper is to demonstrate the use of a system dynamics tool to assess these impacts and by this contribute to making better energy-related choices and to support the achievement of sustainable development goals.

1 Introduction

The topic of shale gas has been the focus of several studies in different countries addressing issues such as its availability, development and potential, the politics frame its exploitation and its impacts or public acceptance. The interest on the topic is well justified, given the increasing rate of production in countries such as United States (U.S.), Canada or China [1,2]. In 2013, the U.S. Energy Information Administration [3] released a report, which presented a world ranking of countries with technically recoverable shale gas reserves, i.e. reserves of gas that could be produced with current technology, regardless of the price of natural gas and its costs of production. In this context, countries with the largest reserves would be China, followed by Argentina, Algeria, U.S., Canada, Mexico, Australia, South Africa, Russia and Brazil as tenth in this ranking.

The fracking or hydraulic fracturing technology associated with horizontal drilling has been widely diffused in the U.S. in the exploration of shale gas, supported by public policies, including significant government grants in a learning by doing process. Supposedly, because of this process, great technological advance has taken place, allowing large-scale production, in the early 2000s, transforming the industry of this sector in the U.S. [4]. Despite this unbridled race by the advance in the exploitation of shale gas, the information provided by the U.S. Environmental Protection Agency [5] shows concern with the related human and environmental health, potential effects on the quality and quantity of drinking water, the use of waste water generated by fracking and competition between water-producing activities, especially in areas of the country with low or irregular water availability [6].

The conditions of shale gas exploitation must be closely observed, since several critical factors can directly influence the economic viability of this activity, such as geographic and geological characteristics, protected areas, indigenous and traditional community lands, agribusiness activities, as well as environmental legislation. Particularly remarkable it is the issue of water stress as the lack of water availability can curtail shale development in many places and the final destination of the return water from fracking would be a sensitive point in this process [7,8]. The projection and planning for the use of water resources along with the monitoring of the characteristics and properties of the water produced could then determine its strict use and destination [9,10].

Other concerns surround this exploration, there are many doubts about the economic effects on employment and income, several reports sponsored by the gas industry may have overestimated these effects [11]. In addition to economic and environmental issues, there is great concern about the approval of local society for the shale gas exploitation. Companies realized the need to increase space for further discussion by academics, the public, regulators, and local decision-makers to build more appropriate regulations [12,13].

There is an expectation of the emergence of large shale gas production industries beyond the US territory. Due to this fact, the International Energy Agency (IEA) [14] drew up the so-called Golden Rules for the Golden Age of Gas, which was a report specially developed with shale gas as the focus. Among other relevant information, the IEA [14] stressed the importance of full transparency of measurements and monitoring of environmental impacts, as well as a commitment to local communities, highlighting society's acceptance of this exploration technology. The U.S. Department of Energy (DOE) showed that the use of the high technology of an information system, together with the management of projects, could minimize the undesirable effects of this activity [15]. A careful selection of sites to drill and more effectively identify the most productive areas, can considerably reduce exploration time and provide a lower risk of seismic or fluid displacement between geological layers [16]. The agency values the application of high standards in design, construction and integrity testing of the well, with particular concerns for the risk of leakage in aquifers.

The possibility of using shale gas is already being considered for Brazil on the energy plans for 2050 but, as the Environmental Thematic Committee (CTMA) highlighted, the extension of these plans still depends on further studies to be elaborated [17,18]. Preliminary evaluations of the National Agency for Petroleum, Natural Gas and Biofuels (ANP), coupled with information from the U.S. Energy Information Administration, created the conditions for the launch in 2013 of the Twelfth Round of Bids for Exploration, Development and Production of Oil and Natural Gas in Brazil. The bid offered 240 exploratory blocks in an auction process [3,19]. These regions present a high potential for the generation of electricity with the production from this onshore gas. The chart presents these regions on the overall Brazilian map (Figure 1).

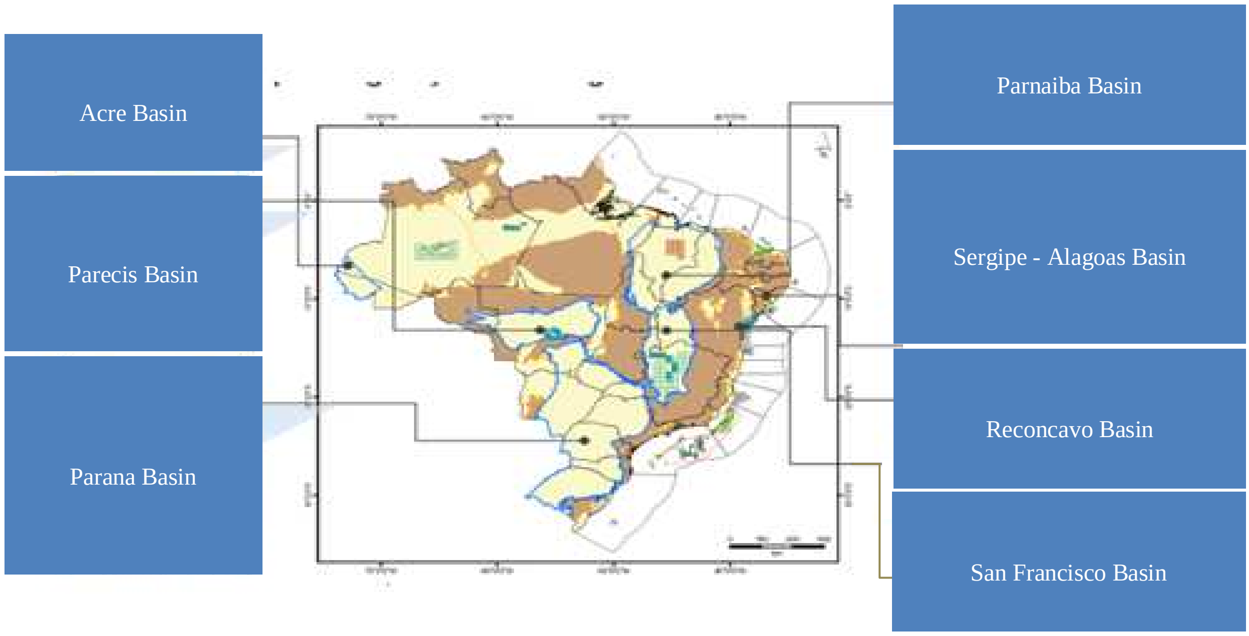

Figure 1 Basins of 12th bidding to oil, conventional and unconventional gas exploitation. Source: ANP 2013[19]

The exploitation of shale gas can be complex and requires a multidisciplinary analysis of the project integrating several dimensions, namely: environmental, economic, technological, legal, and social. If these dimensions would be analysed independently significant impacts should be expected. However, a systemic and integrated perspective for these dimensions should be envisaged to assess their interrelations and potential positive or negative synergetic effects [20]. This is precisely the focus of this study. Firstly, a methodology based on system dynamics for impact assessment of shale gas as an energy source is proposed. Secondly, the methodology will be used for the analysis of the interactions involving the potential impacts of shale gas exploitation by fracking based on the Brazilian case.

2 Methodology

J. Forrester created System Dynamics (SD) in the 1950s at the Massachusetts Institute of Technology on the assumption that the behaviour of a system is generated by the structure of that system. By understanding a system, as being a set of interconnected elements and interacting with each other, to form an organized integer, the dynamics of systems would assess how the parts of that system are related, determining the behaviour of the same, example, a manufacturing plant, an animal cell or an oil base.

In the 1960s, SD moved away from manual simulation and evolved into computational modelling, where Forrester published the classic Industrial Dynamics book [21]. A method of applying SD would be to use modelling as a tool to simulate the behaviour of cause and effect relationships between parts of this system over time [22].

For this research, a critical analysis of the literature was firstly conducted to provide the required context and scientific background for the research. The reviewed literature addressed the topic of shale gas and its impacts at world scale and for the particular case of Brazil. Figure 2 shows the methodological approach for this research.

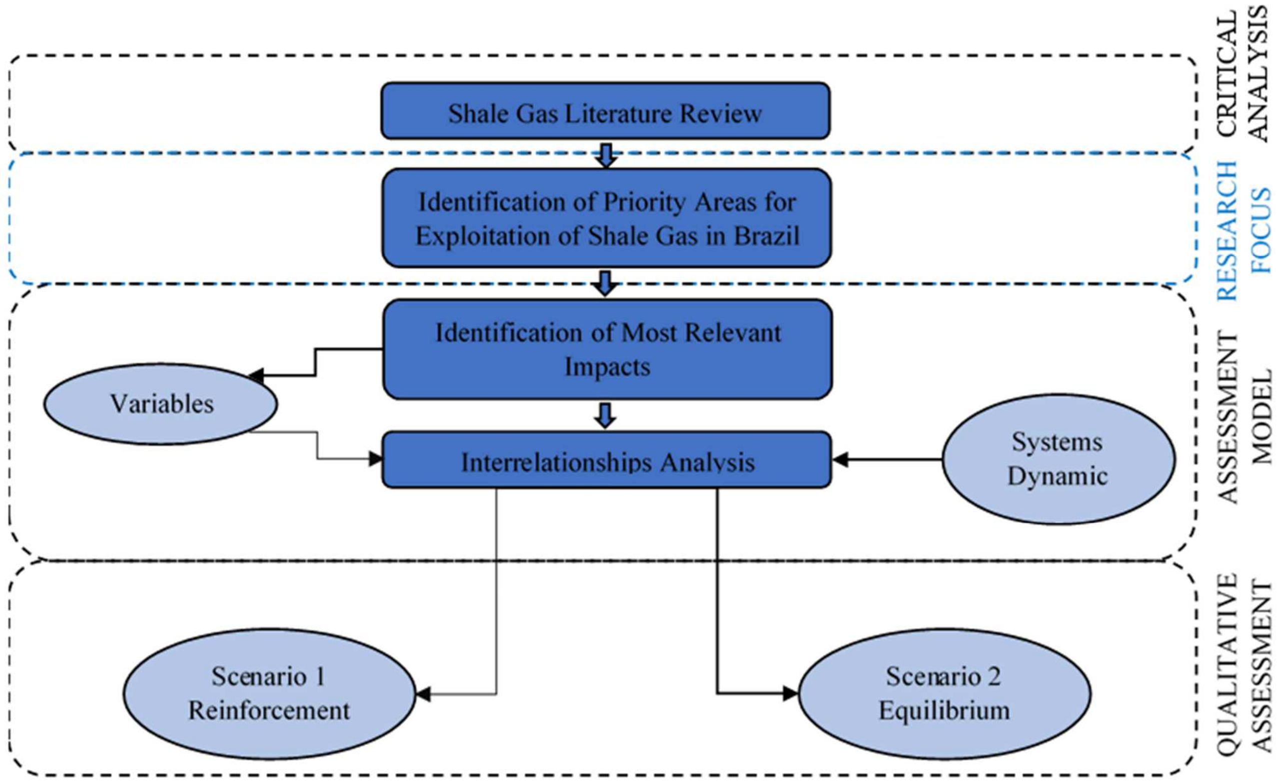

Figure 2 Methodological approach

This literature review allowed us to proceed for the following steps, namely the identification of the priority areas for the exploitation of shale gas in Brazil and the expected impacts of this activity [19]. These impacts were then translated on a list of variables, which were relevant and were considered on the analysis of interrelationships (Tables 1 to 5). The analysis of interrelationships is a key step of the process as it recognizes that the variables should not be handled independently but rather by recognizing their influences, either through positive or negative feedback. As such, the use of system dynamics modelling was considered to be the most adequate approach to analyse the potential impacts of shale gas exploitation. For simplicity and given the information scarcity, a soft or qualitative SD approach was used as the main tool was to assess which variables are affected by each other with no attempt of quantifying the extent of the impacts or flows.

As such, the analysis addressed two mains scenarios:

- Scenario 1 or reinforcement feedback, for which an increase one variable would lead to an increase in related variables and would end up leading to an increase in the initial variable. As such, each variable reinforces the direction of action of the previous variable, either increasing or decreasing output, in what can configure a snowball effect according to the SD Theory.
- Scenario 2 or equilibrium feedback for which an increase one variable would lead to a reduction on a related variable and would end up leading to a reduction in the initial variable. As such, one of the variables reverses the direction of action of the previous variable, which shows cause and effect relationships in what would configure a balancing effect according to the SD Theory.

For the particular case under analysis, a soft modelling approach was used to allow the perception of any system based on the recognition of the cause and effect relationship between variables and feedback structures. The systemic model was developed in a specific software [23] that provides a graphical modelling interface using causal link diagrams.

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Table 1 Variables by economic dimension

Sequential	Variable	Source
1	Costs for society	[24,25]
2	Taxes and royalties	[26,27]
3	Cost-benefit ratio	[25,26,28]
4	Global price of other resources	[29,30]
5	Local development	[26,28]
6	Development / growth of the country	[26,28]
7	Regional energy prices	[31,32]
8	Relative value	[27,29,30]
9	Shale energy supply	[27,33]
10	Shale gas international price	[31,34]
11	Energy demand	[27,33,35]
12	Investment in production	[24,30]
13	Production costs	[24,27,30]
14	Energy of shale	[24,36]
15	Activity gains	[24,27]

Table 2 Variables by technological dimension

Sequential	Variable	Source
16	Importation of technology	[37-39]
17	Importation of equipment	[37-39]
18	Specialized human capital	[28,27,39]
19	Patent registration	[38,39]

Table 3 Variables by environmental dimension

Sequential	Variable	Source
20	Mitigation and treatment costs	[24,25,28]
21	Risks of global contamination	
22	Risks of contamination of surface water	[16,24,33]
23	Risks of groundwater contamination	[16,24,33,40]
24	Production of greenhouse gas (GHG)	[24,33,39]
25	Risks of seismic events	[16,24,33]
26	Safe water availability	[16,28]
27	Water consumption	[16,28]
28	Conflict level by water	[16,39]

Table 4 Variables by social dimension

Sequential	Variable	Source
29	Disorganized displacement of population	[41,42]
30	Number of agreements with science and technology institutions (STI)	[20,39]
31	Number of researches	[38,39]
32	Benefits to society	[25,26]
33	Job and income	[26,38]

Table 5 Variables by legislative dimension

Sequential	Variable	Source
34	Political conflicts	[26,43]
35	Land-use zoning regulations	[41,43]
36	Water resources management	[24,28]
37	Legal conflicts	[26,36]
38	Concession for the shale gas exploration and production (E&P)	[24,27]
39	Regulations	[26,28] [35,44]

3 Results and discussion

From the literature review, the priority areas for shale gas were identified through the auction offered by the ANP, which offered 240 exploration blocks in Brazil, distributed in seven sedimentary basins. These blocks included 110 exploration blocks in New Frontier Basins, which are those whose geological knowledge or technological advancement have not reached the maturity or degree of complexity to reduce the high exploratory risk, and 130 exploratory blocks in Mature Basins, located in regions already under an advanced stage of exploitation, with well-developed infrastructure and specialized local manpower. These Mature Basins included 11 Brazilian states: Acre, Amazonas, São Paulo, Paraná, Mato Grosso, Maranhão, Bahia, Goias, Tocantins, Alagoas e Sergipe [19]. According to Brazilian Environmental Ministry (in Portuguese MMA - Ministério do Meio Ambiente) all the areas made available to shale gas exploitation are above aquifers [16]. Given that connection between the terrestrial surface and the catchment area of the gas is established through a conduction duct made of cement, the possibility of contamination through the duct cannot be excluded. Another possibility of contamination of these aquifers is the existence of natural faults and large scale fractures within or between the formations that may potentially allow flow paths outside the production zone [45,46].

Following the identification of the priority areas for shale gas exploration, the most relevant impacts were related to soil, earthquakes, overlapping with protected areas, water resources, the final flowback water and disposal of chemicals [47-49]. From the identification of these impacts, 39 variables were listed, spanning five dimensions: economic, legislative, technological, environmental, and social. These variables were selected from the scientific literature (Table 1 to Table 5) and distributed through soft modelling, elaborating a causal link diagram (Figure 3).

The model presented numerous formations of reinforcement feedbacks and equilibrium feedbacks, as expected by the systems dynamic's methodology. The analysis was limited to 16 of the most representative feedbacks, namely 6 of reinforcement feedbacks and 10 of equilibrium feedbacks to avoid redundancy. As detailed previously, scenario 1 consists of a set of reinforcement feedbacks called **R1, R2, R3, R4, R5,** and **R6** and scenario 2 includes equilibrium feedbacks called **E1, E2, E3, E4, E5, E6, E7, E8, E9,** and **E10.**

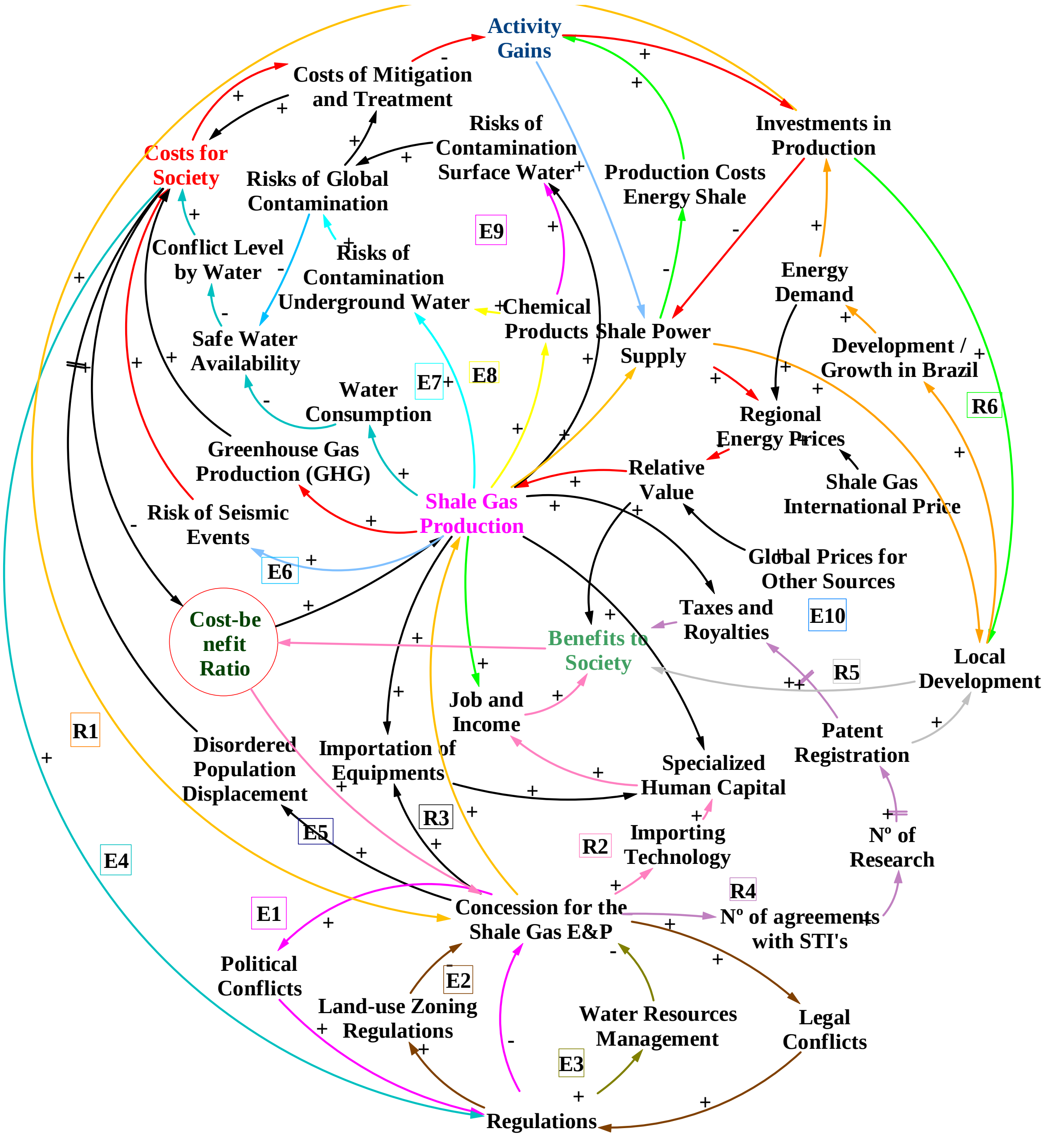

Figure 3 SD Soft Modelling

The combined analysis is represented in Figure 3, which described the interrelation between the set of variables of the model. For simplicity, feedbacks only loops R5 and E8 were chosen to illustrate the systemic thinking of this model and are highlighted in Figures 4 and Figure 5.

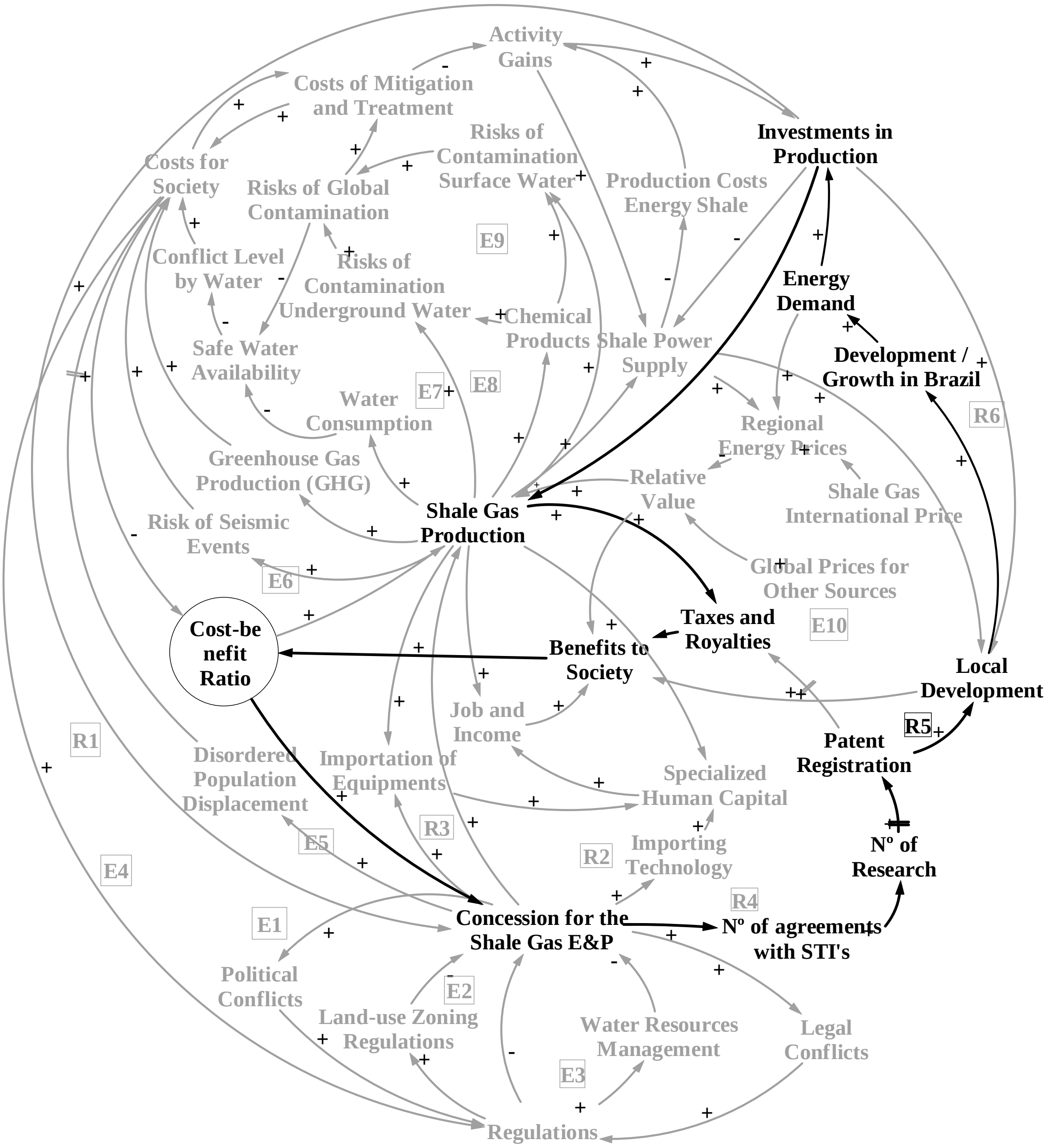

Figure 4 Reinforcement Feedback (R5)

In all loops as well as in **R5**, the analyse can start in any variable, because the feedback is a loop (Figure 4). The increase in the **production of shale gas** generates an increase in the payment of **taxes and royalties** related to this activity, increasing the economic **benefits for society** with the circulation of more currencies. This generates an increase in the **cost-benefit ratio**, giving arguments for the government to increase the number **concession for the shale gas E&P**. The increase in the number of concessions for the shale gas E&P can increment the **number of agreements with STIs** due to the need to increase the **number of researches** related to this new exploratory activity. This expansion in the number of searches may generate an increase in the **number of patents** registered, this growth can generate local development, consequently a **development / growth of Brazil**, which makes it possible to raise the **demand for shale energy**, justifying the intensification of **investments in producing shale gas** and leading to an increase on the initial variable **production of shale gas**.

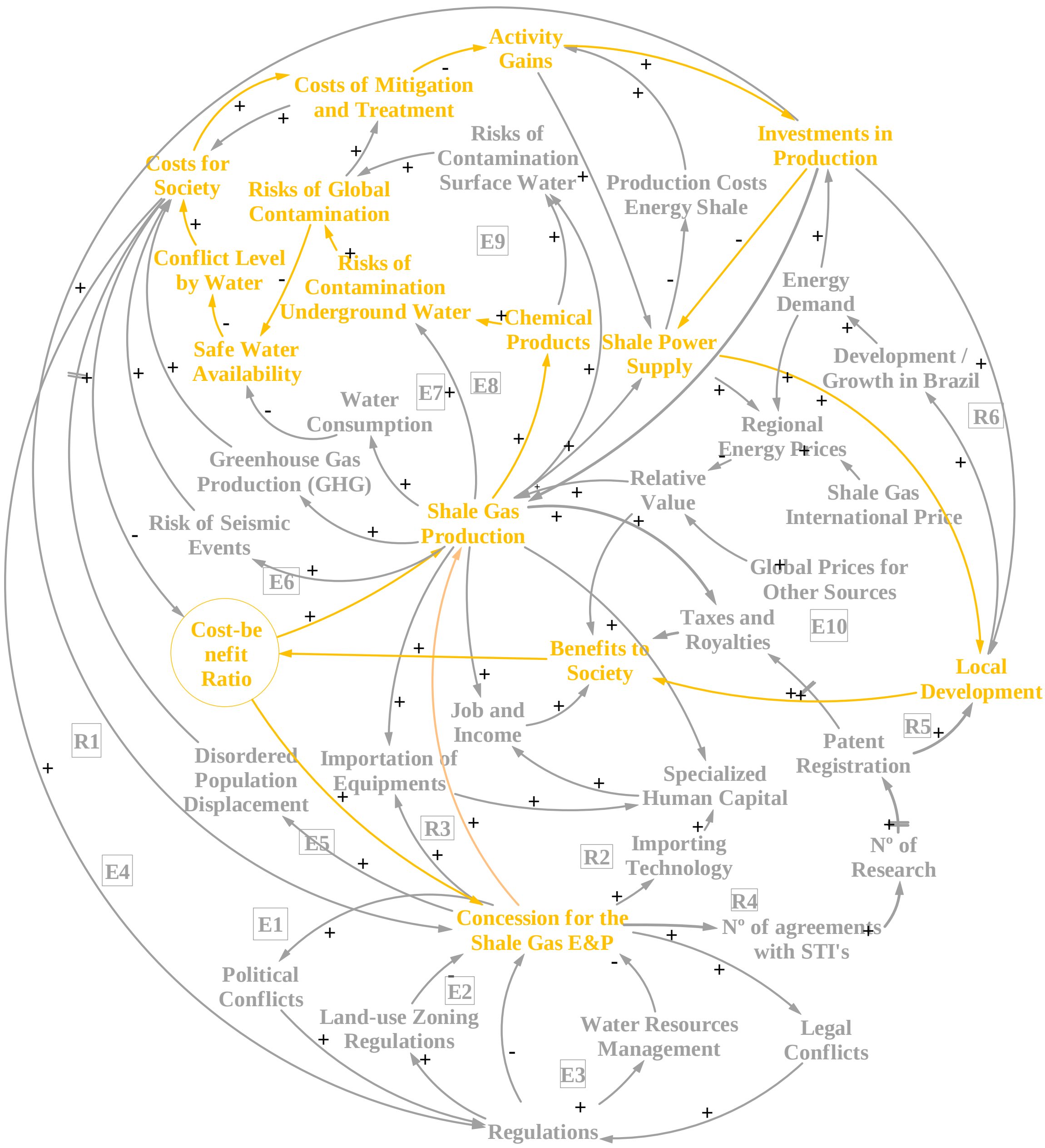

Figure 5 Equilibrium Feedback (E8)

As for the loop E8 and departing again from variable production of shale gas an increase would lead to an increase in the variable's chemicals. In the process of shale gas production, a large amount of chemicals is used in the shale flow. The increase in gas production will result on the need to increase the amount of chemical products used in this shale gas production (Figure 5). Due to the characteristic of this productive process, the increase in this quantity of chemical products also increases the probability of the risks of groundwater contamination. Because of the higher risk of groundwater contamination, a reduction of safe water availability may occur which can intensify the conflict level by water. The conflicts over water may come from other conflicting productive activities of industry, agribusiness, or human and animal consumption. The intensification of this conflict raises the costs for society in the alternative search of new sources of water resources or the rationing of their use. Costs can be intensified due to the heavy use of chemicals in farming. Due to the manipulation of these chemical products, the increasing use of trucks and the arrangement for the flowback, the probability of accidents also increases driving also an increase in mitigation and treatment costs. This would lead to a reduction in the related activity gains and discourage investment in production that would reduce shale energy supply. Reducing shale energy supply would inhibit local development, thereby reducing benefits for society and cost-benefit ratio. As the cost-benefit ratio would be reduced the economic arguments would not be strong enough to justify more concessions. By this factor, the concession for the shale gas E&P would be reduced and consequently, there would be a reduction of shale gas production.

4 Conclusions

Large investments are being considered for the exploitation of shale gas to ensure access to non-conventional sources of energy in different countries. Although U.S. emerges as the main leader for shale gas production, other countries are also analysing the possibility of investing in the sector. However, the reputation of these exploitation activities is highly negative given its foreseen environmental and social impacts. These impacts are discussed globally by government agencies, the scientific community and the civil community, and have already resulted in suspension or a moratorium on this type of activity in several countries.

This study proposed a system dynamic model to analyse the impacts of shale gas exploitation. This approach allowed us to characterize the complexity of activity by presenting the expected impacts as interrelated variables in close loops. From this causal link diagram, it was possible to visualize positive and negative scenarios derived from the possible exploitation of shale gas by fracking. As such, the results can contribute to better decision-making processes in what concerns the evaluation of shale gas as a new source in the energy matrix in different countries, with particular focuses on Brazil.

An independent analysis of all variables cannot clearly show how the economic gains from shale gas exploitation could be offset by the short-, medium- and long-term environmental risks of such exploration. As such, the use of systemic thinking as a management tool can be of great value when dealing with this complex system for the introduction of a new energy source in the country.

For the particular case of Brazil, the regulation can still be classified as fragile and the widespread possibility of forming contaminated groundwater corridors is a matter of concern. Guarani Aquifer, which is the second-largest transboundary aquifer in the world and ensures water supply to four Latin American countries (Uruguay, Paraguay, Brazil, and Argentina), could be strongly affected but shale gas exploitation activities. This water concern underlines the need to properly integrated environmental, social and economic dimensions in the impact assessment.

In summary, the study allowed us to propose and demonstrate a methodology based on soft modelling by system dynamics for impact assessment of shale gas as a new source of energy. Moreover, it opened also important routes for further research, namely the need to move from the soft to the hard system dynamics approach. The hard modelling could be used to better assess the relative importance and delays associated with different loops. This analysis should also contribute to recognize and properly acknowledge the relevance of the impacts under a national and local perspective which should reflect the socio-demographic and economic characteristics of the affected regions.

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