SUSTAINABILITY OF THE ETHANOL EXPANSION IN BRAZIL FROM A WATER-ENERGY-LAND PERSPECTIVE

Christianne Maroun

Tese de Doutorado apresentada ao Programa de Planejamento Energético, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Planejamento Energético.

Orientador: Roberto Schaeffer

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Resumo da Tese apresentada à COPPE/UFRJ como parte dos requisitos necessários para a obtenção do grau de Doutor em Ciências (D.Sc.)

SUSTENTABILIDADE DA EXPANSÃO DO ETANOL NO BRASIL SOB O PONTO DE VISTA DE ÁGUA, ENERGIA E TERRA

Christianne Maroun

Março/2014

Orientador: Roberto Schaeffer

Programa: Planejamento Energético

Devido à perspectiva de aumento da produção mundial de biocombustíveis, a crítica relacionada com as questões de sustentabilidade dessa expansão também cresceu tornando-se uma preocupação mundial. Os modelos atuais nos quais se baseiam o desenvolvimento e a implementação de políticas de água, energia e terra em geral têm foco apenas em cada um dos recursos isoladamente, ignorando as interconexões com outros recursos, podendo comprometer a expansão sustentável de biocombustíveis, uma vez que os recursos água, energia e terra (WEL) são altamente acoplados uns aos outros, por meio de relações de oferta e demanda. A fim de testar o quão desconectadas são as políticas de energia, de recursos hídricos, e de uso da terra no Brasil foi conduzida uma análise integrada baseada nas interfaces entre as políticas setoriais para cada um dos recursos do WEL. O estudo de caso da produção de etanol no Estado de São Paulo foi selecionado para testar, através de políticas específicas brasileiras, se as questões relacionadas com água, energia e terra são integradas. A expansão da produção de etanol no Brasil prevista no Plano Decenal de Energia - PDE 2013-2022 (Política Energética) foi confrontada com o Plano Estadual de Recursos Hídricos de São Paulo (política de recursos hídricos) e com o Zoneamento Agroecológico (ZAE) da Cana (política de uso do solo).

Os resultados mostram que existem restrições de recursos hídricos nas áreas de expansão da cana em São Paulo não considerados no ZAE Cana e no PDE 2013-2022. O ZAE Cana e o PDE não consideram a dinâmica do preço da terra, e o Plano de Recursos Hídricos de São Paulo não apresenta quaisquer atividades de planejamento para a expansão do etanol considerado no PDE. Uma política de biocombustíveis integrando os três recursos e suas respectivas políticas seria importante para o desenvolvimento sustentável dos biocombustíveis no Brasil.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

SUSTAINABILITY OF THE ETHANOL EXPANSION IN BRAZIL FROM A WATER-ENERGY-LAND PERSPECTIVE

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March/2014

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Department: Energy Planning

Due to the plan to increase the worldwide production of biofuels, sustainability issues related to this expansion has also grown and became a global concern. The current models on which the water, energy and land policies´ development and implementation are based only on each resource individually, ignoring connections with other resources, which may jeopardize the sustainable expansion of biofuels, since the water, energy and land resources (WEL) are highly linked to each other by means of supply and demand relationships.

In order to test how disconnected the energy, water resources and land use policies are in Brazil, an integrated assessment was conducted based on the interface between the sector policies for each WEL resource. The case study of ethanol production in São Paulo State was selected to test, through specific Brazilian policies, whether the issues related to water, energy and land are integrated. The ethanol production expansion in Brazil from the Ten-Year Energy Plan - PDE 2013-2022 (Energy Policy) was compared to the Water Resources Plan of São Paulo State (water resources policy) and also compared to the Agroecological Zoning of Sugarcane (ZAE Cana) (land use policy).

The results show that there are restrictions on water resources within the sugarcane expansion areas in São Paulo, which are not considered in the ZAE Cana or in the PDE 2013-2022. The ZAE Cana and the PDE do not consider land price dynamics, and the Water Resources Plan of São Paulo does not contain any planning activities to expand the ethanol considered in the PDE. A biofuel policy integrating all three resources and their respective policies would be important to the sustainable development of biofuels in Brazil.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro-Ecological Zones
ANA	National Water Agency
ANP	National Agency for Petroleum, Natural Gas and Biofuels
AR	Administrative Region
AY	Agronomic Year
BLUM	Brazilian Land Use Model
CEPEA	Center for Advanced Studies on Applied Economics
CH_4	Methane
CLEW	Climate, Land, Energy and Water
CLEWS	Climate, Land, Energy and Water System
CO_2	Carbon Dioxide
CONAB	National Supply Company
CTC	Center for Sugarcane Technology
DAEE	Department of Water and Electric Power of São Paulo
DLUC	Direct Land Use Change
EIA	Environmental Impact Assessment
EPE	Brazilian Energy Research Company
ERD	European Report on Development
FAO	Food and Agriculture Organization of the United Nations
GEASA	Management of Survey and Assessment Crops
GHG	Greenhouse Gases
GMC	General Circulation Models
GWP	Global Warming Potential
HR	Hydrographic Region
IAEA	International Atomic Energy Agency
IBGE	Brazilian Institute of Geography and Statistics
ICSU	International Council of Science
IEA (1)	International Energy Agency
IEA (2)	Institute of Applied Economy of São Paulo
IIASA	International Institute for Applied Systems Analysis
ILUC	Indirect Land Use Change
INPE	National Institute for Space Research
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LEAP	Long-range Energy Alternatives Planning

LUC	Land Use Change
MAPA	Ministry of Agriculture and Food Supply
MESSAGE	Model of Energy Supply Systems and their General Environmental Impacts
N_2O	Nitrous Oxide
NWRC	National Water Resources Council
NWRMS	National Water Resources Management System
NWRP	National Water Resources Policy
NY	New York
OECD	Organization for Economic Co-operation and Development
PDE	Ten Year Energy Plan
WRP SP	São Paulo Water Resources Plan
PNPB	National Program for Production and Use of Biodiesel
PODIUM	Global Policy Dialogue Model
R&D	Research and Development
RBC	River Basin Committees
RBP	River Basin Plans
SCOPE	Scientific Committee on Problems of the Environment
SEI	Stockholm Environment Institute
SINGREH	National System for Water Resources Management
SMA	Municipal Administration Secretary
SUINF	Superintendent of Agribusiness Information
TRS	Total Recoverable Sugar
UGRHI	Water Resources Unity Management
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICA	Sugarcane Industry Association
USA	United States of America
WA	Water Agency
WEAP	Water Evaluation and Planning system
WEL	Water, Energy and Land
WRIS	Water Resources Information System
ZAE Cana	Agroecological Zoning of Sugarcane

1 Introduction

1.1 Context

Concerns about climate change, rising world fuel prices and the growing demand for energy are the key factors driving the interest in increasing renewable energy sources. Although within a global context, fossil fuel generation still dominates the world energy market (Figure 1), the uncertainty in future supply, potentially unsustainable patterns of energy consumption, and the costs of expanding reserves of fossil fuels have led policymakers around the world to seek alternatives from other renewable resources, such as biofuels (MSANGI *et al.*, 2007).

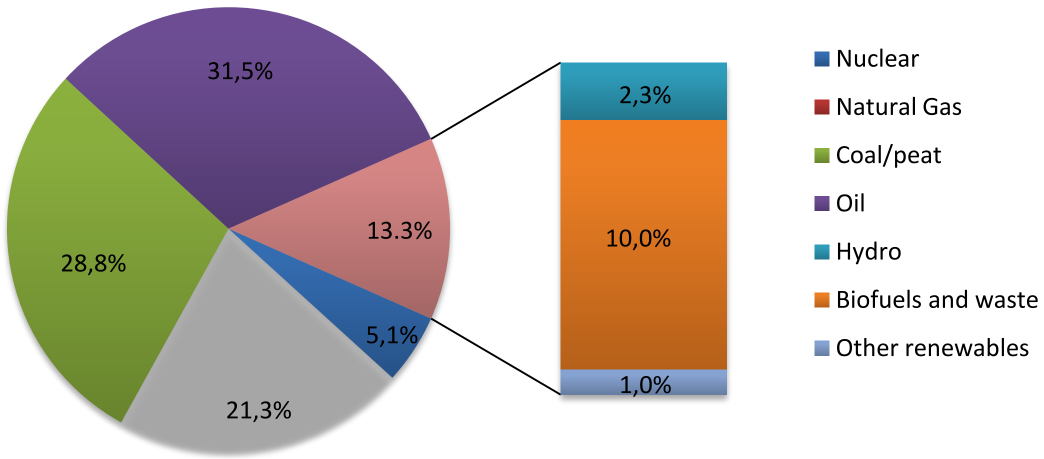

Figure 1 – Fuel shares in global total primary energy supply
Source: Author's development based on IEA (1), 2013

Moreover, the steady increase of gasoline prices over time (Figure 2) and the relatively small share of transport fuel currently being provided by biofuels in the world have prompted global leaders to undertake several initiatives aimed at increasing the proportion of biofuel use in transport (DIAZ-CHAVEZ, 2011).

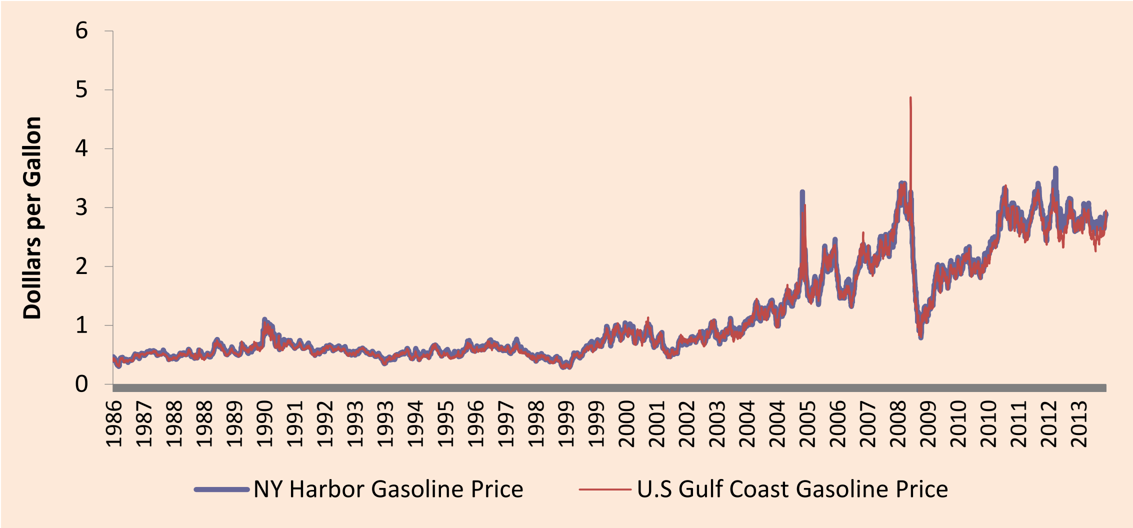

Figure 2 – Evolution of NY Harbor and US Gulf Coast gasoline prices from 1986 to 2014.
Source: Prepared by the author based on EIA (1), 2014

In 2012, ethanol produced from sugarcane, corn and other cereals, and biodiesel from oilseed crops represented only approximately 2.4% of the fuel consumed by the transport sector. Nevertheless, according to the International Energy Agency (IEA (1)) Alternative Policy Scenario, biofuel production could reach nearly 7% of the forecasted demand for road transport fuel in 2030 (IEA (1), 2012). In this regard, the US and Brazil lead the rest of the world in biofuel consumption as shown in Figure 3 (top-ten biofuels consumers in 2011).

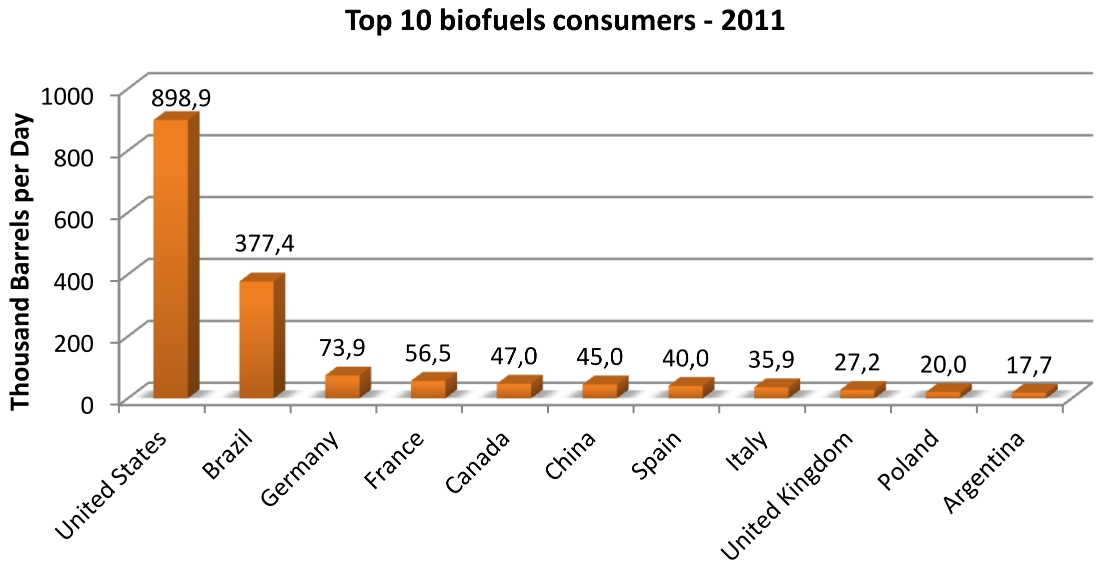

Figure 3 – Top 10 biofuels consumers in 2011.
Source: Prepared by the author based on EIA, 2014

Taking into account that the transport sector is responsible for the greater consumption of oil in the world (Figure 4), it is natural that the transportation sector seeks an alternative energy supply from renewable sources.

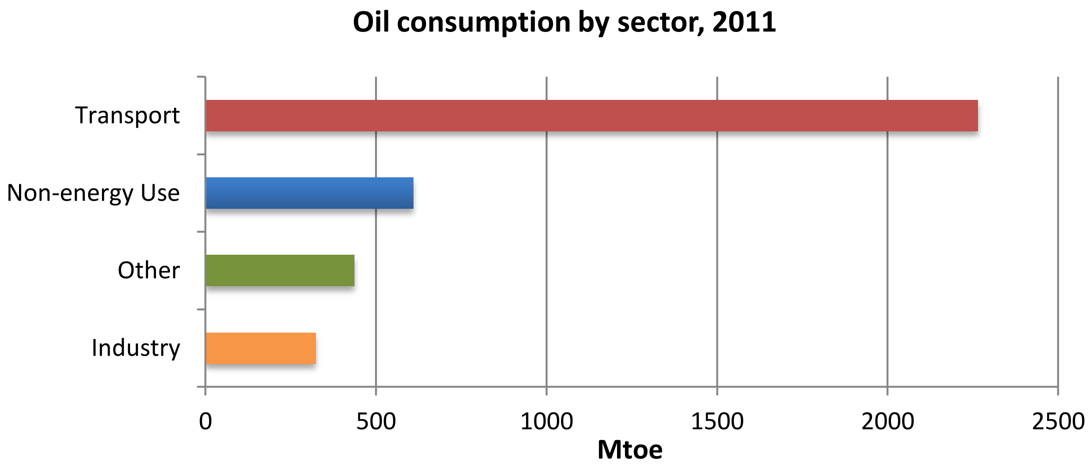

Figure 4 – Total oil consumption by sector in 2011.
Source: Prepared by the author based on IEA (1), 2013

In addition to alleviating the reliance of energy-driven economies on limited fossil fuel sources, biofuels are considered to be a significant contributor towards the economic development of rural areas, and a means of reducing poverty by creating jobs and thus income (MSANGI *et al.*, 2007). According to Goldemberg *et al.* (2008), biomass and biofuel use contribute to rural development and can serve as an important tool for market regulation.

Indeed, the use of biofuels may have many social aspects that can help developing countries grow in a more sustainable way. Thus, biofuels are seen as a promising renewable energy resource, and their potential environmental and economic benefits are becoming more apparent as technological improvements emerge.

Global bioethanol production is mainly concentrated in Brazil and in the United States. Brazil was the main ethanol producer for a long time, but recently United States´ production overcame Brazil's. North American ethanol, however, is produced mainly from corn, with lower biofuel productivity, higher costs of production, and uses more energy to produce the same volume of sugarcane-based biofuel. For instance, the average ethanol production in the United States is 3,200 l/ha.year, while in Brazil this figure is more than twice higher (6,800 l/ha.year) (LA ROVERE *et al.*, 2011).

Biodiesel production is geographically concentrated in the European Union, with Germany and France leading the production. According to the OECD-FAO Agricultural Outlook 2010-2020, the European Union is expected to continue to be by far the major producer and consumer of biodiesel in the world (OECD-FAO, 2011). Figure 5 and Figure 6 show the expected evolution of the world ethanol and biodiesel market until 2020.

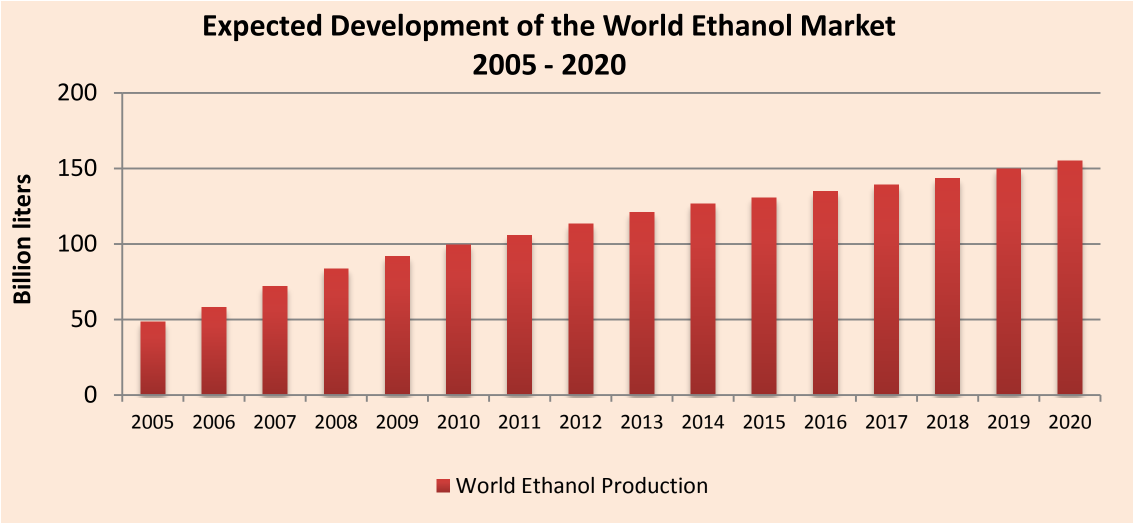

Figure 5 – Expected development of the world ethanol market
Source: Prepared by the author based on OECD/FAO, 2011

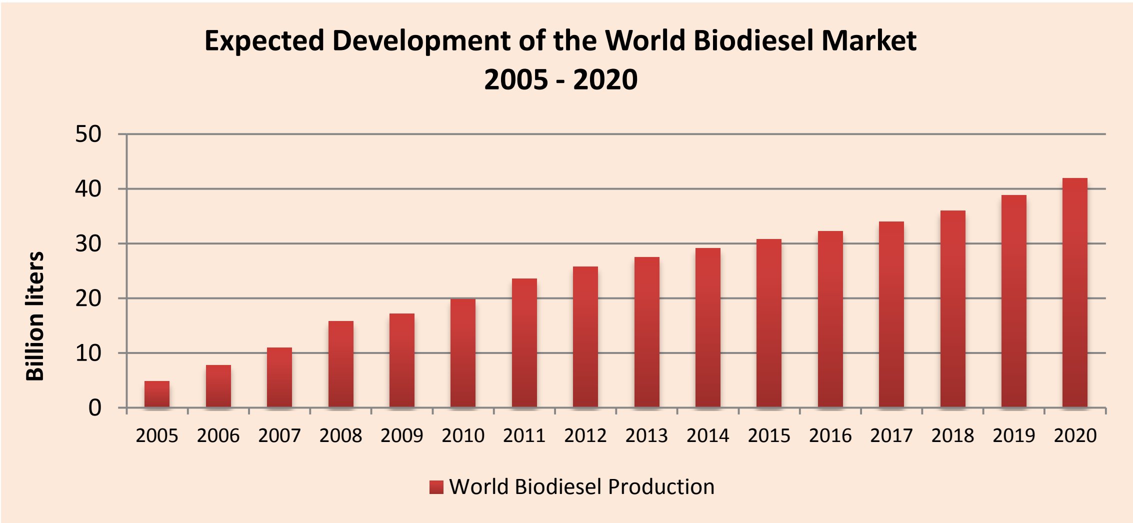

Figure 6 – Expected development of the world biodiesel market
Source: Based on OECD/FAO, 2011

Regarding the increase in the world production of biofuels (Figures 5 and 6), criticism related to sustainability issues has also grown and became a global concern. The impact of biofuels on the environment through deforestation, spread of monocultures, loss of biodiversity and possible higher greenhouse gases (GHG) emissions under uncontrolled land-use change, as well as social and economic issues, has been under evaluation by different researchers in recent years. The issue is intensified with the debate over food versus fuel and the threat that bioenergy demand is likely to affect nutrition through a number of pathways (TIRADO *et al.*, 2010; RATHMANN *et al.*, 2010). The potential of biofuels to contribute to a shift into more sustainable energy systems became contested, and scientists started to question the environmental superiority of biofuels (FAO, 2013a).

Regarding the controversy of different perspectives in the biofuel's sustainability assessment and the important role of Brazil in the global biofuels market, many different prominent authors studied the environmental, social and economic issues related to the Brazilian biofuels production (COELHO *et al.*, 2006; GARCEZ and VIANNA, 2009; GOLDEMBERG *et al.*, 2008; GOLDEMBERG and GUARDABASSI, 2009; HALL *et al.*, 2009; LEHTONEN, 2009; PACCA and MOREIRA, 2009; POUSA *et al.*, 2007; RATHMANN *et al.*, 2010; TAKAHASHI and ORTEGA, 2010; RATHMANN *et al.*, 2011; BORZONI, 2011; LA ROVERE *et al.*, 2011; NOGUEIRA, 2011; GALDOS *et al.*, 2013; NOGUEIRA and CAPAZ, 2013). As most of the sustainability analyses, which are complex and involve a great number of dependent and independent variables, the results of the various studies also show different conclusions.

In Brazil, ethanol and biodiesel supply 25% of the road transport fuel (NOGUEIRA and CAPAZ, 2013), which is a very high percentage when compared to the world figures already mentioned: 2.4% of the fuel consumed by the transport sector (IEA (1), 2012).

The successful inclusion of biofuels in the Brazilian fuel structure in the past 30 years was the result of a combination of leverage mechanisms (MAROUN and SCHAEFFER, 2012), which acted, simultaneously and comprehensively, in the different parts of the ethanol and biodiesel value-chains. The Brazilian National Alcohol Program – Proalcool, launched in 1976, was based on several interventions by the federal government. After different phases (HIRA and OLIVEIRA, 2009), the increase in the production of ethanol starting in 2003 arose from vehicles with "flexible" (flex-fuel) motors sold in Brazil. Most of the new vehicles have been equipped with such engines (89% of the vehicles produced in the country in 2013 were of the flex-fuel type) (ANFAVEA, 2014). This acceptance comes from the fact that the "flex" car gives the consumer greater autonomy when choosing which fuel to buy at the service station, enabling drivers to opt for the fuel they prefer. Because of the flex-fuel cars, and also due to the compulsory addition of anhydrous ethanol to gasoline (in a range of 20% to 25%), ethanol production has practically doubled in the country since 2003, achieving 23.2 billion liters in 2013 (Table 1).

Launched in 2004, the National Program for the Production and Use of Biodiesel (PNPB) made it obligatory to add a fixed percentage of biodiesel to mineral diesel, which is currently 5% in volume (B5, MAPA, 2011). To a large extent, it was possible to bring forward the use of B5 by mobilizing the biodiesel's value-chain. An example is total biodiesel output in Brazil in 2013 (2.9 billion liters, Table 1), as well as the present production capacity of the 64 licensed biodiesel plants (7.9 billion liters per year) in the country, which is significantly higher than the captive demand for biodiesel, taking into consideration total diesel consumption in that same year (ANP, 2014a).

Table 1 – Biofuels production in Brazil and the evolution of its share in final energy consumption

Ethanol Production (million liters)			Biodiesel Production (million liters)			Biofuels share in the energy matrix (%)	
2003	2013	Change	2003	2013	Change	2003	2013
12.623	23.226	+84%	1.167	2.949	+153%	3.4	5.5

Source: Prepared by the author based on UNICA, 2014; ANP, 2014b and EPE, 2013.

The Brazilian production of ethanol and biodiesel is mostly based on the sugarcane and soy production chains. In 2013, sugarcane occupied over 8.5 million hectares of the country's arable areas (87% located in the South/Southeastern/Center-west regions and 13% in the North-Northeastern regions), with a total production of 589 million tons and productivity of 69.4 tons per hectare. Considering the yield in total recoverable sugar (TRS), 48% of the output was allocated to the fuel market, and 52% to the food market (CONAB, 2013). With regard to soybeans, in 2011 this crop was responsible for supplying 81% of the vegetable oil demand for biodiesel production (ANP, 2012). That is, over 12 million tons of soybeans (16% of total soy production in Brazil in 2011[1]) were allocated to biofuel production.

Taking into account the Brazilian position of one of the most important players in the international biofuels scenario and the essential debate about bioenergy sustainability, the development of new studies introducing different perspectives is of great importance. In this regard, given growing global demands of water, land and energy, which are resources directly involved in the biofuels production, put these issues in the center of the debate of the Brazilian biofuels sustainability. Important authors have studied the three issues through an array of methodologies and perspectives, such as water footprint assessment (GERBENS-LEENES *et al.*, 2012; HERNANDES *et al.*, 2013), Energy Balances (MACEDO *et al.*, 2008) and Land Use Changes (WALTER *et al.*, 2010; LAPOLA *et al.*, 2010). Nevertheless, it is important to note that the use of each affects demand for the others (IAEA, 2009).

[1] Soybean production in Brazil, in 2011, amounted to 75.3 million tons, occupying an area of 24.1 million hectares (MAPA, 2012). It is the largest national agricultural crop area.

Additionally, the use of all affects the climate, generating a perverse vicious cycle, since climate changes will affect the three issues both directly and indirectly. Figure 7, adapted from a joint presentation of the Stockholm Environment Institute (SEI) and the European Report on Development (ERD) in the 2011 Bonn Conference on “The Water, Energy and Food Security Nexus”, shows the interrelations between the three more important resources related to biofuels production: water, energy and land.

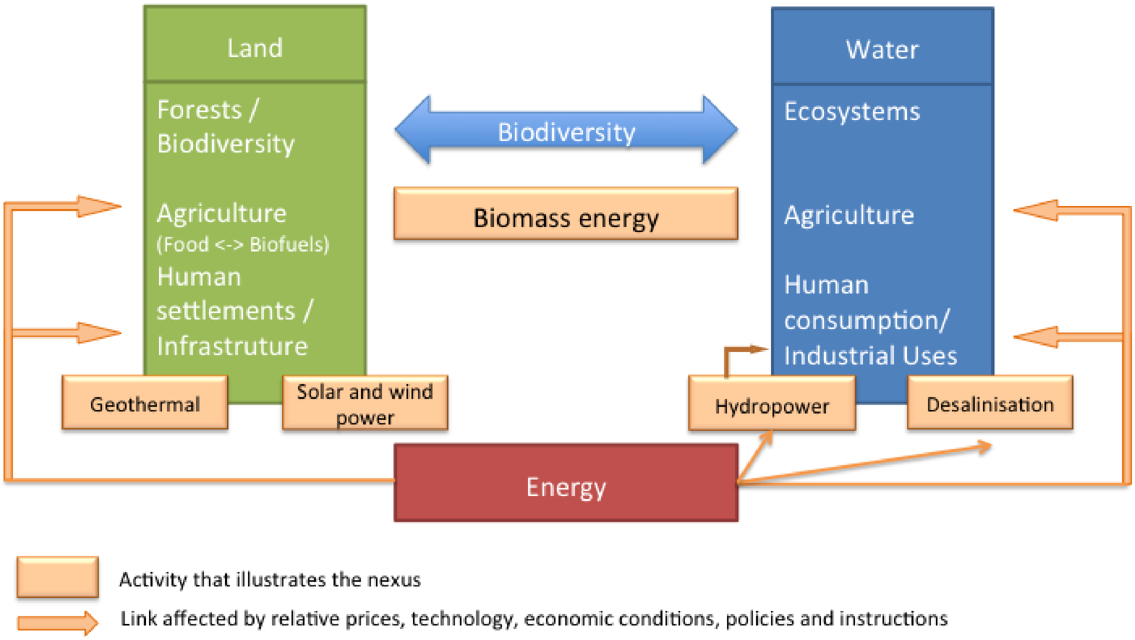

Figure 7 – Interrelations between Water, Energy and Land
Source: Prepared by the author adapted from SEI, 2011

These interdependencies mean that energy policies based on energy analyses alone, for example, might have adverse unforeseen effects on water resources, land resources and the climate. The same is true for water policies based only on analyses of water issues, and for land policies based only on land-use analyses. Since the current policies are based in existing models that in general focus on one resource and ignore interconnections with other resources, better methods and models that consider all the linkages among water, energy and land (WEL) are therefore needed (IAEA, 2009).

1.2 Objectives of the present study

In the aforementioned context, the general objective of this study is to analyze the sustainability of the ethanol expansion in Brazil comparing the results of separate analyses of water, energy and land issues within the water-energy-land (WEL) nexus analysis.

Therefore, the general objective of the present study is to answer the following question: Is there a difference in the results comparing the WEL nexus analysis and the analysis of each resource of the WEL independently?

Since the current policies are based on existing models that in general focus on one resource and ignore connections with other resources, which can often lead to misleading conclusions for structuring public policies, this study also sought to examine how disconnected are the policies of Brazilian water-use, land-use and energy in relation to the ethanol expansion in the country. For this purpose, an assessment of specific policies related to water, energy and land was conducted for the ethanol production expansion in Brazil, focusing on the integration of the WEL policies. Additionally, there was an assessment of the need to develop a sectoral policy for the ethanol production and use in Brazil integrating water, energy and land resources.

Whereas the State of São Paulo (SP) is the largest producer of ethanol from sugarcane in the world (SÃO PAULO, 2013) and is also responsible for over 50% of ethanol production in Brazil, SP was selected as the case study for the development of the analysis of this thesis. Additionally, SP already has a developed structure for the production of ethanol with skilled labor in the various stages of the ethanol production chain, as well as the presence of high technology and institutes of applied research. Therefore, using the State of São Paulo as the sample for testing the integration of policies related to WEL seems to be appropriate for the present analysis.

In the case of water, the analysis was limited to the availability of surface waters for the ethanol expansion in the State of São Paulo (SP), taking into consideration the São Paulo Water Resource Plan (WRP SP) and the areas of the expansion of the ethanol production in the state. The specific objectives related to the separate analysis of water issues were assessing the availability of water in the areas of ethanol expansion in São Paulo and if the São Paulo Water Resources Plan considers the expansion of ethanol production foreseen in the Brazilian energy policy (PDE 2022).

The analysis of the issues related to energy was conducted in three different perspectives. The first was related to the mechanisms for the Brazilian biofuels programs implementation and their results so far in order to subsidize the analysis of the importance of having a specific policy for the ethanol expansion in Brazil. The second perspective was related to Brazil´s current energy policy, the Ten-year Energy

Expansion Plan (EPE, 2013) produced by Empresa de Pesquisa Energética (Brazilian Energy Research Company, EPE), which foresees an expansion of the ethanol production in Brazil of almost 100% (from 27.3 to 54.5 billion liters). Finally, the third perspective included an analysis of the energy balance of ethanol in Brazil in order to identify possible impacts of other policies on it.

For the WEL analysis, the expansion of ethanol production in Brazil under the Ten Year Energy Plan - 2013-2022 EDP (Energy Policy) was cross-checked with the São Paulo Water Resources Plan (water policy) and the Agro-Ecological Zoning of Cane (land use policy).

In order to evaluate the originality of this thesis, Chapter 2 presents a comprehensive overview of the most important studies related to the analysis of biofuel's sustainability in the world and particularly in Brazil. Although this study focuses its analysis in the ethanol production expansion, it was important to check published work related to sustainability of biofuels in order to evaluate the originality of the application of the WEL nexus in Brazil. Therefore, this overview aimed to identify new proposals of sustainability frameworks and integration across issues related to biofuels analysis.

The methodology and scope of the present work are presented in detail in Chapter 3. The separate analysis of the three parameters (water, energy and land) can be found in Chapters 4, 5 and 6, respectively, and the assessment of the interrelation of the results and the sectoral policies are presented in Chapter 7. Chapter 8 presents the conclusions and final considerations of this study and Chapter 9 includes suggestions for future works.

2 Overview of Biofuels Sustainability in Brazil

More than twenty years after the ECO-92, when the definition of Sustainable Development was accepted by the global community, there are still many studies (LORA *et al.*, 2011; SINGH *et al.*, 2012; FAO, 2013a; GASPARATOS *et al.*, 2013; NOGUEIRA *et al.*, 2013; RIBEIRO, 2013; MATA *et al.*, 2013) regarding sustainability definitions and worldwide differences in meanings and views still exist. Nonetheless, some main considerations are commonly accepted. The general concept of sustainable development points to aspirations towards achieving a quality of life that can be maintained for many generations. This tendency comes from the idea that sustainability is: socially desirable, economically viable and ecologically sustainable. Sustainable development is then the complex of activities that can be expected to improve the human condition in such a manner that the improvement can be maintained (MUNRO, 1995).

Other than the three pillars previously mentioned (social, economic and environmental), in recent years the discussion of sustainable development has evolved to include other components, such as policy and institutions along with linkages and overlaps between the issues related to the three pillars of sustainability (DIAZ-CHAVEZ, 2011). According to Mayer (2008), the sustainability of human-environment systems is determined through three main characteristics: resilience to disturbances, both natural and anthropogenic; desirability to human societies; and temporal and spatial scale boundaries. Resilience and desirability determine policy goals, and the scale determines the system to be monitored and managed to reach those goals. Therefore, sustainability assessments shall be conducted with a systemic perspective instead of analyzing separate compartments.

In this context, quantifying the progress towards sustainability is currently at the center of an ongoing debate and a number of different methodologies for its assessment have been proposed. However, very few (if any) seem to be able to assess sustainability adequately in a holistic manner (GASPARATOS *et al.*, 2012).

Population growth, an expanding middle class with changing lifestyles and diets, and the urgent need to improve water, energy and food security for the poorest place growing pressure on limited resources. Unless there are significant changes to the ways that we produce and consume, agricultural production will have to increase by about 70% by 2050 and about 50% more primary energy has to be made available by

2035. Such increases would have far-reaching implications for water and land resources (SEI, 2011).

Therefore, biofuels, as a feasible source of primary alternative energy that uses water and land in great proportions, are in the center of the world needs and attention regarding sustainability. Several studies focusing technology, economic viability, environmental and social issues have been developed since the last decade. In general, the studies of biofuels sustainability have focused on the three traditional pillars of sustainable development (social, environmental and economic), analyzing specific issues related to one or two of the three categories. Deforestation, biodiversity extinction, monocropping, soil degradation and water depletion are also common assessed issues (LORA *et al.*, 2011). An array of powerful appraisal techniques ranging from life cycle assessment to remote sensing, econometric and complex land use change models, to name just a few, has been employed to assess the broad range of sustainability impacts associated with biofuel production and use (GASPARATOS *et al.*, 2013).

The importance of such studies that analyze separately the most important issues related to biofuels sustainability is out of question, as they create the basis for specific policies and development of new technologies.

Examples of recent studies that analyzed a wide range of issues related to biofuels sustainability in the world are very common since major biofuel policies have been implemented in the last years, needing strong scientific basis for their structuring. More than 4,000 biofuel-related academic papers were published in 2011 alone (GASPARATOS *et al.*, 2013). Regarding biofuels and sustainability, a search done by the author of this theses in Science Direct[2], looking for the terms "sustainability of biofuels" and filtering them by year, showed that the number of published papers in Science Direct grew from 219 in 2007 to 1,830 in 2013. Figure 8 shows this evolution through the years.

[2] Science Direct is one of the most important bibliographic database containing abstracts and citations for peer reviewed academic journal articles

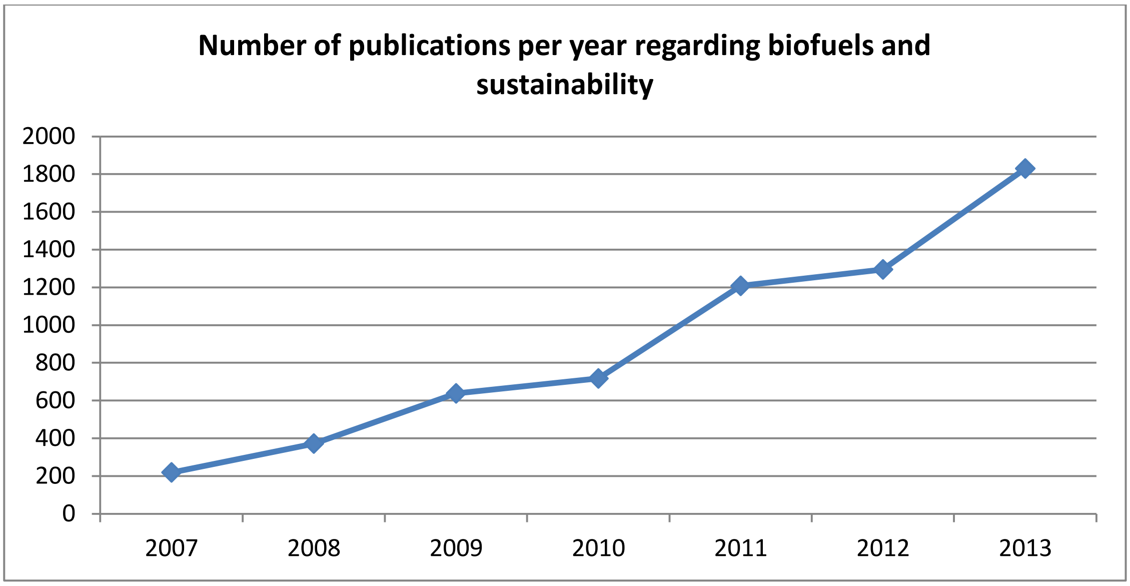

Figure 8 – Publications per Year Regarding Biofuels and Sustainability.
Source: Prepared by the author based on GASPARATOS *et al.*, 2013

2.1 Recent Studies of the Sustainability of Biofuels in the World

Among the various examples, two studies shall be cited since they tried to cover all essential environmental, social and economic issues related to biofuels, as well as policies and their implementation in different countries. The first study is the *International SCOPE Biofuels Project* (2007-2010), which was commissioned by the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Science (ICSU) (SCOPE, 2009). This project was created in response to environmental concerns over the biofuels expansion in the world. The second study, *Biofuels and the sustainability challenge: A global assessment of sustainability issues, trends and policies for biofuels and related feedstocks*, was conducted by the Food and Agriculture Organization of the United Nations (FAO, 2013a). Since both studies are very comprehensive, they were chosen to be analyzed in more detail in this chapter to provide an overview of what has been studied in the last decade concerning biofuels sustainability.

2.1.1 International SCOPE Biofuels Project (SCOPE, 2009)

The International SCOPE Biofuels Project aimed to perform an objective, science-based assessment of biofuels in the world in order to provide a comprehensive, systematic, and comparative analysis of the environmental benefits and costs of biofuel technologies. The project was conducted both at the global and sub-global levels, so as to take into account specific physical and societal dimensions in the main regions of the world. The methodology of the project involved a compilation and synthesis of the best available science-based objective information to address the question ***"what are the characteristics of an environmentally desirable and sustainable biofuel?"***

The study resulted in a collection of 17 papers that compiled the most important issues included in the analysis of biofuels sustainability and technology. Thirteen papers are considered *Rapid Review Papers* related to specific biofuels sustainability concerns, and four papers compile the results of a meeting held in Germany where the issues were discussed by academic representatives.

The most important result includes an analysis of biofuels and emission of greenhouse gases (GHG). Other environmental effects are also mentioned, but received less attention. Regarding GHG emission or, better, GHG balance, the study concluded that some biofuel systems could increase the release of GHG relative to the fossil fuels they replace. In the case of ethanol from sugarcane used to replace fossil fuels in transportation in Brazil, authors state that a substantial reduction in net GHG emissions may result: 80% to greater than 100% savings are recorded. On the other hand, most of the studies summarized by SCOPE may underestimate the release of nitrous oxide (N_2O), which is around 300-fold greater than CO_2 in its ability to warm the planet[3]. Moreover, in relation to GHG emissions, the study points out the greatest concerns with the effect of indirect land-use change (ILUC), since most of the life-cycle analysis approaches do not include indirect effects associated with the scaling up of production. When biofuel cropping is associated with the conversion of native ecosystems, the net greenhouse-gas balance is negative, and more greenhouse gases are emitted to the atmosphere than if fossil fuels were used instead. In theory, the carbon debt of this conversion can eventually be re-paid through the extended use of biofuels over time, but this requires many decades or even hundreds of years to balance out the initial carbon losses.

ILUC also interferes in biodiversity: agro-ecological modeling indicates that the expansion of sugarcane and crops for biofuels in Brazil will likely be focused on the

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[3] The ability of a certain GHG to warming the Planet is measured by the Global Warming Potential (GWP), which is proposed by the IPCC as a metric to convert multi-gas emissions into carbon dioxide (CO_2) equivalent emissions on a common scale (MOURA, 2013). The GWP of the N_2O within the Kyoto Protocol is 310.

Cerrado region of Central Brazil. This area represents about 9% of the total area of tropical savannas in the world and is one of the world's biodiversity hotspots. In the United States and European Union, some lands that are currently set aside for conservation reasons, including protection of biodiversity, are expected to be converted and used to grow crops for increased biofuel production.

Another issue analyzed is the competition for freshwater. According to the results of the study, roughly 45 billion cubic meters of irrigation water were used for biofuel production in 2007, representing six times more water than people drink globally. They conclude that, although alternative feedstock crops can be used to reduce the demand for water in biofuel production, water implications of future large-scale biofuel production remain uncertain. Local and regional air pollution due specifically to the burning of sugarcane fields before harvest are of concern, as well as severe water pollution resulting from runoff from agricultural fields and from waste generated during the production of biofuels. The study cites that the increase in corn production to support ethanol goals in the United States is predicted to increase nitrogen inputs to the Mississippi River by 37%. The authors also refer to the disposal of the "vinasse" (organic waste from the sugarcane-ethanol system) as a potential source of water pollution through the runoff to surface water and contamination of groundwater.

Regarding the results of this comprehensive study it is concluded that the most relevant impacts in biofuels sustainability are related to land (ILUC and GHG emissions, and loss of biodiversity) and water needs and contamination.

SCOPE also conducted an analysis of the policies and programs related to biofuels in developing countries. Conclusions vary significantly from one country to the other, but in general terms, it was possible to provide evidences related to the type of production for specific crops and biofuels. The first one is related to large-scale production systems, which can be divided in large monoculture plantations so as to maximize profits for large-scale farmers, processors and energy companies; and a second type where feedstocks are grown on smaller farms and then sold to commercial processors.

Despite the specific results described above, a general conclusion of the study is that ***"the environmental consequences of biofuels depend on what crops or materials are used, where and how these feedstocks are grown, how the biofuel is produced and used, and how much is produced and consumed".*** Depending on those elements, effects in sustainability can be both positive and/or negative.

2.1.2 Biofuels and the sustainability challenge: A global assessment of sustainability issues, trends and policies for biofuels and related feedstocks (FAO, 2013a)

This study developed by the Food and Agricultural Organization of the United Nations (FAO, 2013a) aimed to be a comprehensive study attempting to integrate into a single report the major issues related to biofuels and their respective feedstocks sustainability. Although most of the cited literature in the study is not updated, as most of the data and analysis presented were published more than five years ago (2008, 2007 and even data from the 90s), this study published in 2013 is an important source of information and tried to integrate issues related to sustainability.

The authors state that environmental sustainability assessments for biofuels are difficult owing to the complexity and the multiplicity of global, local and regional indicators. The study also analyzed initiatives on sustainability via regulations, directives or private-led certification schemes and came to a conclusion that they have had no clear and measurable impact, apart from their importance. A key problem continues to be a lack of consensus on measurement methodologies (such as life-cycle analyses and the way to tackle indirect land use change). Moreover, certification schemes are of recent creation and continue to be impeded by inherent measurement and monitoring problems, which vary according to situation (location, feedstock, technology, alternative resource use, policy environment and local capacity). Until progress is made on these obstacles, the approaches pursued so far will continue to be selective and haphazard, focusing on self-selected sustainability measures and *ad-hoc* rules such as no-go zones for high carbon stock or biodiversity-rich areas.

The study points out that the three core dimensions of sustainability are interlinked and can best be approached holistically. There is a huge gap between the conceptual definitions of standards, principals and criteria and actual testing and verification on the ground. The socio-institutional, economic and environmental dimensions are or can be seen as complementary and not unrelated or contradictory (JABAREEN, 2008 *Apud* FAO 2013).

The assessment of specific issues was based mostly on case studies which emphasized that the expansion of biofuels, especially under intensive production systems, could have negative impacts on biodiversity (e.g. replacement of natural forest with biofuel crops, spread of monocultures), water availability under scarcity, reduce water quality, soil degradation, negative carbon and energy balances, potential conflict with food production and food security, as well as worsening GHG emission levels because of indirect land-use change.

For the purposes of the present study, the most important results of the FAO report related to sugarcane ethanol in Brazil were selected and described in the item 2.1.2.1.

2.1.2.1 Sustainability of Sugarcane Ethanol in Brazil

Based on literature of 2008 and 2009 (KUTAS, 2008 and GOLDEMBERG and GUARDABASSI, 2009), the study points out that the expansion of sugarcane ethanol in Brazil is expected to take place in the state of São Paulo (SP) and that sugarcane production will reach an amount of 1,040 million tonnes in 2020.[4]

In the case study of sugarcane ethanol in Brazil, FAO (FAO, 2013a) compiled the most important studies related to GHG emissions, including an overview of studies related to land use change, pollution, water sustainability, labor issues, and land.

In the case of GHG balance, the study of FAO cited the Life Cycle Assessment (LCA) in a "seed-to-factory" approach developed by Macedo *et al.* (2008). According to this LCA, an energy balance of 9.3 was found in production and use of ethanol from sugarcane, using data from 2005/06. In the same study the energy balance was projected to improve to 11.6 and the avoided GHG emissions to 2,930 kg CO_2eq m^{-3} by 2020.

The sensitivity analysis revealed that cane productivity as well as ethanol yields played the largest roles in both energy and GHG balances. Also the use of bagasse in biomass boilers and for excess electricity gave rise to variation in the results. In a study conducted by Luo *et al.* (2009), a possible future scenario included the use of both sucrose and bagasse for ethanol production, while heat and power were generated only by wastes. The authors found an increase in GHG emissions compared with the baseline. The authors of the FAO study state that this is explained by the fact that the GHG savings potential is higher for the electricity generation of bagasse than for the use of it as a fuel.

Regarding GHG emissions, the FAO study concluded that the Brazilian sugarcane ethanol can generate higher GHG-emission savings compared with other

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[4] It is important to note that these figures are considered very optimistic today. As mentioned previously (see Chapter 1), the forecast for the sugarcane production in Brazil in 2022 is 557Mt according to the Ten-year Energy Planning produced by the Brazilian Government (PDE 2013-2022).

temperate-based biofuels, using an LCA estimation that does not factor in land-use change impact. However, there is still considerable debate over whether GHG-emission savings from Brazil's sugarcane ethanol are still positive once indirect land change (ILUC) is taken into account and if sugarcane expansion moves into sensitive areas such as the Cerrado. In this regard, the study highlights the work conducted by Nassar *et al.* (2008), which reported that the sugarcane plantations will likely continue to expand into crop and pastureland. Also, indirect land conversion effects were estimated as low because the productivity of cattle production had increased (and had the potential to increase even further).

Regarding pollution, the FAO study based its analysis on the air pollution resulting from harvest practices, notably the common practice of field burning before manual harvest to make the cutting easier and to remove snakes and spiders. Cane burning lowers soil quality and organic material, increases the risk for cane diseases and produces higher emissions of CO, CH_4, non-methane organic gases and particulate matter. When tied to manual harvesting, burning raises the risk of respiratory diseases and other health problems for workers. However, the authors recognize that the Brazilian government has enacted measures to reduce cane burning and encourage mechanical harvesting, but the latter is not practical in all cases because of topography (e.g. hills, valleys). Burning practices are on track to be phased out by 2017 in the state of São Paulo and other states might follow (GOLDEMBERG *et al.*, 2008). This measure will allow reduction in GHG emissions in a volume equivalent to 6 million tonnes of CO_2, considering 2008 as a reference year.

Water sustainability was also an issue of concern regarding sugarcane ethanol in Brazil. According to the study, some authors argue that impacts on soil and water quality do not pose particular problems, since sugarcane is mostly rain fed in Brazil, especially when biological control methods and biological nitrogen fixers are used.

Nonetheless, where production is intense, water pollution and soil erosion should be considered. Measures such as contoured ploughing, absorption terraces and leaving residues on the field are already taken by some producers and could become more common in the future. In most of the mills, the ethanol production process requires about 1.23 m^3 of water per ton of sugarcane. The bulk of this water is recycled. According to Neves do Amaral *et al*. (2008), new technologies could even result in ethanol plants becoming water exporters.

Labor issues were also analyzed by the study, but as they are not part of the analysis of the present work they will not be summarized in this section.

Regarding land issues, the FAO study points out concerns about the expansion of sugarcane plantations in the Cerrado region, which is a region as important for biodiversity as the Amazon region. There is a risk that sugarcane plantations may replace areas of food production or expand into forest reserves. According to Sparovek *et al*. (2007), in the state of São Paulo and its surrounding area and in the Center-West region, livestock production can be expected to decrease or be displaced to local marginal areas.

The authors state that the increasing demand for land for sugarcane in Brazil has led in some instances to the conversion of grasslands and wooded savannah for crops, which has released stored carbon dioxide (CO_2) and displaced previous users such as cattle farmers who move into tropical forests in search of new pasture. According to Oladosu *et al.* (2009), sugarcane land expansion is more than 90 percent from pasture and other cropland. The study also cites that the plantations were expanding into traditional lands of indigenous people (the reference for that is CEO, 2009).

The Sugar Cane Agro-ecological Zoning (ZAE Cana) legislation, launched in 2009 by the Brazilian Government, deserved a special mention, since it aims to guide the sustainable expansion of sugar cane production in the future and protect sensitive areas and native vegetation. ZAE Cana prohibits the expansion of sugar cane production and the installation of new units of ethanol production in the Amazon and Pantanal biomes, and in the Upper Paraguay River Basin.

According to the FAO study, over 34 million hectares of land currently underutilized or occupied by livestock or degraded pastures are identified in ZAE Cana as suitable for sugar cane production. The increase in livestock productivity in Brazil (i.e. head of cattle per ha), which today is considered to be low, may provide new areas for sugar cane production.

One interesting general conclusion of the study is *"If the past is any guide, the market forces alone are unlikely to be the sole drivers of these processes, and the role of policy support (through incentives or disincentives) will also be critical in guiding the outcomes"* (FAO, 2013a). In other words, the authors of the FAO study agree that policies are decisive in decisions and implementations of processes related to sustainability of biofuels.

Although the above mentioned studies are very comprehensive in the sense of studying the most important issues related to biofuels, as most of all the others, they fail to provide comprehensive and coherent conceptual frameworks that can put the diverse impacts and *trade-offs* related to biofuels sustainability in a broad perspective, establishing a clear correlation across issues.

Sustainability analysis of any major sector of human activity involves use different word of a large number of areas of knowledge, if treated properly in the full life cycle. The interdependence of these areas can make any analysis always "incomplete", being possible to broaden the scope, depth, and consider new points of view (UNICA, 2007).

Most recent analyses indicate a range of environmental concerns and benefits that vary greatly depending on the biomass feedstocks and the cultivation methods used; the type of biofuel; the technology used to convert the biomass into fuel; the type of energy used to power the conversion; the location where the feedstocks and biofuels are produced; and the extent to which a growing demand for biofuels induces changes in land use and land cover (HOWARTH *et al.*, 2009). In this context, many different studies concentrated efforts in all the above mentioned items, in separate analysis. The big question today is how to integrate those issues in a comprehensive framework.

In a 2013 study, Gasparatos *et al*. discussed whether it is desirable to synthesize the evidences of the impacts of biofuels in a clear, coherent and policy relevant manner. The authors concluded that the adoption of a unified synthesis framework or the rejection of one as a standard recipe should not apply in all situations. Biofuels experts shall remain open and reflexive about the policy implications of their own methodological choices, as well as to be sensitive to the context and the demands from the stakeholders. The ultimate aim of biofuel appraisals must be to provide a basis for an informed and balanced democratic debate on the one hand, and transparent decision-making on the other (GASPARATOS *et al.*, 2013).

Although not said straightforward, the analyses conducted by the comprehensive global studies cited in this chapter led to very similar conclusions: it is very difficult, if not impossible, to generalize results when it comes to the analysis of biofuels sustainability.

In this regard, both the study conducted by SCOPE and the work developed by FAO, support their analysis in case studies, which had different perspectives and results.

The results of Gasparatos *et al.* (2013), have encountered similar conclusions. The authors acknowledge that having a unified framework for analyzing biofuels sustainability can be useful in specific cases where there is enough maturity of analysis, as for example, sugarcane ethanol in Brazil. On the other hand, authors agree that in less established cases involving policies and scientific uncertainties, a unified framework can be counterproductive, as it would tend to prematurely suppress debate and conceal key topics of disagreement.

The results of the assessment of recent studies that intended to undertake a comprehensive analysis of biofuels sustainability in the world show that, although covering the most important issues, they do not establish a cross-check among them. These results confirm the originality of this thesis in worldwide coverage analysis.

An assessment of the recent comprehensive studies related to biofuels sustainability in Brazil was also undertaken to check the originality of the proposed analysis of this thesis and the results are presented in item 2.2 of this Chapter.

2.2 Recent Studies on the Sustainability of Biofuels in Brazil

The increase in the use of biofuels in substitution of fossil fuels in Brazil and the country's importance to the world biofuels production trend has raised several concerns regarding the sustainability of biofuels in Brazil. Several studies have been conducted in the last decade regarding ethanol and biodiesel production and use in Brazil. The most cited issues can be illustrated by the impacts of burning sugarcane fields, GHG and energy balance, and social concerns. Recently, impacts of biofuels in land use change, food security and water quality have gain space in the biofuels sustainability debate.

Some important Brazilian authors, such as José Goldemberg, Luis Augusto Horta Nogueira, and Isaias Macedo are very active in defending biofuels in Brazil, especially ethanol from sugarcane.

According to Goldemberg *et al.* (2008), "biofuels use contribute to rural development, allowing additional income and job creation for developing countries, contributing to the sustainability of natural resources, collaborating with GHG emission reduction in a cost-effective way and diversifying the world's fuel needs". In a recent study (NOGUEIRA and CAPAZ, 2013), Horta Nogueira and Silva Capaz evaluated the evolution, achievements and perspectives on food security related to biofuels in Brazil. Their conclusion was that "biofuels currently represent a relevant and competitive element of Brazil's development strategy and present interesting synergies with food security without any remarkable negative impact on food availability, including food availability for trade".

However, the ethanol production in Brazil, while widely regarded as one of the world's most economically efficient and technologically advanced programs, has followed a trajectory similar to that of other large-scale, capital-intensive agricultural sectors, and some authors claim that it is not succeeding in reducing poverty and social inequities (HALL *et al.*, 2009; LEHTONEN, 2009). Moreover, with the end of burning of sugarcane fields and introduction of mechanization, rural jobs in the sugarcane fields will be reduced, thus creating a mass of unskilled workers that will have to be absorbed. On the other hand, the mechanical harvesting will create new and higher quality jobs in the equipment production and operation chains. (LA ROVERE *et al.*, 2011). The same can be observed for the biodiesel production in Brazil. Although the Brazilian Program for Production and Use of Biodiesel (PNPB) was created regarding mostly social concerns, it seems that its implementation is derailing from the original goals. Despite the efforts of the government in creating regulations to stimulate the inclusion of family farmers in the biodiesel production, such as the Social Fuel Stamp, the outcomes of the program show that the family farmers have a small participation in the production, being mere producers of grains.

The environmental impacts of the ethanol use have to be assessed both at the production and consumption levels. Burning sugarcane fields, which has been a common practice in Brazil for many years, was a major concern for several authors because of the environmental and health hazards associated with this activity. This issue is being treated by the environmental agencies in Brazil and will be resolved in the medium term through recent laws and agreements between governmental authorities and the sugarcane industry (in 2007 a protocol was signed by the government of the state of São Paulo and the Union of Sugarcane Industry determining the end of the burning of fields by 2017).

Another important issue related to the production and use of ethanol and biofuels in general is the GHG balance, since biofuels are expected to reduce GHG emissions, contributing to mitigating climate changes. Life-cycle GHG emissions of biodiesel arise directly from LUC and from the use of fertilizers and fuels and indirectly from the manufacture of feedstock inputs (CASTANHEIRA *et al.,* 2014). Regarding GHG emission reductions, it seems to be a consensus among researchers that the production and use of ethanol in Brazil have a very positive direct influence on GHG emissions mitigation (SZKLO *et al.*, 2005; COELHO *et al.*, 2006; MACEDO *et al.*, 2008; GOLDEMBERG and GUARDABASSI, 2009; PACCA and MOREIRA, 2009; HIRA and OLIVEIRA, 2009; GOLDEMBERG, 2008; LA ROVERE *et al.*, 2011; MOREIRA *et al.*, 2014). The mitigation occurs through the use of ethanol as a fuel in substitution to gasoline in the transportation sector, as well as through the generation of electricity using sugarcane bagasse that replaces fossil-fuel power generation. Moreira *et al.* (2014) state that there is no doubt that biofuels have significant greenhouse gas mitigation potential and calculated that the substitution of sugarcane ethanol for oil displaces 56 gCO_2 per MJ (MOREIRA *et al.*, 2014).

In this regard, Luo *et al*. (2009), reported a comparative Life Cycle Assessment (LCA) of different fuel alternatives, considering different proportions of ethanol in the gasoline in two different scenarios: (1) the base case, which is based on the current technology applied in the production of ethanol; and (2) the future case, where the bagasse is used mainly for ethanol production, instead of generating electricity. The results for GHG mitigation comparing all the fuel alternatives are presented in Figure 9. Through this study it is possible to conclude that the production and use of ethanol in Brazil presents positive GHG balance. Other interesting finding of this study is that GHG emissions reduce much less in the future case, since there will be no electricity produced via bagasse.

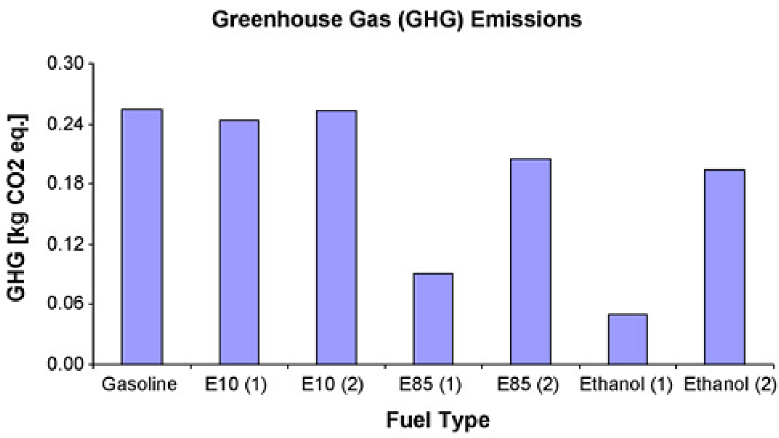

Figure 9 – GHG emissions from LCA.
Source: LUO *et al.*, 2009

Other recent studies, however, start to question the Brazilian ethanol in terms of GHG emission reduction. Some authors claim that most of the calculations and LCA developed so far did not include the effects of indirect land use change (ILUC) (FAO, 2013a; LANGE, 2011; GAO *et al.*, 2011; ZILBERMAN *et al.*, 2010; OLADOSU and

KLINE, 2013). This effect can have a negative influence in the GHG balance, since the expansion of sugarcane plantations can indirectly dislocate cattle herb and other cultures to areas in Cerrado or the Amazon forest causing suppression of forested areas.

In a study conducted in 2009, Pacca and Moreira calculated the carbon neutralization capacity of Brazil's ethanol program since 1975. Their results show that the neutralization of land-use change emissions would have been achieved in 1988, and the mitigation potential of ethanol would have been 390 tCO_2/ha. The authors also calculated the forecasts of the sector up to 2039 showing that the mitigation potential in 2039 corresponds to 836 tCO_2/ha, or 5.51 kg of CO_2 per liter of ethanol produced (55% above the negative emission level) (PACCA and MOREIRA, 2009).

The direct land use change (DLUC), which is strongly related to GHG emissions, is also an important issue concerning the production of ethanol and biofuels. A study published in 2010, (WALTER *et al.*, 2010), used the national Census of Agriculture of 1996 and 2006 (IBGE 1998, 2009) to evaluate the variation in the use of land (pastures, forests, crops and sugarcane) in the states of São Paulo and Mato Grosso. The study concluded that the expansion of sugarcane areas in São Paulo displaced mostly pasturelands, while in Mato Grosso it was irrelevant compared with other agricultural uses. Therefore, it is highly improbable that DLUC due to sugarcane expansion has caused deforestation (WALTER *et al.*, 2010).

Another item of concern regarding biofuels sustainability is the observed shift in land use away from food production, which is needed to feed humanity. Greater monetary returns to farmers through the incorporation of lands for agro-energy can impact in food production (RATHMANN *et al.*, 2010). Gauder *et al.* (2010) assessed the quantity of future food and ethanol production in three different scenarios. The study concluded that more than 20 million hectares would be available for agricultural production in the upcoming years, and no constraints on food production were evident due to the expansion of land used for sugar cane production in all three scenarios. On the other hand, the figures posed by Gauder *et al.* (2010) are very simplified, since the competition for land between food and fuel involves complex dynamics and local relations. According to Rathmann *et al.* (2010), who studied Parana State in Brazil, the emergence of agro-energy on a large scale has altered the land use dynamic, with a shift of areas traditionally allocated to food production to biofuels, contributing to increase the food prices in the short run.

Regarding GHG mitigation derived from biodiesel production and use, high variations are observed in LCA studies, depending on the yield used for biodiesel production (mainly palm oil and soya), the technology applied, and on specific local issues, such as the agriculture mechanization level, crop and farm management, and changes in land use (CASTANHEIRA *et al.*, 2014).

High savings of biodiesel from palm oil depend on high yields, those of the soya on credits to by-products. As in the case of ethanol, negative GHG savings, i.e. increased emissions, may result, in particular when production takes place on converted natural land and the associated mobilization of carbon stocks is accounted for (UNEP, 2009). Figure 10 shows the variations of GHG balance depending on the yield utilized for biodiesel production.

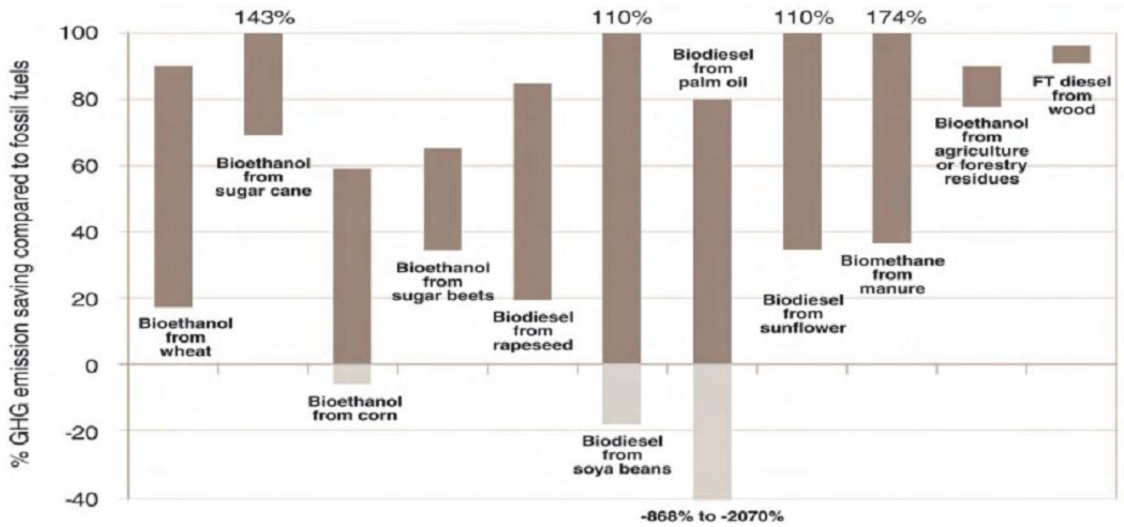

Figure 10 – GHG savings of biofuels compared to fossil fuels.
Source: UNEP, 2009

Due to the vastness of the individual areas and the difficulty of analyzing different issues together, there is little work focusing on how to support decision-making at the nexus of water, energy and land (BAZILIAN *et al.*, 2011). Despite the different focus and methodologies of most of the studies related to sustainability of biofuels in Brazil, none of them conduct an evaluation across issues. The great majority of the studies present separate analysis of the representative issues concerning biofuels sustainability. It is important to verify if policies to develop bioenergy alternatives to fossil fuels in Brazil have been done in the absence of a wider understanding of the full costs and benefits from multiple perspectives, including an integrated analysis of the most important issues.

The need to analyze factors together reinforces the need for better methods and models that consider all the linkages among them (IAEA, 2009). Considering that water, energy and land are important issues in the production of biofuels and that they are interrelated, it is important to check methodologies already applied in different studies which aimed to integrate them. Therefore, in Chapter 3, four studies that integrated the analysis of issues in different countries and their respective methodologies are presented, as well as the scope and methodology of the present work.

3 Methodology and Scope of the Study

As can be observed in Chapter 2, the literature researched in this work does not present any study that seeks to integrate water, energy and land (WEL) issues related to the biofuels production in Brazil. Even worldwide, the complexity of conducting an analysis that incorporates WEL issues and other items that influence the sustainability of biofuels, such as climate change, suitable methodologies are still under development for the creation of a framework of analysis that is effective in integrating multiple issues.

Most decisions and policy making related to land-use, energy and water systems occur in disconnected institutional entities with little, if at all, coordination or communication between each other (WELSCH *et al.*, 2014). Howells *et al.* (2013), in a jointly institutional paper (Royal Institute of Technology of Sweden; International Atomic Energy Agency; International Renewable Energy Agency; International Institute for Applied Systems Analysis; Stockholm Environment Institute; United Nations Department of Economic and Social Affairs; Food and Agriculture Organization; and Mauritius Agricultural Research and Extension Unit), dedicated to offer inputs for the Rio+20 conventions stated that "*This (institutional disconnected decisions regarding water, energy and land) could lead to incoherent policy-making, where a strategy or policy implemented in one area undermines a policy goal in another. For instance, the strong drive by many governments to promote biofuels over the past decade did not foresee the full impact of rapid biofuel expansion on land and food markets, nor the potentially adverse consequences of land-use change associated with the expansion of biofuel production on the emissions of greenhouse gases (GHGs)*".

Energy, water, and land resources and associated support ecosystems constitute the foundation on which all human societies rely for their existence, productive development, security, and well-being. All three resource sectors are highly related to one another through supply-demand relationships that support both human socioeconomic activities and the ecosystems on which societies rely for critical services (DOE, 2012). Especially in the case of the production of biofuels, the three resources are deeply involved and interrelated. Therefore, it is of great importance that policy making related to the value chain of biofuels be based on data produced accordingly to the interactions of these fundamental resources. Moreover, biofuel-related policies shall consider the integration of individual policies. This means that an energy policy of a country involving biofuels shall be integrated with the water resources plan and water policies as well as land-use policies.

Existing and widely applied project-based methodologies that intend to analyze the triple bottom line of sustainability (environment, social and economic) in a multidisciplinary context, such as the Environmental Impact Assessment (EIA) and its similar studies, are common practice in the individual analysis of diverse items related to sustainability. In Brazil, for example, the requirement of an EIA is a fundamental premise of the environmental permit for all projects and activities subject to licensing that could cause significant environmental degradation (BRASIL, 1986. Resolução CONAMA nº 01, de 23 de janeiro de 1986 and BRASIL, 1997a. Resolução CONAMA nº 247, de 19 de dezembro de 1997). Therefore, activities such as ore and fossil fuel extractions, construction of roads, railways, ports, and sanitary landfill, need to develop an EIA in order to prevent and/or mitigate environmental and socio-economic damage that may affect the ecological and socioeconomic balance. The scope of the EIA comprises the technical activities of environmental assessment, the environmental impact analysis, the definition of mitigation measures and the development of monitoring projects. On the other hand, in general terms, this kind of study is not able to build an interrelation of the resources under assessment, since this interrelation requires not only accurate representations of each individual sector, but also a detailed understanding of the scale-dependent interactions among them. There is a clear lack of methodologies that integrate the issues in an interdisciplinary way.

According to the references revised in the present work (UNEP, 2009; LUO *et al.*, 2009; SCOPE, 2009; KUTAS, 2008; GOLDEMBERG and GUARDABASSI, 2009; GOLDEMBERG, 2008; FAO, 2013a; GASPARATOS *et al.*, 2013; NOGUEIRA and CAPAZ, 2013; among others) the first attempt to the integration of more than two issues in a broader assessment was the nexus methodology presented in 2011 at the "Bonn 2011 Nexus Conference: the water, energy and food security nexus" (background paper developed by HOFF, 2011). The nexus approach intends to optimize issues across different sectors, rather than evaluate and maximize one issue at a time. This integrated approach intends to promote innovative concepts. A nexus approach can support a transition to sustainability, by reducing trade-offs and generating additional benefits that outweigh the transaction costs associated with stronger integration across sectors. The nexus focus is on system efficiency, rather than on the productivity of isolated sectors (HOFF, 2011).

The theoretical WEL nexus approach presented in the Bonn 2011 Conference was the basis for the creation of different methodologies pursuing the integration of issues related to sustainability. An evolution of the nexus approach is the Climate, Land, Energy, and Water (CLEW) System, which was proposed by the International Atomic Energy Agency - IAEA (IAEA, 2009). Acknowledging the importance of conducting integrated analysis of the different issues related to sustainability, especially in energy planning, the Agency led an effort to develop a model capable to consider the interrelations of CLEW analysis. The approach developed involved different existing global models regarding the CLEW. The specific focus of the CLEW System (CLEWS) is on the expansion of a systems approach to underpin the analysis of sustainable development with an emphasis on CLEW resources. In this context, CLEWS considers improvements over existing approaches such as the IAEA MESSAGE model,[5] which provides and supports analysis of a country's or region's energy system; the Water Evaluation and Planning system (WEAP)[6], commonly used for water planning, and the Global Policy Dialogue Model (PODIUM)[7] used for water scarcity and food security planning, among others. A module-based approach is adopted, where data is passed between sectoral models in an iterative fashion (HOWELLS *et al.*, 2013). CLEWS, still under development, tries to include in this new perspective a finer geographical coverage, simplified data requirements, a medium-term temporal scope, multi-resource representation (including their inter-linkages) and software accessible to developing country analysts (IAEA, 2009). The ultimate goal is to help decision makers assess different technological options with diverse benefits and disadvantages; estimate the impacts of different development scenarios; and analyze and evaluate policies.

The initial outline of a CLEW system introduced by IAEA is presented in Figure 11. Although it is not mentioned in the IAEA documents related to CLEWS, it is clear that this initial outline is strongly based in the Life Cycle Analysis (LCA)

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[5] MESSAGE (Model of Energy Supply Systems and their General Environmental Impacts) is a systems engineering optimization model, which can be used for medium to long-term energy system planning, energy policy analysis and scenario development. The model provides a framework for representing an energy system with its internal interdependencies (IIASA, 2001).
[6] The WEAP energy model is maintained and supported by the Stockholm Environmental Institute: http://www.weap21.org/
[7] PODIUM is maintained and supported by the International Water Management Institute http://podium.iwmi.org/podium/

methodology. The interrelations presented follow the steps of the life cycle of each of the parameters under analysis, not favoring an interconnection of the CLEW. This is a result of the process used to build the outline, which considered each one of the four items (climate, land, energy and water) and its life cycle and after that an integration of the separate approaches that resulted in the integrated outline presented in Figure 11.

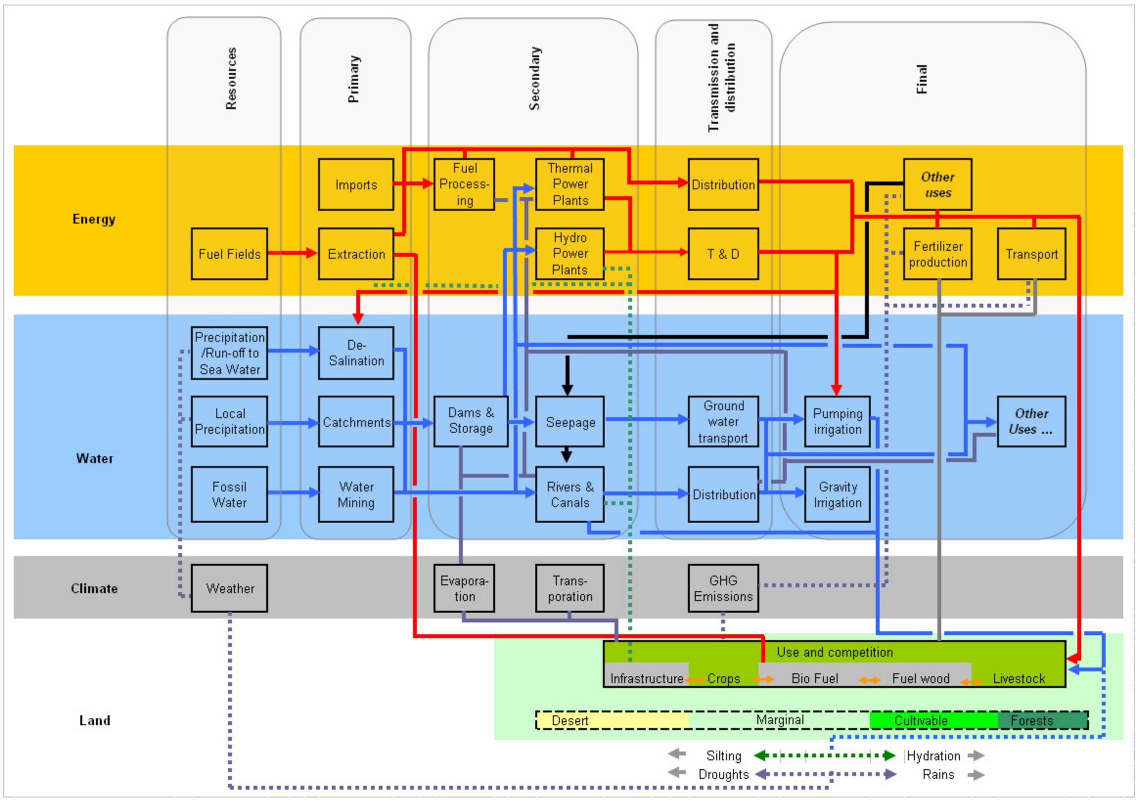

Figure 11 – Aggregate CLEW reference system diagram
Source: IAEA, 2009

The approach introduced by IAEA deals with the aspects related to the production of the items related to CLEW, but does not consider the impacts of the anthropogenic activities related to the issues under assessment. Examples of impacts are deforestation, water pollution, and desertification, among others. For example, it is not clear if the impacts in the availability of water due to deforestation, for example, will be covered in this outline.

This first outline was improved in a conclusive study developed by Welsch *et al.* (WELSCH *et al.*, 2014). This work was able to build a model integrating the CLEW and demonstrates quantitatively the added value of such an integrated CLEWS assessment. Welsch *et al.* (2014) compared conclusions derived from a pure energy planning model with those of an integrated CLEWS approach. The study was conducted in Mauritius, which was identified as an ideal case study given its diverse climate, growing water stress, and its focus on reshaping agricultural land-use and decreasing fossil fuel imports (WELSCH *et al*., 2014). In the Mauritius case study the authors used well established models for energy (LEAP), water (WEAP) and land planning (AEZ), as well as climate change models as an input tool. For climate change the General Circulation Models (GCM[8]) and their corresponding climate projections were obtained. Climate projections were used to derive temperature and rainfall assumptions, which were applied to the other resource models. For land-use it was used Agro-Ecological Zones land production planning model (AEZ[9]) and the Water evaluation and Planning System (WEAP[10]) was applied in the water planning case. Figure 12 shows the outline of the study conducted.

[8] General Circulation Models (GCMs) are numerical models representing physical processes in the atmosphere, ocean, cryosphere and land surface. They are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas. (IPCC, 2013).

[9] The AEZ approach is a GIS-based modeling framework that combines land evaluation methods with socioeconomic and multi-criteria analysis to evaluate spatial and dynamic aspects of agriculture. The International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization of the United Nations (FAO) have been continuously developing the AEZ methodology over the past 30 years for assessing agricultural resources and potential. (IIASA, 2012).

[10] WEAP is a practical tool for water resources planning. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, storage, pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.(SEI, 2011).

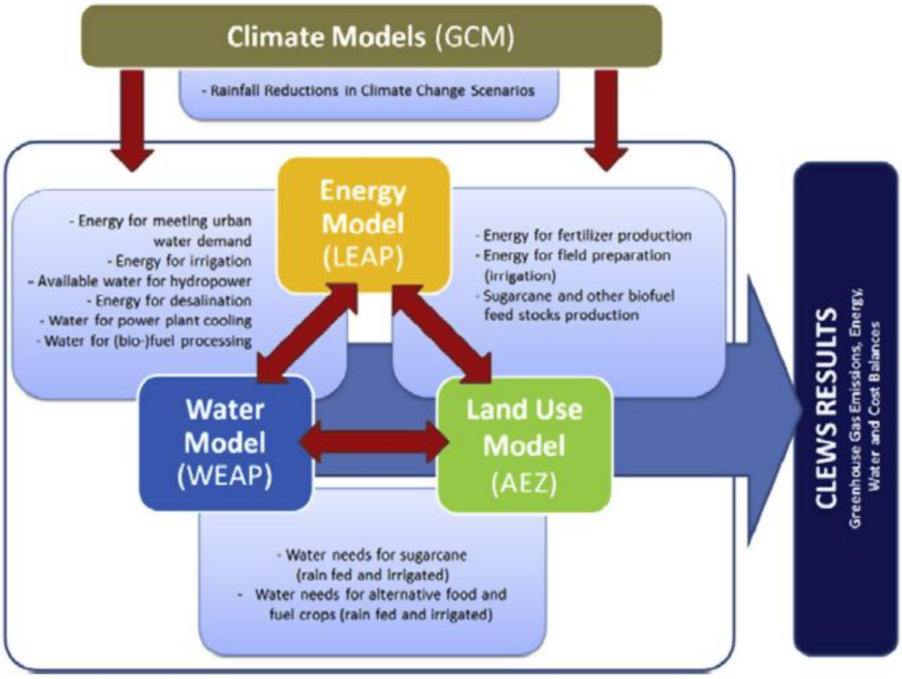

Figure 12 – Outline of the CLEWS study in Mauritius
Source: WELSCH *et al.*, 2014

The energy system was assessed with the Long-range Energy Alternatives Planning (LEAP) tool, which is a widely used software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute (SEI, 2008). LEAP is not a model of a particular energy system, but rather a tool that can be used to create models of different energy systems. This model alone was used as the current practice in the Mauritius case study.

After comparing the results of the energy model alone with the results of the integrated analysis of the CLEW, the study conducted for Mauritius concluded that there is a significant difference in the results of the pure energy planning model and the CLEWS approach. The substitution of imported gasoline with domestic ethanol produced from sugarcane was economically and environmentally attractive in a business as usual setting. However, when the decrease of rainfall was considered as an input item (derived from climate change scenarios), emissions increase due to the need of higher volumes of water to be desalinated and pumped. Net emissions mitigated from introducing ethanol in the transport fleet are more than offset by increased emissions from increased coal electricity generation to be used in the ethanol plantations (BAZILIAN *et al.*, 2011).

Another study conducted in order to test the CLEWS was undertaken in Burkina Faso (see HERMANN *et al.*, 2012). In this study a business-as-usual scenario of land expansion rates of 4% annually for agriculture was compared to a proposal of investment in providing increased amounts of energy to agriculture in Burkina Faso in order to intensify the agricultural practices. This proposal can result in multiple benefits not only in terms of improved yields but also through a reduced need for agricultural land expansion in the future, resulting in quantifiable benefits in terms of saved GHG emissions through increased sequestration in growing forest areas (HERMANN *et al*., 2012).

Gulati *et al.* (2013) analyzed the water-energy-food security nexus regarding challenges and opportunity for food security in South Africa. Although the authors recognize that a deeper analysis is required for a more detailed understanding of the production cycle, food prices and food security relationships, preliminary results show that the energy and water systems play a significant role in driving the availability, quality and affordability of food.

In the Technical Report by the U.S. Department of Energy in Support of the National Climate Assessment (DOE, 2012), the importance of the water-energy-land and climate integrated analysis is emphasized. The approach used was the consideration of the interface between two of the three resources (water-energy; energy-land; and land-water) and the three of them related to climate variability and change (Figure 13). In the Technical Report they call the approach “climate-EWL nexus”.

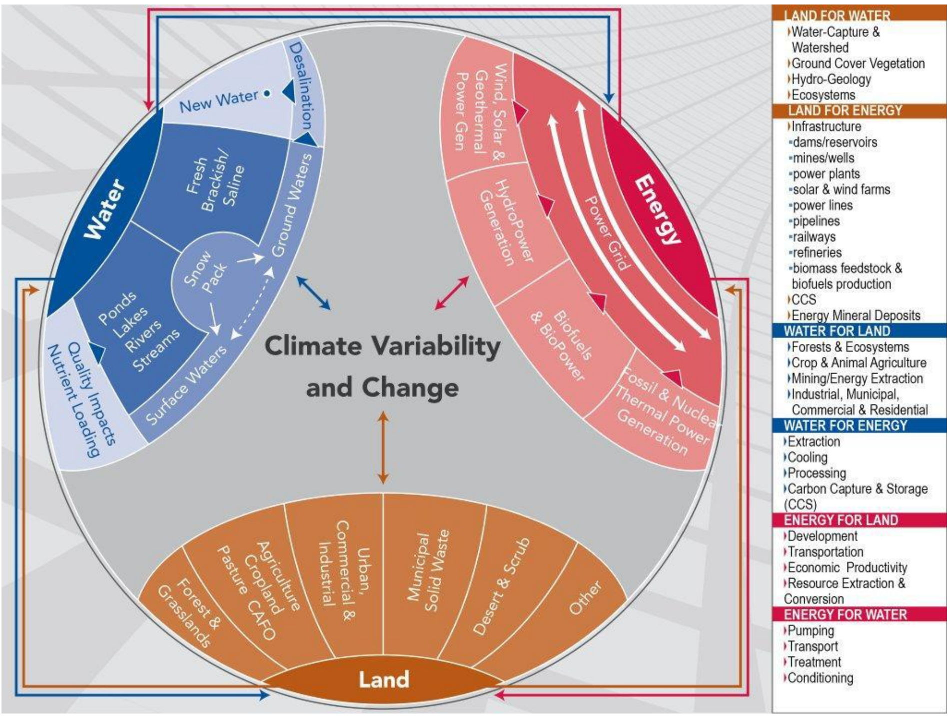

Figure 13 – Illustration of the climate-EWL nexus showing linkages and interactions among the three resource sectors with climate change variability and change.
Source: DOE, 2012

The lack of integration of policies linked to WEL can generate vicious cycles which influence the sustainability of biofuels. For example, deforestation reduces water availability. With greater need for irrigation due to the reduction of water availability, the energy demand is increased, which will require more land for power generation, resulting in more deforestation. Another example would be the adoption of more intensive policies for controlling deforestation. These policies, if not treated in a nexus perspective, could result in less land for growing biofuels, making available land more expensive (supply and demand). The most expensive land would entail the use of poorer quality land for cultivation, requiring more irrigation and inputs, increasing energy demand. With more energy demand in the production, biofuels would present a less favorable energy balance, increasing their cost of cultivation, which not always can be passed on to consumers. The producer will then seek cheaper land of poorer quality, establishing the vicious cycle. If these feedbacks are not treated crosswise into sectoral policies, the vicious cycles can jeopardize sustainability of biofuels. Figure 14 illustrates the cited vicious cycles.

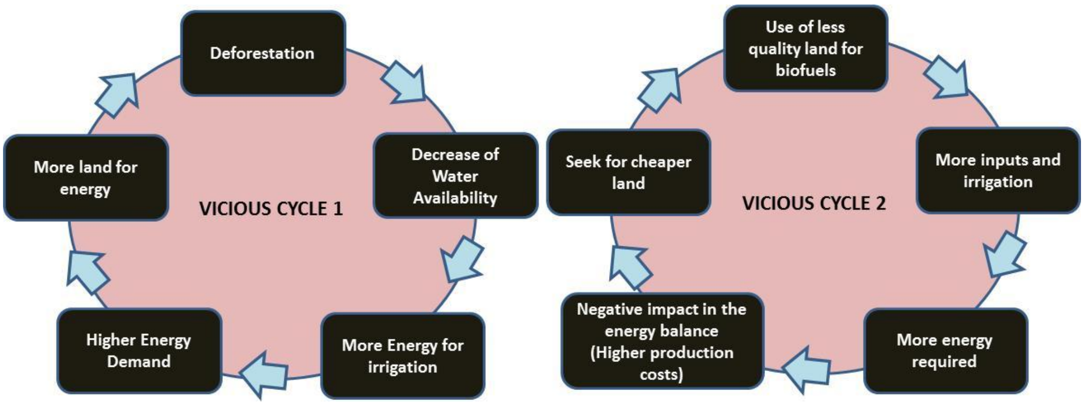

Figure 14 – Examples of possible vicious cycles due to non-integrated policies.
Source: Author's development

As mentioned in the introductory section, the main objective of this study is to determine the difference in the outcome of the sustainability analysis of the ethanol expansion in Brazil when water, energy and land are analyzed separately and when analyses are crossed according to the methodology of nexus. Taking into account the amplitude of each of the issues under consideration and the various possibilities for enhancing the analysis of every single item (water, energy and land), it was necessary to limit the analysis in order to make the work feasible. Thus, this study was not intended to be a comprehensive analysis of each resource, but to conduct an analysis of items that could be properly assessed and that could be cross-checked with the other resources.

To achieve these goals, the case study of the production of ethanol in Brazil was selected in order to test if the issues related to water, energy and land are integrated. The justifications for choosing the Brazilian ethanol production follow:

- The importance of the sustainability of the Brazilian ethanol in the national and international context of bioenergy production (see Chapters 1, 2 and 5);
- Brazilian ethanol production is well established, derived from a program implemented more than 30 years ago (Proalcool) that acted through the value-chain of the production, distribution and use of ethanol in Brazil (see Chapter 5);
- The possibility of exporting the Brazilian experience with ethanol to other developing countries;
- The importance of guaranteeing the sustainability of the Brazilian ethanol involving the three pillars of sustainability: environment, social and economic (not only the economic, related to the energy demand);

- The importance of integrating the water, energy and land issues in the sustainability assessments of ethanol in Brazil, since the production of bioenergy involves land and water issues in a broader manner than other types of energy;
- The importance of integrating policies for achieving sustainability in general, and in particular for ethanol in Brazil;
- Ethanol production has more than doubled in Brazil since the introduction of flex-fuel vehicles (see Introduction and Chapter 5);
- According to the most recent Ten Year Energy Expansion Plan 2022 (PDE 2013-2022), produced by Empresa de Pesquisa Energética (Brazilian Energy Research Company, EPE, 2013), ethanol production in Brazil is expected to rise from 27.3 billion liters in 2013 to 54.5 billion in 2022.

To undertake the study an assessment of selected issues related to the WEL was conducted for the specific case of ethanol in Brazil. The scope of the analysis and limitations for each of the separate resources analysis are explained in detail in Section 3.1.

3.1 Scope and Methodology of the Study

3.1.1 Choice of the case study of the Ethanol Expansion in São Paulo State

Regarding the evolution of sugarcane production, the state of São Paulo has an important participation in the national output (Figures 15 and 16), and sugarcane production is very concentrated in this state.

According to the National Supply Company (CONAB), to the Superintendent of Agribusiness Information (SUINF) and to the Management of Survey and Assessment Crops (GEASA), in 2011/2012, there were 402 sugarcane mills in Brazil. 42% of the national total, or 169 mills, were located in the state of São Paulo. There is a concentration of units in the Center-South of Brazil, with almost 80% of the national total (Figure 15).

Figure 15 – Location of the Brazilian Sugarcane Mills (concentration in the State of São Paulo).
Source: ZAE Cana (MAPA, 2009).

In view of the growing incorporation of land for the production of sugarcane in Brazil, which occurs especially in São Paulo and that São Paulo was responsible for the production of 51% of the total ethanol produced in the country in 2013, the present work considers São Paulo as a sample for the analysis of the policies carried out in this study. Figure 16 shows the evolution of the ethanol production in Brazil and the participation of São Paulo in the total.

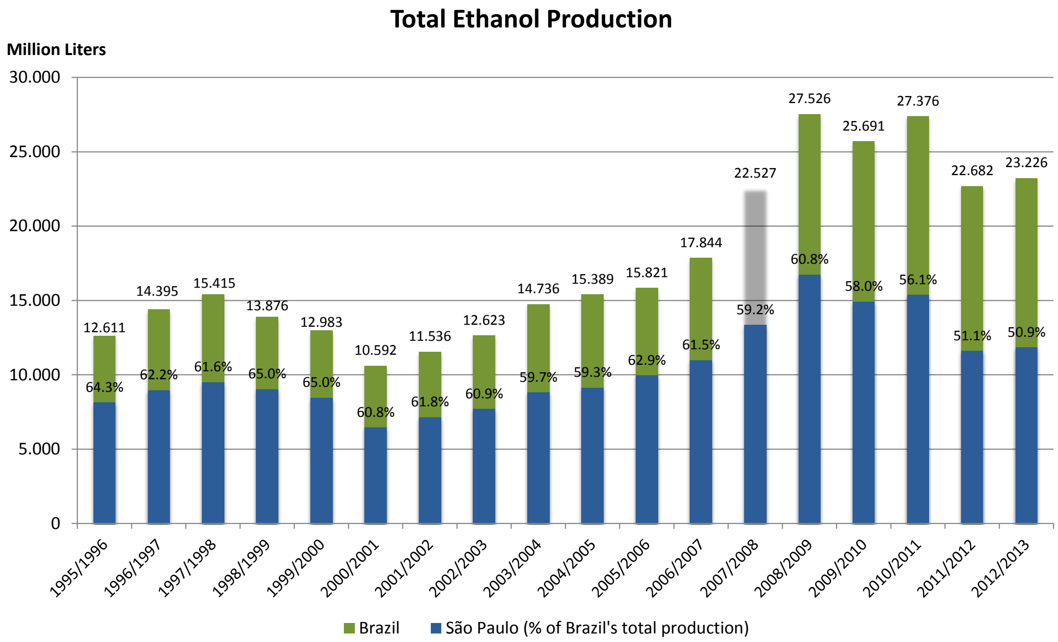

Figure 16 – Evolution of the production of ethanol in Brazil and the participation of São Paulo in the total.
Source: Author's development based on UNICA (UNICA, 2014).

Moreover, it is important to notice that the state of São Paulo is the largest producer of ethanol from sugarcane in the world (SÃO PAULO, 2013). Its quality of soil and favorable climate for agricultural cultivation (especially sugarcane), and skilled labor in the various stages of the ethanol production chain, as well as the presence of advanced technology and institutes of applied research, are some of the reasons for those figures.

Therefore, using the state of São Paulo as the sample for testing the difference in the results of separate and integrated analyses and also how disconnected are the policies in Brazil seem to be appropriate for the present analysis.

3.1.2 Scope of the Water Analysis

The water analysis conducted in the present study was limited to the assessment of the availability of surface water for the ethanol expansion in the state of São Paulo. The National Water Resources Policy (NWRP - Política Nacional de Recursos Hídricos) is the most important policy related to water-use in Brazil. The NWRP, implemented by the Federal Law n. 9,433, introduced in 1997 the concept of water resources management recognizing the river basins as the management unity. (BRASIL, 1997b. Lei nº 9.433, de 8 de janeiro de 1997). Within the implementation of the NWRP, there were established state plans for water resources management for each state in Brazil, as well as specific river basin plans.

Therefore, the water analysis of this study considers the São Paulo State Water Resources Plan (WRP-SP) and the river basin plans of the areas of ethanol expansion in São Paulo as a basis for checking if the expansion of ethanol in São Paulo is sustainable considering the water availability in the river basins where the ethanol expansion is foreseen in the state.

The purpose of the water analysis was to answer the following questions:

- Does the São Paulo Water Resources Plan consider the expansion of ethanol production foreseen in the Brazilian energy policy (PDE 2022)?
- Is there availability of water in the areas of ethanol expansion in São Paulo?

The analysis of water issues, answering the above-mentioned questions is presented in Chapter 4 of this thesis.

3.1.3 Scope of the Energy Analysis

The analysis of the energy issues was conducted in three different perspectives. The first one is related to the mechanisms for the Brazilian biofuels programs implementation and their results so far. In this regard, there were analyzed the leverage mechanisms that established Proalcool and the National Program for Production and Use of Biodiesel (PNPB). Understanding those mechanisms and their results was the basis for the analysis of the importance of having a specific policy for the ethanol expansion in Brazil presented in Chapter 7.

The second perspective is related to the actual energy policy, since Proalcool is no longer a formal program. This analysis was based on the Ten Year Energy Expansion Plan (EPE, 2013) produced by Empresa de Pesquisa Energética (Brazilian Energy Research Company, EPE). According to this Expansion Plan, between 2013 and 2022, ethanol production in Brazil is expected to rise from 27.3 billion liters to 54.5 billion liters, including exports of Brazilian ethanol, which are expected to grow from the current 3.0 billion liters to 3.5 billion liters in 2022. To meet this demand, sugarcane production in the year 2022 is estimated to reach 995 million tons (an increase of 57%

in relation to 2013). Considering a productivity gain of sugarcane per hectare of 2.4% per year[11], this will require a total farming area of 11.3 million hectares (EPE, 2013).

Finally, the third perspective includes the analysis of the energy balance of ethanol in Brazil in order to identify possible impacts of other policies on it. The data used was a compilation of the data produced and published by the most important researchers of this issue in Brazil.

Chapter 5 presents the detailed analysis of the issues related to energy.

3.1.4 Scope of the Land Analysis

The complexity and breadth of policies for land use in Brazil make the analysis of this item also complex and comprehensive. Therefore, the analysis of the policies of land use was divided into three different items: a) Agro Ecological Zoning for sugarcane in the State of São Paulo (ZAE Cana); b) Dynamics of the price of land for the expansion of the ethanol production in São Paulo, and c) Direct Land Use Change (DLUC) related to the sugarcane plantations in the state of São Paulo.

Presidential Decree number 6961 of September 2009 established the Agro-Ecological Zoning of Sugarcane (ZAE Cana). This document, especially with regard to the state of São Paulo, was analyzed in order to understand their intersections and points of convergence (or divergence) with the energy policy and the NWRP regarding the sugarcane sector in Brazil.

The dynamics of the price of land in the state of São Paulo were also evaluated with the intention of determining its influence on land use and consequently how this use can influence the vicious cycle presented earlier (vicious cycle 2) and also land use change. Also, the price of land was cross-checked with the areas of expansion proposed by ZAE Cana aiming to check the preferred areas for the expansion in the state of São Paulo.

Furthermore, to verify whether there is Land Use Change (LUC) related to the expansion of sugarcane, a review of the most important literature was conducted. These results were used to understand what kind of activities sugarcane expansion will dislocate for cross checking with PDE and WRP SP.

The main questions to be answered in the case of land are the following:

[11] Calculated based on the increase in productivity (EPE, 2013)

• Does the expansion of the ethanol production in São Paulo under the PDE 2022 entail direct land use change? Ethanol is expanding in such a way that induces deforestation? What activities will be dislocated due to the sugarcane expansion?

• How is the use of land for ethanol production? What are the dynamics of pricing? What is the influence of the price of land in the type of land use for this expansion?

• ZAE Cana is aligned with PDE and WRP SP?

The analysis of land-use issues is presented in Chapter 6.

3.1.5 WEL Nexus Methodology

In order to test if the separate analysis of issues differ from the integrated analysis applied to the expansion of biofuels production in Brazil, an integrated analysis was performed using the results of the separate analysis of each resource.

The applied methodology was based on interfaces between the sectoral policies for each of the WEL resources and their outcomes. The integrated analysis was based on the methodologies proposed by the DOE (DOE, 2012) and the IAEA (IAEA, 2009), as well as in the case studies analyzed for Mauritius and Burkina Faso (WELSCH *et al.*, 2014; HERMANN *et al.*, 2012). Figure 17 shows the outline of the interrelations that were analyzed in the present work. It is important to notice that this interrelations are specific to biofuels. Therefore, it does not include some of the items described in the scheme developed by the DOE (Figure 13). As can be seen in Figure 17, a cross between the analyzed resources (water, energy and land) is proposed, where the intersections are the specific policies of each resource. The integrated analysis inteded also to subsidize the conclusion of the necessity of a specific policy for biofuels that integrates the basic resources for this bioenergy production.

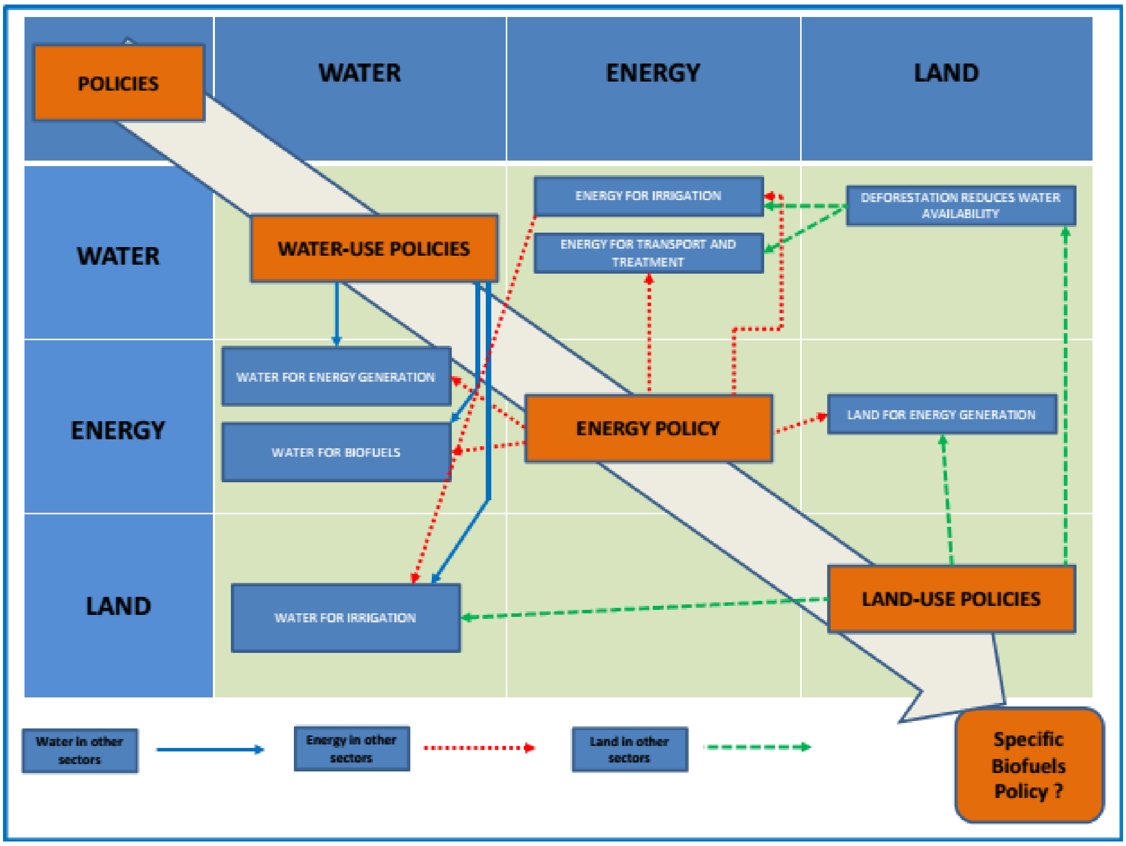

Figure 17 – Integrated Analysis applied to Biofuels.
Source: Author's development

Therefore, using the expansion of ethanol in the State of São Paulo as a sample and answering the specific questions related to each resource of the WEL, it was possible to conclude if the results change when an integrated analysis is conducted, and how disconnected are the specific policies. Additionally, the analysis provided subsidies for the understanding of the need of a sectoral policy related to ethanol production in Brazil. Figure 18 shows a schematic summary of the relationships tested in this study. The scheme showed in Figure 18 is specific for the ethanol expansion in the State of São Paulo.

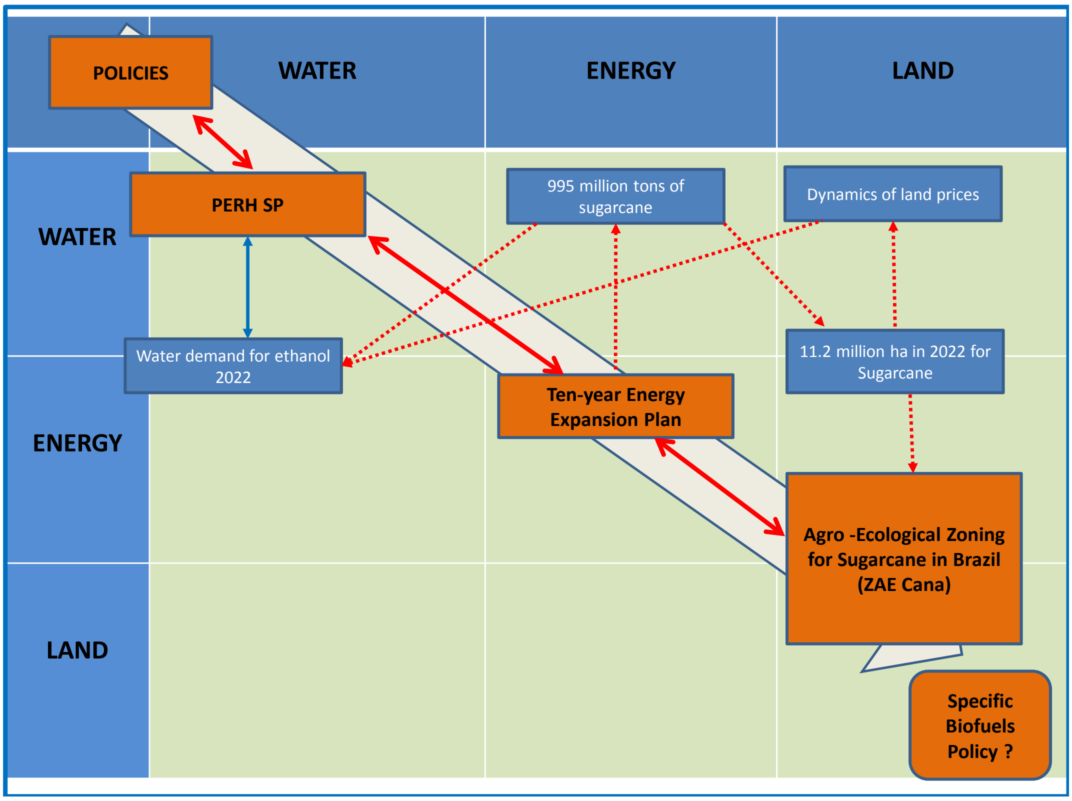

Figure 18 – Schematic summary of the relationships tested in this study.
Source: Author's development

This WEL nexus analysis is presented in Chapter 7 where the individual results were cross-checked leading to an integrated analysis. With this assessment it was possible to answer the two main questions of the present work already mentioned:

1) How disconnected are the Brazilian water-use, land-use and energy policies in relation to biofuels expansion in Brazil?
2) Is there a need to develop a sectoral policy for biofuels integrating water, energy and land resources?

4 Water

As mentioned in Chapter 3, the analysis water issues and policies and its correlation with related land and energy issues and policies is essential for a comprehensive analysis of the sustainability of ethanol production expansion in Brazil. Water is being increasingly demanded and increasingly less available around the world. Therefore, it is important to the ethanol expansion in Brazil to view water strategically.

In agriculture, there is a close association between water and energy, sometimes complementary, and other times, conflicting. As shown previously, a large amount of energy is consumed to pump water to irrigate crops, which is an associated demand. On the other hand, multi-purpose dams, which combine power generation and irrigation, can justify investments that would not be economically feasible for one purpose. In contrast, conflicts may arise over water distribution for hydropower for irrigation at the same dam (GAZZONI, 2009).

In this context, the analysis presented in this chapter intends to clarify the following questions related to water within the ethanol production in São Paulo State:

a) Does the São Paulo Water Resources Plan consider the expansion of ethanol production foreseen in the Brazilian energy policy (PDE 2022)?
b) Is there availability of water in the areas of ethanol expansion in São Paulo?

Answering the above questions will help to show how disconnected the water policies in relation to land and energy policies are, as well to support the conclusion if there is a need for a specific policy for ethanol on Brazil.

Water is a basic requirement for the development of any society. The conservation of water is part of commitment to the future generations to build a sustainable world. In nations with water shortages, there are several efforts to guarantee water conservation. On the other hand, in nations without water shortages, no great efforts are being made to manage water use. Currently, over 40% of the world population suffers from water supply constraints (PEREIRA, 2009), which should be strong motivation for further studies be conducted on local, regional and worldwide perspectives regarding the proper use of water resources.

Even considering the importance of water for human activities and for agriculture in particular, there are few studies that analyze the impact of bioenergy on the water systems. One of the most cited authors who developed several studies related to water and biofuels, especially the biofuels water footprint (WF) in the world, is

Winnie Gerbens-Leenes. According to this author (GERBENS-LEENES *et al*., 2012), the first study of the relationship between water availability and future biomass use concluded that in large-scale, bioenergy production doubles the global evapotranspiration[12] from cropland between 1990 and 2100 (BERNDES, 2002). This study also found that the leading energy scenarios did not take water into account when estimating future biomass use. Although conducted in 2002, the concerns presented in the study are still important in the current scientific view of water-use and biofuels. Gerbens-Leenes *et al*. (2009) shows that the WF of energy from biomass is nearly 70 to 700 times larger than that of fossil fuels. According to Gazzoni (2009), the average water demand for fossil energy is 1 m^3/GJ, compared with 46-500 m^3/GJ for biofuels. Globally, more than 90% of the water needed is used for the production of raw material and only a relatively small amount is used in biomass processing.

In a 2012 study, Gerbens-Leenes *et al.* assessed biofuel scenarios related to water for 2030, considering the International Energy Agency Alternative Policy Scenario as a basis (see IEA (1), 2012). The authors concluded that the global biofuel water footprint will increase more than tenfold from 2005 to 2030 and that the USA, China and Brazil together will contribute to half of the global biofuel WF. On the other hand, in a 2010 UNESCO-IHE report authored by Mekonnen and Hoekstra (MEKONNEN and HOEKSTRA, 2010), the global water footprint related to crop production was analyzed in the period from 1996-2005, and authors found that the total water footprint was largest for India (1047 Gm^3/yr), China (967 Gm^3/yr), and the USA (826 Gm^3/yr). These finding show that Brazil uses less water than other large biofuels producing countries.

Regarding sugarcane in Brazil (the largest producer of sugarcane in the world) different authors state that most of the cultivation is rainfed (UNICA, 2007; GOLDEMBERG, 2008; ANA, 2009). However, a survey based on 103 mills indicated that more than 12% of the sugarcane area in Brazil was irrigated in the 2011/2012 season, compared to less than 10% in the previous season (PINTO *et al.*, 2011), which shows that the irrigation on sugarcane in Brazil is increasing over time.

Although Brazil is endowed with large fresh water resources when compared to most other countries, there is an unequal spatial distribution of these resources within the Brazilian territory. According to the National Water Agency (ANA), about 80% of

[12] Evapotranspiration (ET) is the combination of two separate processes: water lost from the soil surface by evaporation and from the crop by transpiration. (FAO, 2014)

the water available is concentrated in the Amazon Hydrographic Region, where the population density is very low and the figures for consumptive water demand are also very low (ANA, 2013a). Figure 19 shows the Brazilian Hydrographic Regions and Table 2 presents the water availability for each Hydrographic Region (HR) presented in the 2013 study of the Brazilian National Water Agency (ANA) (Conjuntura dos Recursos Hídricos no Brasil – ANA, 2013a):

Table 2 – Water Availability per Hydrographic Region in Brazil

Hydrographic Region (HR)	Average flow (m^3/s)	Water Availability (m^3/s)
Amazônica	132,145	73,748
Tocantins-Araguaia	13,799	5,447
Atlântico Nordeste Ocidental	2,608	320
Parnaíba	767	379
Atlântico Nordeste Oriental	774	91
São Francisco	2,846	1,886
Atlântico Leste	1,484	305
Atlântico Sudeste	3,167	1,145
Atlântico Sul	4,055	647
Paraná	11,831	5,956
Uruguai	4,103	565
Paraguai	2,359	782
Brasil	179,938	91,271

Notes:

- The HR Amazônica still comprises an area of 2.2 million km^2 in foreign territory, which contributes with an additional 86,321 m^3/s in terms of average flow.
- The HR Uruguai still comprises an area of 37,000 km^2 in foreign territory, which contributes with an additional 878 m^3/s in terms of average flow.
- The HR Paraguai still comprises an area of 181,000 km^2 in foreign territory, which contributes with an additional 595 m^3/s in terms of average flow.

Source: Adapted from ANA, 2013a

Figure 19 – Brazilian Hydrographic Regions.
Source: ANA, 2013a

Water may be required for consumptive[13] and non-consumptive[14] uses. In Brazil, as in most of the countries in the world (FAO, 2013a), the most significant use in terms of withdrawal in the year 2010 was irrigation, followed by urban supply, representing 54% and 22% of the total, respectively (ANA, 2013a). However, compared to China, India, USA, Japan, Iran and Pakistan, the demand for water for irrigation in Brazil is significantly lower, which results mainly from aspects of agricultural cultivation (higher water availability during periods of germination and growth of

[13] Consumptive water use implies a substantial reduction in the quantity or quality of the water that returns to the system after being withdrawn (KHOLI *et al.*, 2010).
[14] Non-consumptive water use does not substantially change the withdrawn water, almost all of it returning to the system. Most in-stream water uses are non-consumptive (KHOLI *et al.*, 2010).

agricultural crops) and / or economic (low availability of agricultural credit to purchase irrigation equipment) (FAO, 2013b).

As can be noticed in Figure 19, most of São Paulo State is located in the Parana HR, which has a water availability (measured by ANA in superficial waters) of 5,956 m^3/s. Although the total availability of water in the Parana Basin is high, the situation in different specific river basins can be of concern (see section 4.3 for more details). In this case, resources should be managed so that the potable water resources are not fully used for the expansion of the sugarcane crop, for which the quality of water is not fundamental, as it is in the case of human consumption.

The Brazilian National Water Resources Policy (NWRP) instituted in 1997 a form of water management based on river basins. In the implementation of this policy, structures were implemented in the river basins of the country in order to establish the decentralized management of water resources in Brazil. Thus, it is important for the analysis to be conducted in this chapter, the presentation of the structure imposed by NWRP (session 4.1). Considering the scope of the analysis devoted to the São Paulo state, specific management structures for São Paulo are presented in session 4.2, especially the São Paulo Water Resources Plan 2012 - 2015.

From the cross-examination of these documents and the answers to the key questions mentioned earlier in this chapter, which will be used in Chapter 7 of this study (Nexus Methodology to Water-Energy-Land), it will be possible to test how disconnected are the water policies in relation to land and energy policies, as well to subsidize the conclusion if there is a need for a specific policy for ethanol in Brazil.

4.1 National Water Resources Policy (NWRP)

In 1997, the Federal Law n. 9,433 established the National Water Resources Policy (NWRP) and created the National Water Resources Management System (NWRMS) in order to ensure the current and future generations water in good quality and sufficient availability through rational and integrated use, prevention, and protection of water resources against critical hydrological events. This policy is based on the principles that water is a public good; it is a limited natural resource which has economic value; its management should assure the multiple uses of water; the river basin is the territorial unit to the implementation of the NWRP; and the management of water resources should be decentralized and include the participation of the government, users and communities (BRASIL, 1997b. Lei nº 9.433, de 8 de janeiro de 1997).

The NWRP defines the “River Basin Plans” (RBP, Planos de Bacias), which should be implemented by the Water Agency (WA) and approved by the River Basin Committees (RBC). This plan will set out data regarding water quality, priority uses, availability and demand, streamlining goals, guidelines for charging the use of water resources, proposals for restricted areas, etc. NWRP established a new organizational framework composed of the National Water Resources Council (NWRC), State Water Resources Councils (SWRCs), River Basin Committees (RBCs), State Water Resources Management Institutions (SWRIs) and Water Agencies (WAs) (VEIGA and MAGRINI, 2013)

The NWRP also has guidelines on water bodies, which should be classified according to its characteristics and its preponderant use. The water bodies should be rated according to the CONAMA Resolution 20/86 which stipulates the criteria for classification of water bodies as sweet, salty, brackish or saline.

The grant of the water rights, which is another instrument of the NWRP, aims to guarantee quantitative and qualitative control of water use and the effective exercise of rights of access to water resources. The right to use water resources under federal domain should be given by the National Water Agency (ANA), in accordance with the provisions of the River Basin Plan. Water bodies under federal jurisdiction are the rivers, lakes and dams that divide or pass through two or more states, or even those who pass through the border between Brazil and another country. For other rivers, such as those in domain of the states, the institution managing the water resources of that state is responsible for the grant.

The NWRP also outlines water usage charges, inserting the polluter pays principle for the use of water resources issues. The charge for water use treated by the NWRP aims to encourage the rationalization of this resource and to give the population the understanding of the actual value of water resources. The revenue of the water usage charge is to be invested in the river basin.

Moreover, the NWRP implemented the Water Resources Information System (WRIS), which aims to provide support for the formulation of Water Resources Plans, as well as to gather, promote and permanently update data on quality, quantity, availability and demand for the water resources of the country.

The National System for Water Resources Management (SINGREH) consists of the National Water Resources Council (NWRC), which is deliberative and normative upper body; the National Water Agency (ANA), a government agency under a particular structure linked to MMA (Ministry of Environment) and with administrative and financial autonomy to ensure the implementation of NWRP; the States Water Resources Council; the River Basin Committees (RBC); the Institutions of federal, state, and municipal governments whose responsibilities relate to the management of water resources; and the Water Agencies (WA) that after the formation of the River Basin Committee (RBC) may be established to act as executive secretary of one or more RBC.

The National Water Resources Council (NWRC) develops activities since June 1998, occupying the highest court in the hierarchy of the WRIS. It is a board that develops rules of mediation between the various water users, being, therefore, largely responsible for the implementation of water resources management in the country. Its main responsibilities are to analyze proposals for amendments on water resources legislation; to establish additional guidelines for implementation of the NWRP; to promote joint planning of water resources with national, regional, state planning and industrial users; to arbitrate conflicts over water resources; to decide on projects where water resources repercussions go beyond the scope of the states that will be implanted; to approve proposals for the establishment of river basin committees; and to approve the NWRP and monitor its implementation, among others.

The River Basin Committees are considered the basis of a participatory and integrated water management, and have a deliberative role. These joint committees are composed of representatives from government, civil society and water users, which make decisions regarding the river basin where it operates.

4.2 São Paulo Water Resources Plan (WRP SP, 2013)

In São Paulo State, the Water Resources State Policy, instituted by Law 7,663/1991 establishes decentralization, participation and integration as principles for the development of the São Paulo Water Resources Plan (SÃO PAULO, 1991. Lei nº 7.663, de 30 de dezembro de 1991). The São Paulo Water Resources Plan (WRP SP) is now in its 6th version, for the quadrennial 2012-2015.

For the purpose of water management, São Paulo State was divided into 22 Water Resources Management Units (in Portuguese, Unidades de Gerenciamento de Recursos Hídricos - UGRHI), which were adopted since the WRP SP 1994/1995. The 22 UGRHI of São Paulo State are included in the basins of the Parana River and Southeast Atlantic, following the basins established by the National Water Resources Council (NWRC).

The actual WRP SP (2012-2015) was based on the WRP SP 2004-2007, which meant a breakthrough in the interactive process as it established strategic and general goals, an investment program in three scenarios (desirable, likely, and recommended) and updated the programs to be developed by each UGRHI.

From the approval of WRP SP 2004-2007 to the current date, the River Basin Plans for the 22 UGRHI were developed and / or updated, along with Situation Reports for Water Resources in São Paulo and UGRHI for the years 2008, 2009, 2010 and 2011. The investment plan from the WRP SP 2004-2007 program guided the WRP SP 2012-2015 to revise the actions, programs and projects then proposed, together with the collegiate and the executing agencies, in order to obtain a planning set and possible actions to be performed. Therefore, the WRP SP 2012-2015 is an update of the WRP SP 2004-2007, indicating targets, deadlines, source of funds, institutions and monitoring indicators, seeking to ensure inter-sectoral work necessary for water resource management (WRP SP, 2013). It should be noted that studies should always have the river basin as their planning unit, focusing on their context, on the UGRHI, whose boundaries are highlighted in Figure 20 (SIRGH, 2013).

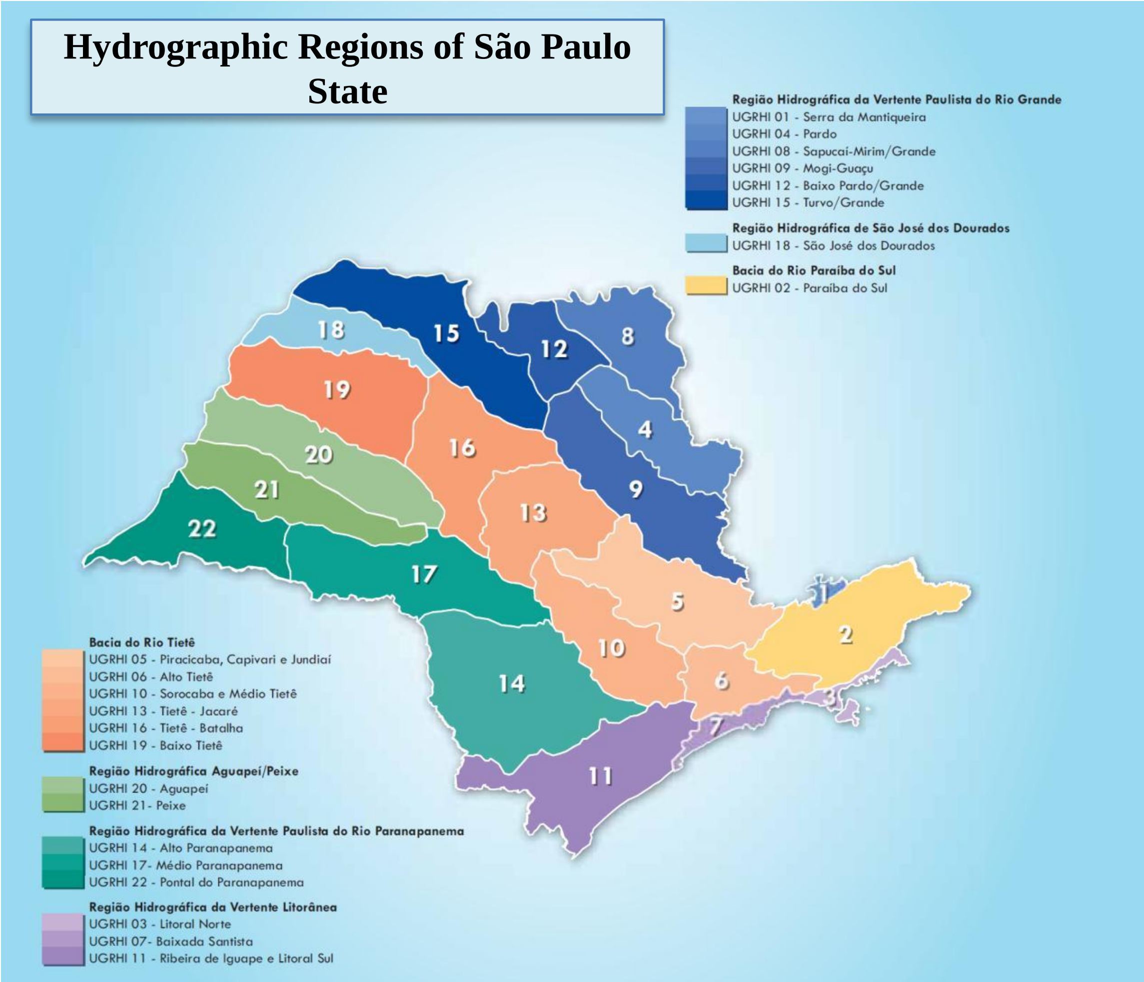

Figure 20 – Hydrographic Regions – River Basins and Units of Water Resources Management from the state of São Paulo.
Source: Adapted from SIRGH, 2013

Regarding underground water, the aquifers of São Paulo State are classified into two major groups: sedimentary aquifers (Furnas, Tubarão, Guarani, Bauru, Taubaté, São Paulo, Litorâneo) and fractured aquifers (Pré-Cambriano, Pré-Cambriano Cárstico, Serra Geral e Serra Geral Intrusivas). Among the sedimentary aquifers, Guarani, Bauru and Taubaté are very important for productivity, and used for residential water supply.

The Bauru Aquifer occupies almost the entire western portion of São Paulo State, an area of 96,880 km^2. This aquifer supplies to the largest number of municipalities in the state. The Guarani Aquifer, considered the largest source of fresh water underground in the world, covers 76% of the state´s territory. The aquifer has an outcrop area of about 16,000 km^2. The Taubaté Aquifer is located in the Paraíba do Sul River valley, in the eastern portion of the state of São Paulo, occupying an area of 2,340 km^2. The region is a major economic hub between São Paulo and Rio de Janeiro cities, encompassing important cities, such as São José dos Campos, Jacarei and Taubaté. The Serra Geral Aquifer extends throughout the central and western region of the state, between Bauru Aquifer and the Guarani Aquifer, with an area of outcrop of about 20,000 km^2.

4.3 Demand and Water Availability

According to the WRP SP 2012-2015, the per capita availability[15] of surface water in São Paulo indicates a situation of attention in 2010. The UGRHI that have the lowest levels of per capita availability are also those with most concentrated population: Alto Tietê (135 m^3/inhabitants.year), Piracicaba, Capivarí e Jundiaí (1.069 m^3/inhabitants.year) and Sorocaba e Médio Tietê (1.831 m^3/inhabitants.year), showing the correlation between water availability and demographic-social dynamics of the state of São Paulo. According to the WRP SP, in 2010, the UGRHIs 05-PCJ and 06-AT remained in critical condition, and UGRHI 10-SMT and 13-TJ in situation of attention.

In terms of groundwater availability, the evolution of per capita availability of groundwater showed almost stable situation in the period 2007-2010. Both in 2007 and in 2010, UGRHI 06-AT, 05-PCJ and 13-TJ showed the lowest per capita availability of groundwater in the state. The most extensive areas with high vulnerability in São Paulo’s UGRHIs are 02-PS, 04-PARDO, 08-SMG, 13-TJ, 14-ALPA, 18-SJD and 22-PP, indicating the need for greater care in installation of future activities and for detailed studies on potentially polluting activities.

Whereas the issue of water use is local or regional, and global models in many cases do not reflect the dynamics observed in specific river basins, the use of primary data was prioritized for the estimates of the present work. When they were not available, several references were analyzed to obtain the statistics needed, for example, the demand of water for the ethanol production in São Paulo State, including the use of water for the production of sugarcane and the use of water for the conversion of sugarcane in ethanol (industrial use).

Considering the analysis conducted in the present study, it is important to check the availability of water in the river basins related to the expansion of sugarcane

[15] In this work, the term "availability" considers the volumes that can be captured from a source, regardless of the status of water balance. (CPTI, 2008).

in São Paulo State. These figures shall be cross checked with the forecast of the demand of water for this expansion in order to verify if the river basins have sufficient water for the expansion considered in the PDE 2013-2022 (boundary conditions, Chapter 3).

In this context, it is important to understand in which UGRHIs the expansion occurs both for the production of raw material (sugarcane plantations) and for the industrial production of ethanol (sugarcane mills).

Rudorff *et al.* (2010) analyzed the dynamics of the cultivated sugarcane area through Landsat type images (CANASAT project)[16] for each Administrative Region (AR) of São Paulo State from agronomic year[17] (AY) 2003/04 to 2008/09. In the timeframe analyzed by the authors, a major increase in sugarcane production was observed not only in traditional sugarcane and annual crop producing regions such as Ribeirão Preto, Central, Franca and Barretos, but also in regions that are more devoted to cattle-raising in the western part of São Paulo State such as São José do Rio Preto, Araçatuba and Presidente Prudente. These figures were confirmed by Novo *et al.* (2012) that reported an increase in land for sugarcane in the administrative regions (ARs) of Franca and São José do Rio Preto between 2003 and 2008 of 38% and 125%, respectively. More recent data obtained in the CANASAT project for the AYs between 2009 and 2012 shows that this tendency remains the same, with an increase of 8.33% in São José do Rio Preto and 9.13% in Presidente Prudente, the two most important regions for the expansion of sugarcane, between 2009 and 2012. Table 3 shows the expansion in sugarcane areas from 2003/2004 to 2011/2012 for Araçatuba, Ribeirão Preto, São José do Rio Preto, Barretos, Central, Franca and Presidente Prudente and also the UGRHIs where they are located.

[16] The CANASAT project was developed by the National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais - INPE), the Industry Sugarcane Association (UNICA), the Center for Advanced Studies on Applied Economics (CEPEA) of the Luiz de Queiróz Agricultural School (Esalq/USP) and the Center for Sugarcane Technology (CTC). The project annually maps the cultivated sugarcane areas in the South-Central region of Brazil using Landsat type images and geospatial processing techniques. (RUDORFF *et al.*, 2010)

[17] An agronomic year consists of the last six months of one year and the first six months of the next. (NOVO *et al.*, 2012)

Table 3 – Evolution of the sugarcane cultivated area per UGRHI

Administrative Region (AR)	Total Sugarcane Cultivated Area (ha x 1,000)			Increase in the period 2009-2012 (%)	UGRHI
	2009-2010	2010-2011	2011-2012		
Central	449	452	466	3.79	Tietê-Jacaré
Presidente Prudente	409	428	446	9.13	Peixe
São José do Rio Preto	698	724	756	8.33	Turvo/Grande
Araçatuba	572	587	597	4.44	Baixo Tietê
Ribeirão Preto	483	482	483	0.00	Pardo
Franca	501	500	504	0.45	Sapucaí-Mirim/Grande
Barretos	397	401	411	3.47	Baixo Pardo/Grande

Source: Developed by the author based on CANASAT (CANSAT, 2014); WRP 2004-2007 (Anexo B) (SÃO PAULO, 2013)

Regarding the location of the sugarcane mills, the same tendency can be observed. The ARs of Araçatuba, Ribeirão Preto, São José do Rio Preto, Barretos, Central, Franca and Presidente Prudente have been responsible for an average of 68% of the total production of ethanol in São Paulo state in the last 10 years. Table 4 shows the production in each AR and the total production of São Paulo State between 2003 and 2012 and also the participation of the ARs in study in the total production of the state.

Table 4 – Ethanol production per year in each Administrative Region

	Ethanol Production (1,000 m^3)									
Administrative Region (AR)	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Araçatuba	285	374	371	560	909	1661	1550	1450	758	801
Ribeirão Preto	774	847	973	982	1366	1420	1010	1115	806	669
São José do Rio Preto	337	405	624	822	1328	1760	1703	1571	827	923
Barretos	78	171	267	426	676	872	860	826	572	581
Central	140	215	276	459	609	770	625	534	369	394
Franca	199	270	345	369	476	513	472	582	414	279
Presidente Prudente	107	224	304	369	450	673	847	975	861	596
Total ARs studied	1920	2505	3160	3986	5813	7669	7067	7054	4607	4244
Total São Paulo	2872	3783	4522	5631	8399	10716	10728	10220	6844	6235
Total ARs in relation to SP (%)	**67**	**66**	**70**	**71**	**69**	**72**	**66**	**69**	**67**	**68**

Source: Developed by the author based on SÃO PAULO, 2014

Therefore, taking into consideration the seven selected UGRHIs listed in Table 5 (Tietê-Jacaré, Pardo, Peixe, Turvo/Grande, Baixo Tietê, Sapucaí-Mirim/Grande and Baixo Pardo/Grande), the São Paulo Water Resources Plan was analyzed in terms of:

a) Total water availability considering the $Q_{7,10}$, which is the minimum flow of 7-day and 10-year recurrence time (with a 10% risk that values less than this occur in any year) (L. Mendes, 2007);
b) Actual demand in the seven selected water basins including all uses;
c) The impact of the agro-energetic industry of ethanol in the water availability; and
d) Water management in the specific basins focused on sugarcane expansion.

Regarding the total water availability considering the $Q_{7,10}$, and the demand in the seven selected water basins including all uses, it is important to investigate the conditions of water restriction in the areas of sugarcane expansion (UGRHIs Pardo, Sapucaí-Mirim/Grande, Baixo Pardo/Grande; Turvo/Grande; and Peixe). In accordance with the analysis of the River Basin Plans and with the WRP SP 2012-2015, the situation of the region is still comfortable (Table 5), with the current demand achieving 28% of the measured $Q_{7,10}$. Regarding individual basins, the situation is already problematic in the basins Turvo/Grande and Baixo Pardo/Grande, in which the current demand already exceeds 50% of the $Q_{7,10}$. In the UGRHI Baixo Pardo/Grande it is observed that the current agricultural demand alone amounts 55% of the minimum flow of 7-day and 10-year recurrence time (SÃO PAULO, 2013).

Table 5 – Water availability x Actual water demand in the Regions of Sugarcane Expansion

Administrative Region	UGRHI	$Q_{7,10}$ (m^3/s)	Actual Demand[1] (m^3/s)	% $Q_{7,10}$[2]
Central	Tietê-Jacaré	40	16.40	41
Presidente Prudente	Peixe	29	2.39	8
São José do Rio Preto	Turvo/Grande	26	15.28	59
Araçatuba	Baixo Tietê	27	6.21	23
Franca	Sapucaí-Mirim/Grande	30	12.09	40
Ribeirão Preto	Pardo	28	4.85	17
Barretos	Baixo Pardo/Grande	21	15.22	72
TOTAL ARs		**201**	**72.44**	**28**

[1] Actual demand for all uses in 2011 reported in the WRP 2012-2015 (SÃO PAULO, 2013)
[2] Percentage of the $Q_{7,10}$ in use in 2011
Source: Prepared by the author based in SÃO PAULO, 2013; PARDO, 2008; TIETÊ/JACARÉ, 2008; TURVO/GRANDE, 2008; BAIXO TIETÊ, 2009; SAPUCAÍ-MIRIM/GRANDE, 2008; BAIXO PARDO/GRANDE, 2008; PEIXE 2008.

The criterion established by Law 9,034/94 of São Paulo State (São Paulo, 1994. Lei nº 9.034, de 27 de dezembro de 1994) is that the water grants[18] ("outorgas") may not exceed 50% of the $Q_{7,10}$ of the river basin. Therefore, unless the specific River Basin Plan institute a different basis, it is noted that in some of the basins of sugarcane expansion, the availability of water resources can be a limitation issue for the sugarcane expansion. As mentioned before, in two of the seven UGRHIs analyzed, the water use is already greater than 50% of the minimum flow of 7-day and 10-year recurrence time ($Q_{7,10}$). Moreover, although the demand for all uses is still under 50% of the $Q_{7,10}$ of the region, 28% are already compromised.

These figures are confirmed by Pereira (2009) and Brunini (2009). According to Pereira (2009), water restriction in the area of sugarcane expansion range from high to moderate. Figure 21, reported by Brunini (2009), shows the expansion areas of sugarcane and their water restriction.

Figure 21 – Areas of Sugarcane Expansion and their water restriction.
Source: BRUNINI, 2009

The River Basin Plans analyzed do not present a forecast for the water use in a future scenario. Therefore, for calculating the demand for all uses in 2022 it was assumed an increase of 1.5% per year, which is the predicted growth rate of the

[18] Water grants ("outorgas") are the permit granted by the government needed for water use by consumers in a certain river basin. ANA provides the grant for Federal river basins. For river basins of the state of São Paulo this grant is of responsibility of the Department of Water and Electric Power of São Paulo (DAEE).

population in some of the River Basin Plans. Results show a demand for all uses in 2022 of 2.8 billion m^3, representing 46% of the $Q_{7,10}$ (6.3 billion m^3).

Now, it is important to verify the water demand for ethanol for 2022 considering the expansion foreseen in the PDE 2013-2022 to understand the impact of the agro energetic industry of ethanol in the water basins.

There is a consensus among the most important researchers of ethanol production in São Paulo (UNICA, 2007; GOLDEMBERG, 2008; SMEETS *et al.*, 2008; PEREIRA, 2009; GAZZONI, 2009; and OLIVÉRIO *et al.*, 2010), that the impacts of the sugarcane culture on the water supply (volumes and quality) are small under the conditions found in São Paulo (UNICA, 2007). Hernandes *et al.* (2013) stated "as irrigation volumes are usually small, critical water stress situations would hardly be reached, regarding sugarcane plantations in the state of São Paulo, where the rain-fed conditions are appropriate for sugarcane cultivation". In fact, data from 2006 suggests that sugarcane plantations in São Paulo were mostly rain-fed as already mentioned in this chapter. According to the last IBGE[19] census (IBGE, 2006), 473,126 ha of sugarcane plantations were irrigated in São Paulo, totalizing 15% of the total sugarcane planted in the State (3,045,402 ha).

According to ANA (2009), in Brazil and especially in the sugarcane region of the Center-south (where São Paulo is included) there is no use of water for full irrigation of sugarcane fields. Irrigation occurs only in certain regions where there is the rescue or supplemental irrigation with small water slides normally using wastewater from industrial processes (ferti-irrigation).

However, verifying the water grants for sugarcane irrigation in São Paulo State in the Paraná Basin ("outorgas" ANA) between 2001 and 2013, it is possible to observe the trend of increasing the irrigation in sugarcane plantations. Between 2001 and 2012, there were no grants for irrigation of sugarcane plantations in São Paulo State, but in 2013 water grants were observed, especially in the areas of sugarcane expansion (blue markers in the Figure 22). Those are also the same areas pointed out by Brunini (2009) as of high water restriction (Figure 21). The total volume granted by ANA in 2013 for sugarcane irrigation in São Paulo State was 18,723,321.6 m^3. For evaluating this trend

[19] IBGE, the Brazilian Institute of Geography and Statistics (in Portuguese, Instituto Brasileiro de Geografia e Estatística), is an institution of the Federal Government bounded to the Brazilian Department of Planning, Budget and Management. It is the agency responsible for statistical, geographic, cartographic, geodetic and environmental information in Brazil. (IBGE, 2014)

in more detail, it would be necessary to include also the water grants for sugarcane irrigation provided by the Department of Water and Electric Power of São Paulo (DAEE) (State river basins). Unfortunately, these data were not provided by DAEE for this study, and therefore could not be included in the present assessment.

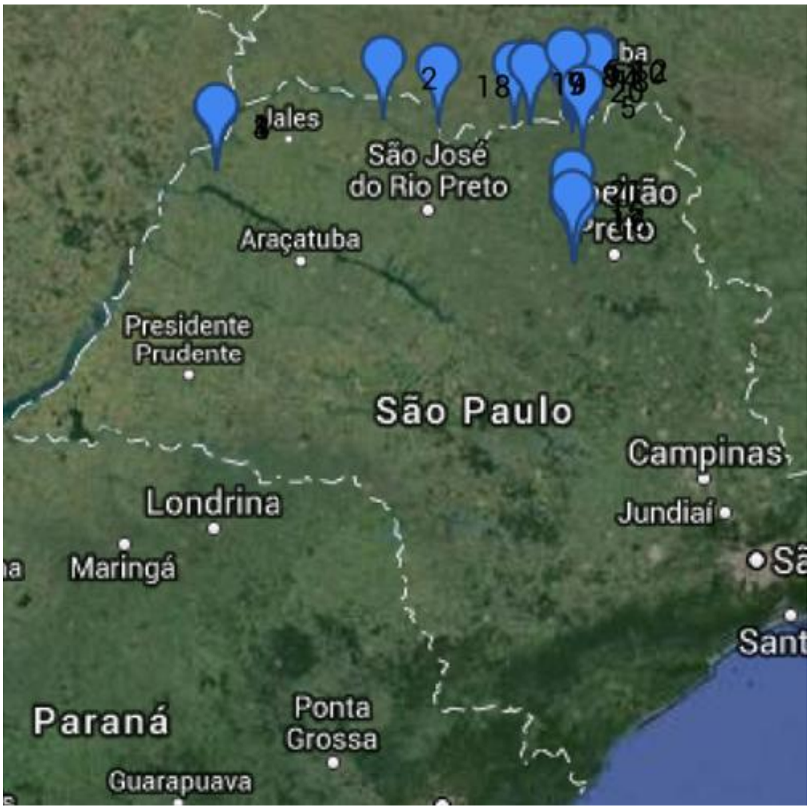

Figure 22 – ANA water grants in São Paulo in 2013.
Source: Drawn up by the author based on ANA, 2013b and Google Earth.

Although there is no sufficient primary data to calculate a forecast of the water needs for sugarcane irrigation in 2022 due to the sugarcane expansion foreseen in the Brazilian energy policy, results show that there is a possibility of increasing irrigation of sugarcane in water basins already subject to hydric stress, as shown in Table 5.

Considering that there is no thorough quantitative data for including irrigation in 2022 in the calculation, in this study the demand of water for sugarcane expansion will be calculated solely considering the industrial demand of the ethanol production.

For the calculation of the industrial demand, initially an analysis of grants of water (“outorgas”) in São Paulo State (“outorgas” DAEE) for the sugar and alcohol industry was conducted to assess the evolution of water use as a function of the ethanol production in the last ten years. Considering the data obtained there seems to be a significant increase in water use by sugar and alcohol industry from 2008 onwards

(Figure 23). This result is clearly distorted in view of the evolution of water use in the sector reported in the literature. Therefore, these figures cannot be used as an indicator for the water demand forecast for 2022. Technicians of the UGRHIs of São José do Rio Preto and Presidente Prudente, through interviews, reported that many companies are regularizing their situation regarding water grants in the last few years, and therefore the figures do not represent a trend of water use in the ethanol production. As can be seen in Figure 23, the amount of water granted by DAEE reached a pick in 2008, what can be a reaction of the River Basins Committees after the introduction of the State Law number 12,183 of December 2005, which implemented the water-use charge in São Paulo (SÃO PAULO, 2005. Lei nº 12.183, de 29 de dezembro de 2005).

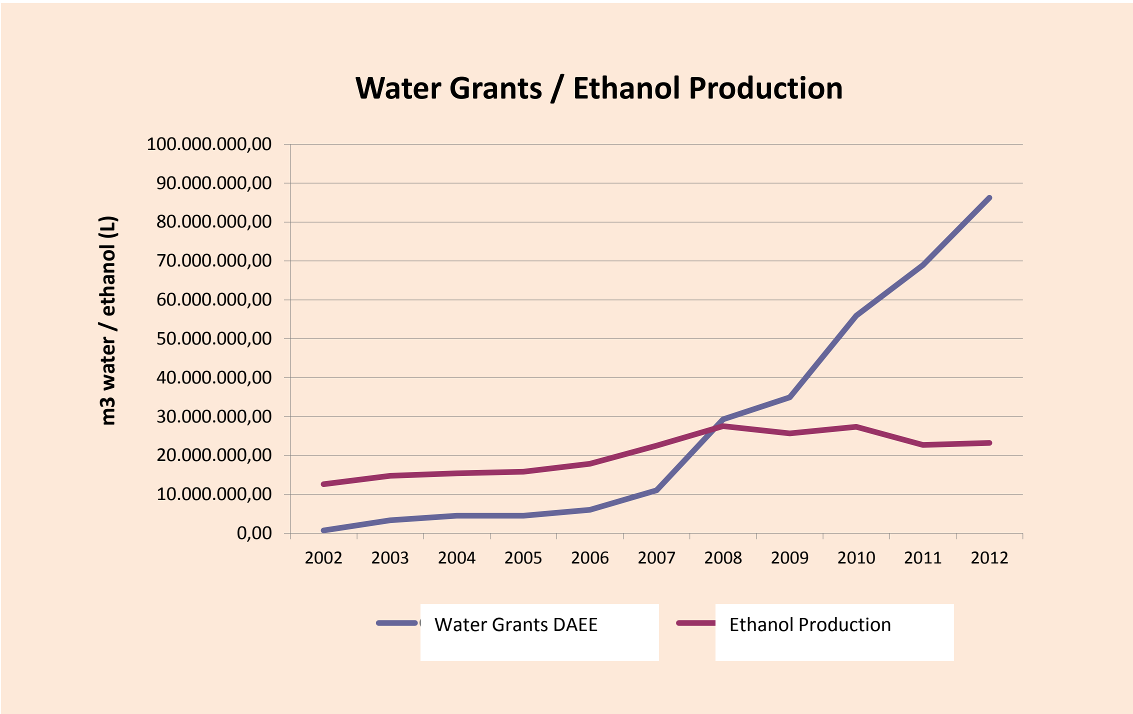

Figure 23 – Evolution of Water Grants for the ethanol industry compared to the ethanol production
Source: Drawn up by the author based on DAEE, 2013

Therefore, the figures used to calculate the demand for industrial use of the sugar mills for 2022 are based in the most relevant literature found in terms of local/regional specific research in São Paulo State (UNICA, 2007; GOLDEMBERG, 2008; SMEETS *et al.*, 2008; PEREIRA, 2009; ANA, 2009; GAZZONI, 2009; and OLIVÉRIO *et al.*, 2010; and HERNANDES *et al.*, 2013).

In the case of water withdrawal for industrial purposes (conversion of cane to ethanol), it was reported by several authors (UNICA, 2007; GOLDEMBERG, 2008; SMEETS *et al.*, 2008; PEREIRA, 2009; GAZZONI, 2009; and OLIVÉRIO *et al.*, 2010), and detailed in the Manual for Conservation and Water Reuse in the Sugar and Ethanol Industry (Manual de Conservação e Reuso de Água na Agroindústria Sucroenergética, ANA, 2009) that the need of water for the conversion of sugarcane in ethanol is around 22 m^3/t cane[20]. However, thanks to internal reuse in the processes, and the practice of returning the water to the crops in the ferti-irrigation[21] systems (GOLDEMBERG, 2008) only a small portion of this total is uptake from the water basins.

In a recent study, Hernandes *et al.* (2013), calculated the Water Footprint for ethanol in São Paulo of 124 m^3/t cane, being the blue water[22] content less than 1.5% of this value (around 1.86 m^3/t cane). The results found by Hernandes *et al.* include the water-use in the industrial conversion of sugarcane into ethanol and are aligned with the results found in local studies by other authors.

Regarding the homogeneity of the figures for water consumption in the references studied, the result obtained by Hernandes *et al.* (2013) for the Blue Water footprint (1.86 m^3/t cane) was used for calculating the specific demand for the expansion of sugarcane in São Paulo State considering the selected water basins. The decision for using these results is based on the date of the study (the selected one is the more recent one) and in the methodology used, which considers all the steps of the ethanol production.

For this calculation it was considered the same participation of the region under consideration in the total production of São Paulo State (68%)[23] as well as that the state would contribute with the same share in the Brazilian production of ethanol as of today (55.7%). Gains in productivity were considered 2.4% per year (EPE, 2013), leading to a total amount of sugarcane of 995 million t for the production of the total ethanol necessary for the expansion of biofuels in the Brazilian energy matrix, as well as exports.

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[20] ANA (2009) reported 22.126 m^3/t cane

[21] Ferti-irrigation is the application of fertilizers using a liquid vector. This technique is usually implemented through irrigation systems. (BIOTEC, 2014) It is possible to use wastewater to irrigate certain cultures through ferti-irrigation, thus reducing the problem of proper treatment and disposal of wastewater. Therefore, ferti-irriation can be a technique for treating organic wastewater by soil infiltration. The use of ferti-irrigation results in fertilizer and labor savings, improves the efficiency of application of fertilizer, and, consequently, increases productivity. (OLIVEIRA *et al*., 2014).

[22] The blue water footprint measures the volume of groundwater and surface water consumed, i.e. withdrawn and then evaporated (Waterfootprint.org, 2014)

[23] The six UGRHIs under analysis were responsible for more than 65% of the total production of the state of São Paulo in the last ten years, with an average participation of 68% in the same period.

As shown in Table 6, with the expansion of the ethanol production the share of the sugarcane industry (plantations plus industrial use) would increase around 5%, totalizing 11.45% of the total available water in the basins of the region. In fact, if these numbers were analyzed separately, the participation would not be of concern. On the other hand, considering that the water basins in the region are already in a worrisome situation, this expansion can have an impact on the water availability. Moreover, it is possible that the new areas would encounter difficulties in obtaining grants ("outorgas") from the responsible institution (DAEE).

Table 6 – Total water demand for sugarcane in accordance with the projected expansion of the national ethanol production

Sugarcane Brazil (t)		**Sugarcane SP (t)**		**Expansion Areas (68%)**		**Water Use (m^3)**		**% Total**	
2013	2022	2013	2022	2013	2022	2013	2022	2013	2022
652016	995000	363396	557200	247109	390040	459623	725474	7,25	11,45

Source: Prepared by the author based on EPE, 2013; CANASAT, 2014; HERNANDES *et al*., 2013; WRP SP (SÃO PAULO, 2013).

Regarding management and planning related to the expansion of sugarcane in the river basin plans in the regions of sugarcane expansion, it appears that none of them, including the São Paulo Water Resources Plan (SÃO PAULO, 2013) has a specific strategy for the sugarcane industry expansion in the region. The basin plans present a comprehensive diagnosis of the current situation of water resources in their areas of reach, but they lack more consistent future planning inferences.

The Pardo River Basin Plan (Ribeirão Preto administrative region), for example, whose cane plantations represent 97% of temporary crops in the region, has a chapter on "projects to be implemented to define the potential future use of water resources". In this chapter, the plan states that "The foundations of information and the bodies of SMA and DAEE are not unified, generating different information about the same physical space, which are generated and stored according to different interests and purposes. Analyzing the data on water grants ("outorgas") available for download at the website of DAEE, there are inconsistencies regarding the systems and flow as informed as they are different than the ones effectively implemented or in operation ... " and, given this difficulty of obtaining consistent information it is not possible to underline a future planning for the hydrographic basin.

Taking into account the three more important river basins regarding the sugarcane expansion in São Paulo – Peixe, Turvo/Grande and Baixo Tietê - which are the river basins where most of the administrative regions of Presidente Prudente, São José do Rio Preto and Araçatuba are located, it is important to conduct a more comprehensive analysis. Item 4.3.1 presents an analysis of water availability as well as management practices in the three mentioned river basins.

4.3.1 Peixe, Turvo/Grande and Baixo Tietê:

Considering a more comprehensive review of the three most important river basins in terms of expansion of sugarcane in SP, it is interesting to check in more detail the availability of water in each river basin. Also, it is necessary to examine whether their river basin plans incorporate the expansion of ethanol production in their management plans.

- **Peixe (UGRHI 21)**

Peixe River Basin is located in the west part of the State of São Paulo, as shown in Figure 24. The last river basin plan for the Peixe River Basin was developed in 2008, what makes the analysis of its data and planning somehow impaired. However, besides the São Paulo Water Resources Plan (2012-2015), the Peixe River Basin Plan is the only official source of data regarding the river basin.

Figure 24 – Location of Peixe River Basin in the state of São Paulo
Source: Peixe River basin Plan (Peixe, 2008)

Due to the installation and / or potentiation of several sugar and alcohol mills in the region, Peixe River Basin shows a sharp increase in cultivation area of sugarcane (PEIXE, 2008). According to the Brazilian Petroleum National Agency (ANP) there are seven ethanol mills in operation in the river basin in 2014 (ANP, 2014c), as shown in Figure 25.

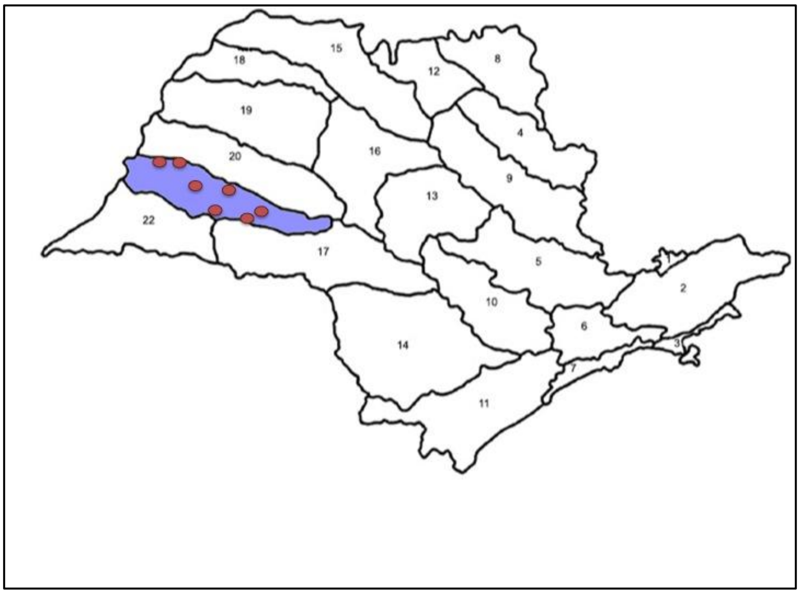

Figure 25 – Location of ethanol mills in Peixe River Basin
Source: Developed by the author based on ANP, 2014c

Among the most important cultivations in Peixe River Basin, in 2008 sugarcane represented 80% of the total, as can be seen in Figure 26.

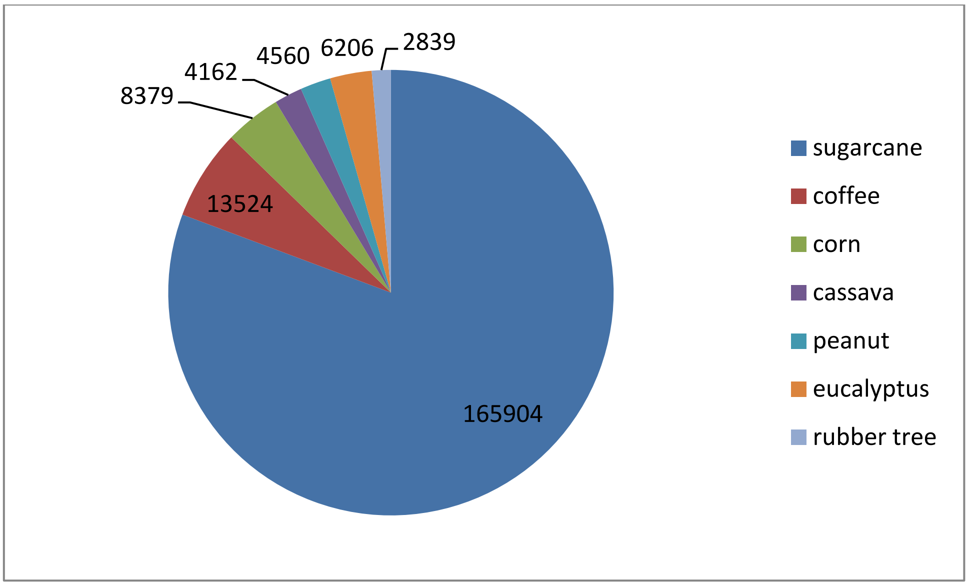

Figure 26 – Comparison of the area (ha) of sugarcane plantations with the other most important cultivations in Peixe River Basin (2008)
Source: Developed by the author with data from Peixe, 2008

According to Peixe River Basin Plan (PEIXE, 2008) the river basin concentrates major ethanol mills in São Paulo, which are large water users. As in virtually every state of São Paulo, the total annual rainfall is, at first glance, to ensure satisfactory agricultural production. However, its distribution throughout the year is not uniform, since the rainfall is concentrated in the period October-March. However, it is not uncommon to occur several days without rain this season (dry spells), and when this happens, the crop failures can be great, or even total. Considering the location of the basin and the proximity with the cerrado region, it is possible that irrigation is an alternative to guarantee crop. However, according to the Peixe River Basin Plan, comparisons between the demands and values found in the register of water grants (DAEE), only serves to demonstrate that the universe of registered irrigation in the grant system is still far from the actual number of existing irrigators in the UGRHI.

Despite the comfortable situation of the basin relative to the supply of water (only 8% of $Q_{7,10}$ is committed), Peixe River Basin Plan indicates: "... it is important to notice that the development of the UGRHI, especially the sugarcane industry, is generating some impacts on the natural resources of the region, thus bringing population growth (floating / permanent) that may require in future water allocations inconsistent with local availability... "

While recognizing that the expansion of ethanol in the Peixe River Basin can generate a situation of water restriction, nothing is proposed in the river basin plan for effective planning to mitigate the effects.

- **Turvo/Grande (UGRHI 15)**

Turvo/Grande River Basin is located in the northwest part of the State of São Paulo, as shown in Figure 27. Similarly to Peixe River Basin, the last river basin plan for the Turvo/Grande River Basin was developed in 2008 and besides the São Paulo Water Resources Plan (2012-2015), the Turvo/Grande River Basin Plan is the only official source of data regarding the river basin.

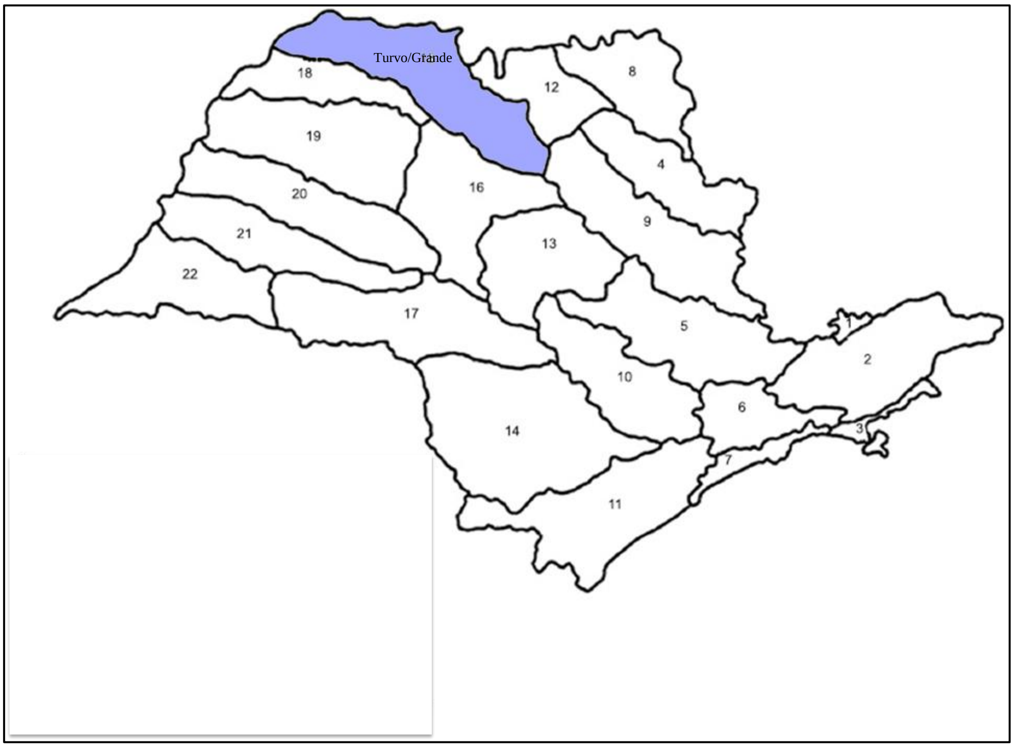

Figure 27 – Location of Turvo/Grande River Basin in the state of São Paulo
Source: Developed by the author

In the case of UGRHI 15 if analysis is performed by abstraction of surface sub-basin, it appears that most of them have totally outweigh the $Q_{7,10}$..

In total, in 2008 when the basin plan for UGRHI 15 was developed, the volume collected superficially already represented over 57% of the minimum flow of 7-day and 10-year recurrence time ($Q_{7,10}$) in the basin (TURVO/GRANDE, 2008).

Even with this high water restriction the sugarcane cultivation area grew 8.33% between 2009 and 2012, with no specific planning in the Basin Plan for this growth. The administrative region of São José do Rio Preto (Turvo/Grande river basin) accounted for 21% of the total ethanol production of the seven administrative regions of ethanol expansion (see Table 4 - Ethanol production per year in each Administrative Region), which represents 14.8% of the total production of São Paulo in 2012.

Figure 28 shows a comparison of ethanol production in the seven basins in the area of expansion of sugarcane. Through the figure it is possible to observe that the river basin Turvo/Grande (São José do Rio Preto AR) had the major contribution for the ethanol production in 2012.

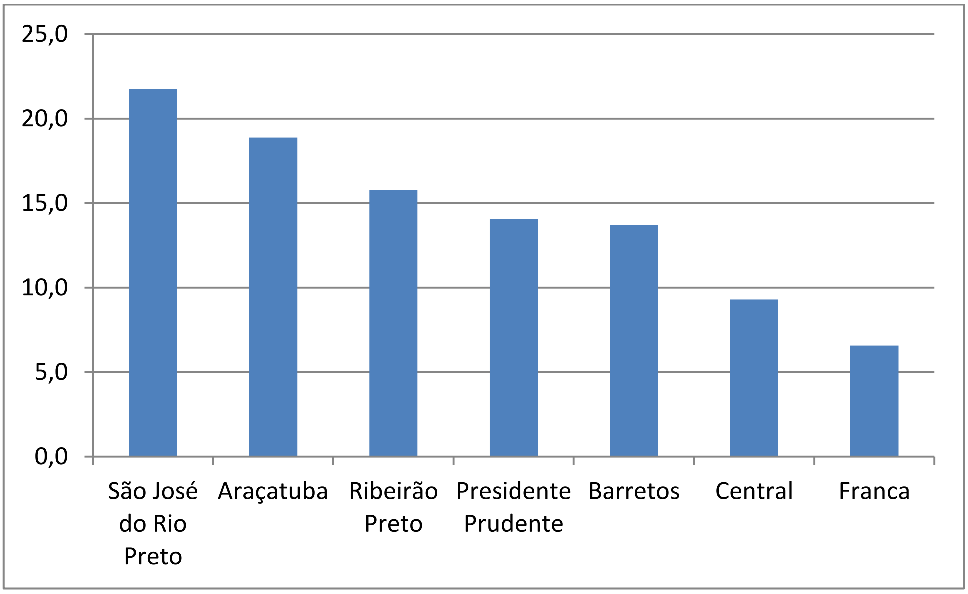

Figure 28 – Percentage of ethanol production in 2012 per river basin of the total ethanol production in the expansion area.
Source: Developed by the author based on SÃO PAULO, 2014

Regarding management and planning, it is observed that although the river basin Turvo/Grande is the most important in terms of ethanol production compared to the other administrative regions of the expansion area, with 15 plants recognized by ANP (ANP, 2014c) (Figure 29), and approximately 15% of total production of São Paulo, the River Basin Plan does not mention the sector specifically.

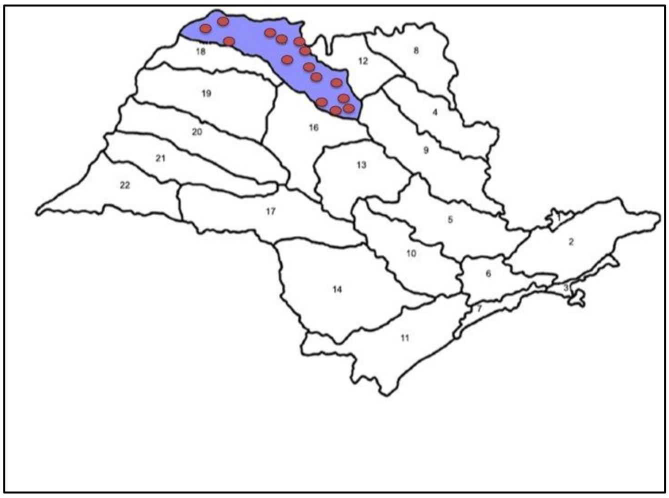

Figure 29 – Location of ethanol mills in Turvo/Grande River Basin
Source: Developed by the author based on ANP, 2014c

In the main goals of the Basin Plan (Turvo/Grande, 2008) there is also no specific mention to the sugarcane and ethanol production expansion.

- **Baixo Tietê (UGRHI 19)**

Baixo Tietê River Basin is located in the northwest part of the State of São Paulo, as shown in Figure 30. The last River Basin Plan for the Baixo Tietê River Basin was also developed in 2008 and besides the São Paulo Water Resources Plan (2012-2015), the Baixo Tietê River Basin Plan is the only official source of data regarding the river basin.

Figure 30 – Location of Baixo Tietê River Basin in the State of São Paulo
Source: Baixo Tietê river basin plan, 2008 (Baixo Tietê, 2008)

The base of the regional economy is agriculture, however sugar and ethanol industry has become the center of business since the 90s. The production of sugarcane account for 7.54% of the value of agricultural production of São Paulo State.

The sugarcane industry is responsible for the main for investments in the region. The development of the sugarcane sector, which was responsible for an increase of 132.5% (Baixo Tietê, 2008) of sugarcane plantations in the river basin between 1997 and 2007, has contributed to the advancement of other economic activities, especially the service sector.

Figure 31 shows the location of plants recognized by the ANP (ANP, 2014c) in UGRHI 19, totalizing 17 mills in the river basin.

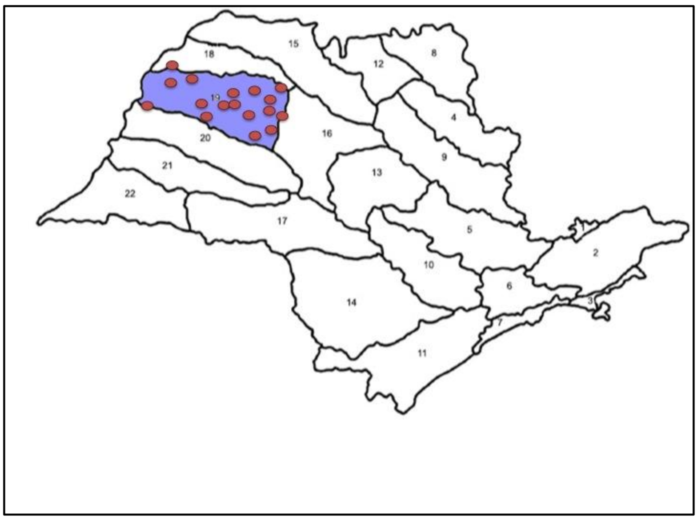

Figure 31 – Location of ethanol mills in Baixo Tietê River Basin
Source: Developed by the author based on ANP, 2014c

Although the river basin still presents a relatively comfortable situation regarding water availability (27% of $Q_{7,10}$) it is important to recognize that the development, especially the sugarcane industry, brought a population growth which may require in the future water allocations inconsistent with local availability or impairment of sources already in critical condition or near the criticality as to the availability of water (Baixo Tietê, 2008).

Further analysis of the three major river basins of the expansion area of the ethanol industry points to a more critical situation in the Turvo/Grande River Basin in the administrative region of São José do Rio Preto. Paradoxically this AR showed the highest production of ethanol in 2012 among the ARs of the expansion region (see Figure 28). The expansion of ethanol in this region will certainly find restriction on the availability of water, since in 2008 the AR had committed 57% of $Q_{7,10}$ and the expansion continued, reaching 59% of $Q_{7,10}$ in 2012 (see table 5). The best situation in terms of availability of water is found in the river basin of Peixe, where only 8% of the $Q_{7,10}$ was used in 2012 for all uses. However, it is flagged in the Peixe River Basin Plan that the expansion of sugarcane and all the development it brings (not just the water consumed directly), may lead to future restrictions.

5 Energy

Regarding the importance of assessing energy issues as a whole, the analysis of energy was conducted in three different perspectives: 1) Mechanisms for the Brazilian biofuels programs implementation; 2) Current energy policy related to ethanol (PDE); and 3) Ethanol Energy Balance. In this context, items 5.1 to 5.3 include the cited analysis.

5.1 Mechanisms for the Brazilian biofuels programs implementation

The successful inclusion of biofuels in the Brazilian fuel structure in the past years was the result of energy policies that combined leverage mechanisms which acted, simultaneously and comprehensively, in the different parts of the ethanol and biodiesel's value-chains (MAROUN and SCHAEFFER, 2012). The most important programs related to biofuels in Brazil were Proalcool and the Brazilian Biodiesel Production Program (PNPB).

Figure 32 shows the interaction of the different components of the value system in the implementation of Proalcool and PNPB.

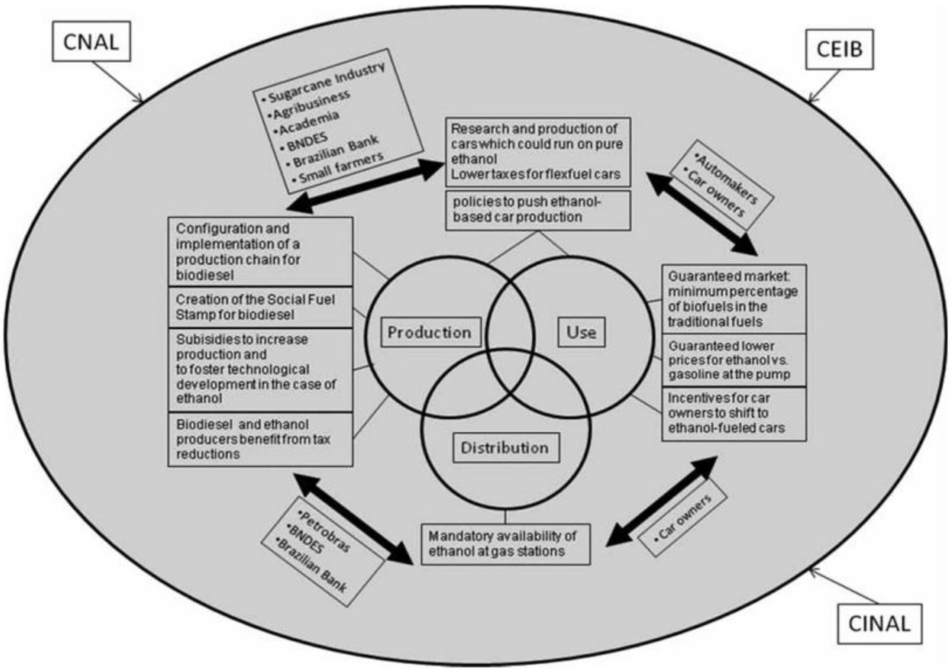

Figure 32 – Interaction of the different components of the value system in the implementation of Proalcool and PNPB
Source: MAROUN and SCHAEFFER, 2012

The Brazilian Ethanol Program (Proalcool) was officially established in the 1970s in response to the first and second "oil shocks" and the low sugar prices in the international market (that put the sugarcane industry at risk). The principal stated goal of the program, among others that will be discussed later in this Chapter, was to save foreign exchange by using ethanol as a supplement to the nation's gasoline supply (HIRA and OLIVEIRA, 2009).

After different phases, the new increase in the production of ethanol starting in 2003 arouse out of a technological innovation. The intensive use of electronics embedded in advanced systems for the control of the fuel mixture and ignition made it possible for vehicles with "flexible" (flex-fuel) motors launched for sale in Brazil. Such motors can use, without any interference on the part of the driver, gasoline (with 20% to 25% of ethanol), pure hydrated ethanol, or even mixtures of these two fuels in any proportion, in accordance with efficiency and drivability requirements and complying with the legal limits for the emission of exhaust gases (JOSEPH JR., 2007). Since then, most of the new vehicles sold in Brazil have been vehicles equipped with such engines[24]. This acceptance comes from the fact that the “flex” car gives the consumer greater autonomy when choosing which fuel to buy at the service station, enabling him or her to opt for the most convenient fuel according to the drivers priorities (lowest price, less greenhouse gases (GHG) emissions, higher efficiency). For this reason, besides the compulsory addition of anhydrous ethanol to gasoline[25], ethanol production has practically doubled in the country since 2003 (see Table 1).

Proalcool and its subsequent policies, which actually are not part of a formal program, are active for over 35 years now, allowing Brazil to be one of the world leaders, with the United States, both in terms of technology and usage of ethanol. There is already a long series of comprehensive studies regarding all types of analyses of Proalcool in the recent past: history (GELLER, 1985; and GOLDEMBERG and MOREIRA, 1999); policy implementation (PUPPIM de OLIVEIRA, 2002); GHG emission reduction (GOLDEMBERG *et al.*, 2004; SZKLO *et al*., 2005; POUSA *et al.*, 2007; GOLDEMBERG *et al.*, 2008); social aspects (NARDON and ATEN, 2008; LEHTONEN, 2009); biofuels programs (HIRA and OLIVEIRA, 2009; HALL *et al.*, 2009; GARCEZ and VIANNA, 2009; TAKAHASHI and ORTEGA, 2010).

The Brazilian Biodiesel Production Program (PNPB) was launched in December 2004, being a much more recent initiative, for which literature and experience are much scarcer. Besides the economic objective of fostering biodiesel production, a major social objective of PNPB was regional development via promotion of small-scale family agricultural units (GOLDEMBERG *et al*., 2004; TAKAHASHI and ORTEGA, 2010). Initially launched with the compulsory addition of 2% in volume to diesel oil (B2), since 2008 PNPB has made it obligatory to add a fixed percentage of biodiesel to mineral diesel, which is currently 5% (B5) in volume (ANP, 2010). To a large extent, it was possible to bring forward the use of B5 by mobilizing the biodiesel’s value-chain. An example of that is total biodiesel output in Brazil in 2010 (2.4 billion liters), as well as the present production capacity of the 67 authorized plants (5.2 billion liters per year), which is significantly higher than the captive demand for biodiesel, taking as basis total diesel consumption in that same year (ANP, 2011a).

[24] Introduced in Brazil in March 2003, flex-fuel type vehicles represented approximately 2.7% of the total number of vehicles produced in Brazil in that year. Nowadays approximately 90% of the vehicles produced in the country are of the flex-fuel type (ANFAVEA, 2014)

[25] Added to gasoline in a range of 22% to 24% since the year 1998, the mandatory percentage for addition was fixed at 25% in July 1, 2007 (ANP, 2011b). As of December 2011, however, this range is again varying between 18-25%, as the availability of ethanol in the domestic market has been reduced due to bad weather conditions, low gasoline prices as well as competition with high sugar prices.

According to the history of the two programs, it is not difficult to notice the conceptual differences regarding the motivation for the development of each program. While Proalcool was a clear effort to guarantee the market for a specific industry (sugarcane) and to seek an alternative fuel to gasoline, PNPB was created for social inclusion and regional development mainly.

Despite the above-mentioned conceptual differences, there are very similar components of the two programs that lead to similar results, which, in most of the cases, conflict with their original objectives. Proalcool and PNPB have a series of leverage mechanisms and other components that were the basis of the successes (and failures) of their implementations. Table 7 compares Proalcool and PNPB regarding the goals and outcomes, their leverage mechanisms and the intervention (CHEN, 2005).

Table 7 – Comparison between Proalcool and PNPB regarding their implementation

	Proalcool	PNPB
Goals	• To increase the net supply of foreign exchange • To reduce income disparities among regions and individuals • To increase national income through the deployment of under-utilized resources • To increase the growth of the domestic capital goods sector • To avoid bankruptcy of the sugarcane industry • To reduce energy dependence from abroad	• To implement the production and use of biodiesel • To implement a sustainable program, promoting social inclusion and regional development • To guarantee competitive prices, quality and supply • To produce biodiesel from different oleaginous plants in diverse regions
Expected Outcomes	• A guaranteed market for ethanol • Modernization of existing distilleries • Research and production of cars which could run on pure ethanol • A light duty vehicle (LDV) fleet running on pure ethanol	• A guaranteed market for biodiesel • Configuration and implementation of a production chain for biodiesel involving different raw materials and different regions of the country • Implementation of a sustainable program, promoting social inclusion • Guaranteed competitive prices, quality and supply • Production of biodiesel from different oleaginous plants in different regions
Leverage Mechanisms	• Large subsidies for the full ethanol production and consumption chain • Mandatory inclusion of a specific percentage of ethanol in all gasoline commercialized in the country • Financial support lines for R&D • Regulation with incentives to the private sector to pursue innovation and invest in ethanol related activities • Incentives for car owners to shift to ethanol-fueled cars	• Subsidies for the production chain of biodiesel • First voluntary and then mandatory inclusion of a specific percentage of biodiesel in all diesel commercialized in the country • Creation of the Social Fuel Stamp to spur the social inclusion in the biodiesel production chain
Intervention	• Guaranteed lower prices for ethanol vs. gasoline at gas stations • Guaranteed minimal prices for ethanol producers • Creation of credit lines for sugar mills to expand capacity • Mandatory availability of ethanol at gas stations • Maintenance stocks to stabilize supply • Establishment of several policies to push ethanol-based car production • Establishment of higher minimum ethanol fuel blends	• Biodiesel producer or buyer benefits from tax reductions • Biodiesel producer or buyer gains the ability to participate in public auctions administered by ANP • Creation of a Social Fuel Stamp • Tax reductions depend on the following factors: region of production of the raw material, type of raw material, and type of farm involved in the production of raw material • First voluntary and then mandatory inclusion of a minimum percentage of biodiesel in all diesel commercialized in the country

Source: Adapted from MAROUN and SCHAEFFER, 2012

In all phases of Proalcool and of PNPB, government interventions, and the focus on value-chains, were very important to increase ethanol and biodiesel production and consumption, as well as to develop their respective technologies.

The comparison between the two programs led to the understanding that, in both cases, despite the differences in their change models, action models and the maturity of the programs, the outcomes have been very similar so far, reflecting the general type of results observed in developing countries, very much focused on large-scale, capital-intensive agricultural sectors. Garcez and Vianna (2009) wrote about PNPB: "Policy fails to give importance to promoting adequate and less intensive agricultural practices, and equally ignores the issue of energy consumption, which is an important aspect of sustainable energy development".

In the case of PNPB, this concern is even more important. It shows the possibility of perverse effects and also the importance of being careful with the three dimensions of sustainable development (economic, environmental and social) of development programs. Among the goals of PNBP, were the implementation of a sustainable program, promoting social inclusion and regional development, and the production of biodiesel from different oleaginous plants in diverse regions. After six years, results lead to large-scale, capital intensive soybean production as the dominating route (84%), the majority of authorized biodiesel production capacity being installed in the affluent Center-west region of the country, instead of in the North and Northeast regions, which were the priority regions in the program inception. Moreover, the role of family farmers is limited to that of producers of grains.

The analysis conducted in this Chapter is important for the identification of the pull and push initiatives that contributed for the inclusion of biofuels in the Brazilian energy matrix, the evolution of its share in final energy consumption and also what would be necessary for boosting the biofuels production in a sustainable way.

5.2 Actual energy policy related to ethanol (PDE)

The initial government controls cited in item 4.1 for sugar and ethanol were eliminated in a transitional regime completed in 1998. Nowadays government only specifies hydrous and anhydrous alcohol and defines the content of ethanol in gasoline. Ethanol is sold in almost all of Brazil's 29 thousand distribution sites (UNICA, 2007).

Sugarcane production increased from about 120 to 240 million tons between 1975 and 1985, stabilizing at this level between 1985 and 1995. Since then, another cycle of agricultural expansion has begun as a result of the continuous growth of exporting sugar. In 1990, the export of sugar was 1.2 Mt, and quickly grew to 19.6 Mt by 2006, which portrays the vast increase and demand for this Brazilian commodity (UNICA, 2007).

According to the National Supply Company (Companhia Nacional de Abastecimento – CONAB), the area cultivated with sugar cane related to the sugarcane industry in 2013/14 agronomic year (AY) was estimated at 8.8 Mha. The state of São Paulo remains the largest producer with more than 51% (4.5 Mha) of planted area. Figure 33 shows the estimated sugarcane production of the Brazilian states in the AY of 2013/2014 and their share in the total sugarcane planted area. (CONAB, 2013).

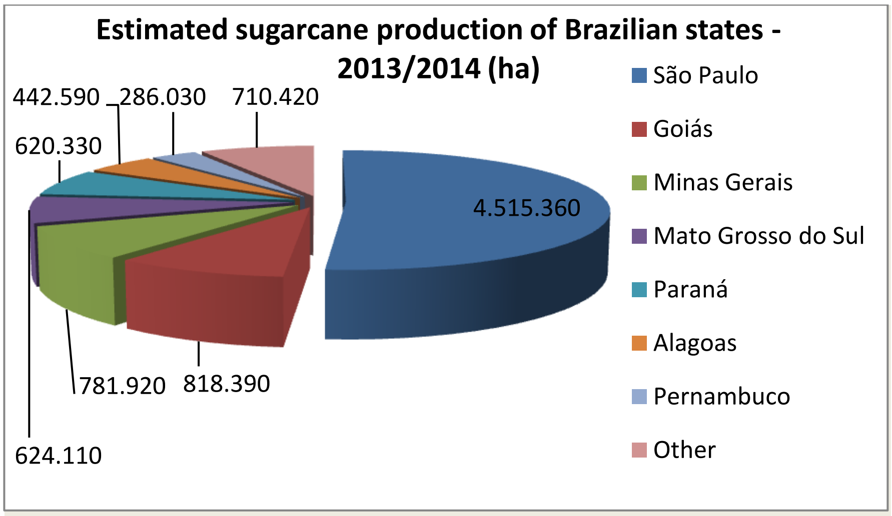

Figure 33 – Estimated sugarcane production in hectares of the Brazilian states in the AY of 2013/2014
Source: Prepared by author based in CONAB, 2013

Currently, ten year energy plans (PDEs) are prepared by the Brazilian Energy Research Company (EPE). The PDE considers the expansion of the Brazilian energy sector and is one of the main instruments of planning the expansion of demand and supply of different energy sources, besides power (EPE, 2013). This study, published annually, is an important tool for the design of development strategies of the country to be traced by the Federal Government in delineating the Brazilian energy policy.

The latest study published is the PDE 2013-2022, which shows the projected expansion of the energy sector in the decade 2013-2022. A differential of the PDE 2022 in relation to the previous plans is the inclusion of meeting specific targets for GHG emissions in its objectives. According to the PDE 2022 climate issue must be in accordance to the Law of the National Policy on Climate Change (BRASIL, 2009a. Lei nº 12.187, de 29 de dezembro de 2009) and Decree 7,390/10 (BRASIL, 2010. Decreto nº 7.390, de 9 de dezembro de 2010), which regulates this Law. This new legal framework established the goal of reducing GHG emissions in 36.1 to 38.9% compared to a reference scenario for 2020. The Decree also established that, in the energy sector, the sector plan for mitigation and adaptation to climate change is the Ten Year Energy Plan itself (EPE, 2013). In this context, the PDE 2022 considers an expansion of the use of biofuels in Brazil to replace the use of fossil fuels, and calculates the emission reductions related to this substitution.

Between 2013 and 2022, it is projected that the Brazilian ethanol market will continue expanding due to the significant increase in the flex-fuel fleet. However, the increase will be lower than the previous plan, due to restrictions on supply of the product. Regarding Brazilian exports, it is estimated a marginal growth "mainly impacted by problems in domestic production" (EPE, 2013). According to Moreira *et al.* (2014), in comparison with oil products, ethanol is only cost effective if appropriate policies exist and this issue shall be analyzed by energy policy makers (MOREIRA *et al.*, 2014).

PDE 2022 foresees the early recovery of the ethanol supply between 2013 and 2016, driven by the return on investments in the renovation of sugarcane cultivation, continuing throughout the period under analysis. From 2016 onwards, an acceleration of the increase in the ethanol supply is expected, as a result of the implementation of new production units. The Brazilian government will make investments in order to reduce the costs of transportation and storage of ethanol will be conducted.

According to this Expansion Plan, between 2013 and 2022, ethanol production in Brazil is expected to rise from 27.3 billion liters to 54.5 billion liters, including exports of Brazilian ethanol, which are expected to grow from the current 3.0 billion liters to 3.5 billion liters in 2022. To meet this demand, sugarcane production in the year 2022 is estimated to reach 995 million tons (an increase of 57% in relation to 2013). Considering a productivity gain of sugarcane per hectare of 2.4% per year[26], this will require a total farming area of 11.3 million hectares (EPE, 2013).

[26] Calculated based on the increase in productivity (EPE, 2013)

In an attempt to assess sustainability concerns related to the ethanol expansion in Brazil, PDE 2022 addresses social and environmental impacts of ethanol in a conventional way (no integration of issues).

Regarding water, the study calculates the volume of water necessary for the ethanol industry in order to supply the expected production of the biofuel, stating that the sugarcane plantations in Brazil are mostly rainfed. Assuming 1.8 m^3/t cane for industrial use (ethanol production), it was found the amount of 1.7 billion m^3 of water needed to the sugarcane expansion. In the PDE it is stated that this number is high, but can be reduced with technological improvements in the mills in the future. However, PDE does not compare the 1.7 billion m^3 with the availability of water in the regions of expansion of sugarcane.

When it comes to land, PDE considers ZAE Cana for the areas of sugarcane ethanol expansion and cross-checks the location of the new mills authorized with the areas for sugarcane expansion considered in ZAE Cana. PDE concludes that the sugarcane expansion will induce to land use change (LUC), especially from pastureland to sugarcane. However, there is no further analysis regarding this LUC.

In general terms, it is important to mention that although the environmental and social analysis of the ethanol expansion cited in the PDE mentions all the relevant points related to the biofuel production, it conducts a superficial evaluation of the issues. Regarding its correlation with other policies related to the WEL resources, ZAE Cana is used as a basis for checking the LUC that will occur due to the sugarcane expansion. On the other hand, indirect land use change, which is in the centre of the international debate in respect to biofuels production in Brazil, is not mentioned.

5.3 Ethanol Energy Balance

The energy balance of a certain product is an essential evaluation when the sustainability of its production and usage is to be assessed. This item is required to evaluate the net effects during the complete well-to-wheel cycle of biofuels.

The benefit of biofuels displacing their fossil fuel equivalents depends on the relative magnitude of fossil fuels input to fossil fuel savings resulting from the biofuel use (MACEDO *et al.*, 2008). The Life Cycle Assessment (LCA) is the most frequently employed methodology for assessing an energy balance. LCA in agriculture focuses primarily on non-renewable energy inputs in the product’s life cycle, from the extraction of the natural resource to the use and disposal of the product (TAKAHASHI and ORTEGA, 2010).

There are already many different studies related to the energy balance involved in the ethanol production and use (GOLDEMBERG *et al*., 2008; LUO *et al*., 2009; MACEDO *et al*., 2004; MACEDO *et al.*, 2008).

Macedo *et al.* (2008) developed the energy balance of the production and use of ethanol from sugarcane in Brazil in 2008 using the average conditions in 2005/2006. The situation for a conservative 2020 scenario was also evaluated. The data used for the fossil energy consumption in the sugarcane production, harvesting and transportation and the fossil energy consumption in the production of ethanol are presented in Table 8.

Table 8 – Energy balance of ethanol

Fossil Energy Consumption in Sugarcane production, harvesting and transportation (MJ tc^{-1})			
Item	**2005/2006**	**Scenario 2020**	**Participation in total for 2020 (%)**
Agricultural operations	13.3	14.8	5.65
Harvesting	33.3	46.9	17.90
Sugarcane transportation	38.6	44.8	17.10
Inputs transportation	10.9	13.5	5.15
Other activities	38.5	44.8	17.10
Fertilizers	52.7	40.0	15.27
Lime, herbicides, insecticides	12.1	11.1	4.24
Seeds	5.9	6.6	2.52
Machinery	6.8	15.5	5.92
Total	**210.2**	**238.0**	**90.8**
Fossil Energy Consumption in the Production of Ethanol (MJ tc^{-1})			
Item	**2005/2006**	**Scenario 2020**	
Chemicals and Lubricants	19.2	19.7	7.52
Building	0.5	0.5	0.19
Equipments	3.9	3.9	1.49
Total	**23.6**	**24.0**	**9.2**
Energy Balance, external flows (MJ tc^{-1})			
	2005/2006	**Scenario 2020**	
Fossil Input			
Sugarcane production/transportation	210.2	238.0	
Production of ethanol	23.6	24.0	
Total fossil input	233.8	262.0	
Renewable Output			
Ethanol	1926.4	2060.3	
Bagasse surplus	176.0	0.0	
Electricity surplus	82.8	972.0	
Total renewable output	2185.2	3032.3	
Renewable Output/Fossil Input (Ethanol + bagasse + electricity)	**9.3**	**11.6**	

It is important to notice from Table 8 that a considerable increase is expected in the fossil fuel energy consumption in the 2020 scenario (from 210.2 MJ in 2008 to 238 MJ in 2020), mainly due to diesel consumption associated with the growth of mechanical harvesting, trash recovering and increase in the machinery utilization (this item more than double for the 2020 scenario, MACEDO *et al*., 2008). This forecast is in accordance with the PDE 2022 (EPE, 2013), which recognizes an intense mechanization in sugarcane processes up to 2022. Burning sugarcane fields, which is still a common practice in Brazil, is a major concern because of the associated environmental and health hazards. This issue is being treated by the environmental agencies in Brazil and will probably be resolved in the medium term through recent laws and agreements between governmental authorities and the sugarcane industry, increasing mechanical harvesting and the use of other machinery. For example, State Law no. 11,241/2002 determines that it is forbidden to burn straw for the purpose of manual sugarcane harvesting, starting in 2021 in São Paulo (SÃO PAULO, 2002. Lei nº 11.241, de 19 de setembro de 2002). Higher utilization of residues in ferti-irrigation, however, will lead to significant reductions of mineral fertilizers demand.

The results of Macedo *et al.* (2008), as well as other results in the literature review (URQUIAGA *et al.*, 2004; LUO *et al.*, 2009), show that the energy balance of ethanol from sugarcane in Brazil is extremely positive. Fossil energy ratio was 9.3 for 2005/2006 and may reach 11.6 in 2020 with technologies already in commercial use. Also, from the results of the energy balance presented, it is important to note that the total fossil energy consumption in sugarcane production, harvesting and transportation corresponds to 90.8% of the total fossil energy consumption for the production of ethanol. That means that changes in the quality of land can have a significant impact in the ethanol energy balance.

Moreover, considering that the production costs of ethanol from sugarcane are low not only due to geographic conditions but also because of the favorable energy balance (COELHO *et al*., 2006), changes in the quality of land use for sugarcane plantations will impact also in the revenue and margins for the sugarcane business in the state of São Paulo.

6 Land

The analysis of the policies of land-use and its correlation with related water and energy policies is essential for a comprehensive analysis of the sustainability of the expansion of ethanol production in Brazil. The present chapter focuses its analysis in the most important Brazilian land-use policies related to the sugarcane expansion. The results of this analysis will be used in Chapter 7 where an integrated analysis of policies will be conducted in order to answer the questions posted in Chapter 3: a) How disconnected are the Brazilian water-use, land-use and energy policies?; and b) Is there a need to develop a sectoral policy for biofuels integrating water, energy and land resources?

As mentioned in Chapter 3, the complexity and breadth of policies for land use in Brazil make the analysis of this item also complex. Therefore, the analysis of the policies of land-use was divided into three different items: a) Agro Ecological Zoning for sugarcane in the State of São Paulo (ZAE Cana São Paulo); b) Dynamics of the price of land for the expansion of the ethanol production in São Paulo, and c) Land use conversion related to the sugarcane plantations / expansion in the state of São Paulo.

Brazil's total surface area is about 850 million hectares, composed of 65% forests and natural vegetation, 23% pasturelands, 7% perennial and annual croplands, and 4% urban settlements. Soybean is currently the main national crop, with a crop area of approximately 23 Mha, followed by corn (13 Mha) and sugarcane (9 Mha) (IBGE, 2012). Regarding the expansion of sugarcane plantations due to the energy policy that increases biofuels in the Brazilian energy matrix and exports, the total farming area for sugarcane in Brazil is expected to reach 11.3 Mha (EPE, 2013).

A key point derived from the literature is that the expected implications related to land use driven by the expansion of ethanol encompass economic, social and environmental impacts (GALLARDO and BOND, 2011). In this regard, there were selected three different aspects for the analysis of the expansion of ethanol in Brazil from the perspective of land use.

The first refers to ZAE Cana, a government initiative that aims to diagnose potential areas for expansion of sugarcane in Brazil, preserving the inherent environmental issues related to the agroenergetic industry regarding land-use. The ZAE Cana is used in the present study for testing the alignment of policies with regard to environmental issues related to land use.

The second part of the test is related to economic issues, which cannot be ignored in any comprehensive sustainability analysis, mainly because it is, in most of the cases, the main indicator for decision-making. Thus, to test the economic aspect of land-use, an analysis of the dynamics of land prices in the area of expansion of sugar cane in São Paulo was conducted. This analysis was based in the work conducted by Schaeffer et al (2011), which was the background paper for the European Report on Development 2011/2012.

Finally, the analysis of the expansion of ethanol in São Paulo from the perspective of land-use considers land use changes (LUC), which is one of the most controversial issues related to the sustainability of biofuels in the international debate.

6.1 ZAE Cana

In an effort to plan the expansion of the sugarcane agroindustry in Brazil, the Ministry of Agriculture and Food Supply (MAPA) developed the Sugarcane Agroecological Zoning (ZAE) in 2009. This is a comprehensive study, led by Embrapa Soils (EMBRAPA[27] SOLOS), involving dozens of renowned institutions and researchers. The purpose of ZAE Cana is to define which areas and regions are appropriate / inappropriate for large-scale sugarcane farming (BNDES, 2008), intending to provide technical support for the formulation of public policies aiming the expansion and the sustainable production of sugarcane in Brazil (MAPA, 2009).

The assessment of potential land for sugarcane production under rainfed conditions (no full irrigation) was conducted through digital processing techniques. The study was based on the physical, chemical and mineralogical characteristics of soils expressed spatially in soil surveys and studies on climate risks related to the culture's requirements. Land vulnerability, climate risk, the potential for sustainable agricultural production and environmental regulations were the main indicators used to the development of the ZAE Cana. In São Paulo State, the areas that were planted with sugarcane (CANASAT Project) in the agronomic year (AY) of 2007/2008 were also

[27] EMBRAPA is the Brazilian Agricultural Research Corporation, connected to the Ministry of Agriculture, Livestock and Supply. Its mission is to enable solutions for research, development and innovation for sustainable agriculture. Embrapa operates through Research, Services and Administrative Units in almost all states of Brazil.

excluded from the zoning, which intends to provide information of adequate land for the expansion of the ethanol agroindustry.

According to the ZAE Cana, the areas suitable for expansion include those currently in intensive and semi-intensive agricultural production, special crops and pasture. These areas were classified according to their potential for sugarcane plantations (high, medium and low) and to their actual use, as follows:

- Ap: Area ocupied with Pasture
- Ag: Area occupied with Agriculture and Pasture
- Ac: Area occupied with Agriculture

The estimates show that Brazil has about 64.7 million ha of suitable land for the expansion of sugarcane crops, and 19.3 million of which have high yield potential. According to the ZAE Cana, “Brazil does not need to incorporate new land to the ethanol production process, which can further expand its growing area without affecting directly the land used for food production, or forest areas”.

The areas considered adequate for sugarcane expansion in São Paulo State totalize 10.6 Mha, of which 58% are currently used for agriculture, 36% for pasture and 6% for agriculture plus pasture (Figure 34).

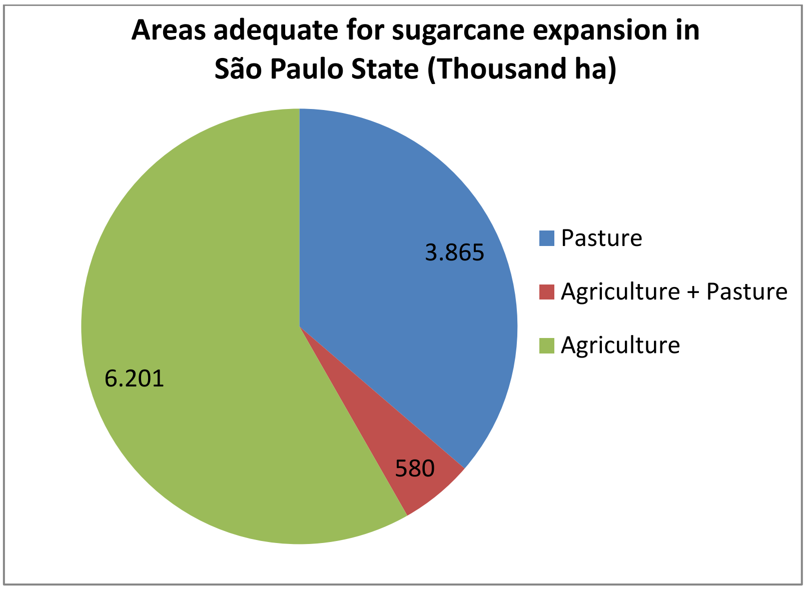

Figure 34 – Share of areas (ha) adequate for sugarcane plantations in São Paulo State according to ZAE Cana.
Source: Prepared by the author based on ZAE Cana (MAPA, 2009).

Whereas the highest percentage of areas adequate to the cultivation of sugarcane (58%) were occupied by agriculture in 2008, it is difficult to understand how the ZAE Cana concludes that following the zoning established by the project (which was regulated by Presidential Decree 6,961/2009 (BRASIL, 2009b. Decreto nº 6.961, de 17 de setembro de 2009)) land use for food production would not be affected. Besides projecting expansion into areas occupied in 2008 mainly with agriculture, the criteria used by ZAE Cana to exclude areas from the zoning did not consider areas for food production. Exclusion criteria were basically related to environmental and technical concern. ZAE Cana excluded areas with native vegetation; the Amazon and Pantanal biomes; the protected areas; indigenous lands; forest remnants; dunes; mangroves; cliffs and rock outcrops; reforestation; urban and mining areas; and land with slopes greater than 12% (in which mechanized harvest is not feasible). In addition, there were excluded the areas already planted with sugarcane in 2008, as mentioned earlier.

Therefore, there is no guarantee that there will not be competition between plantations of sugar cane and food. Figure 35, extracted from ZAE Cana, confirms that the best region for sugarcane expansion in São Paulo State is composed of the areas previously discussed in Chapter 5 (Water), where the expansion is actually happening, according to the monitoring of the CANASAT project (red circles).

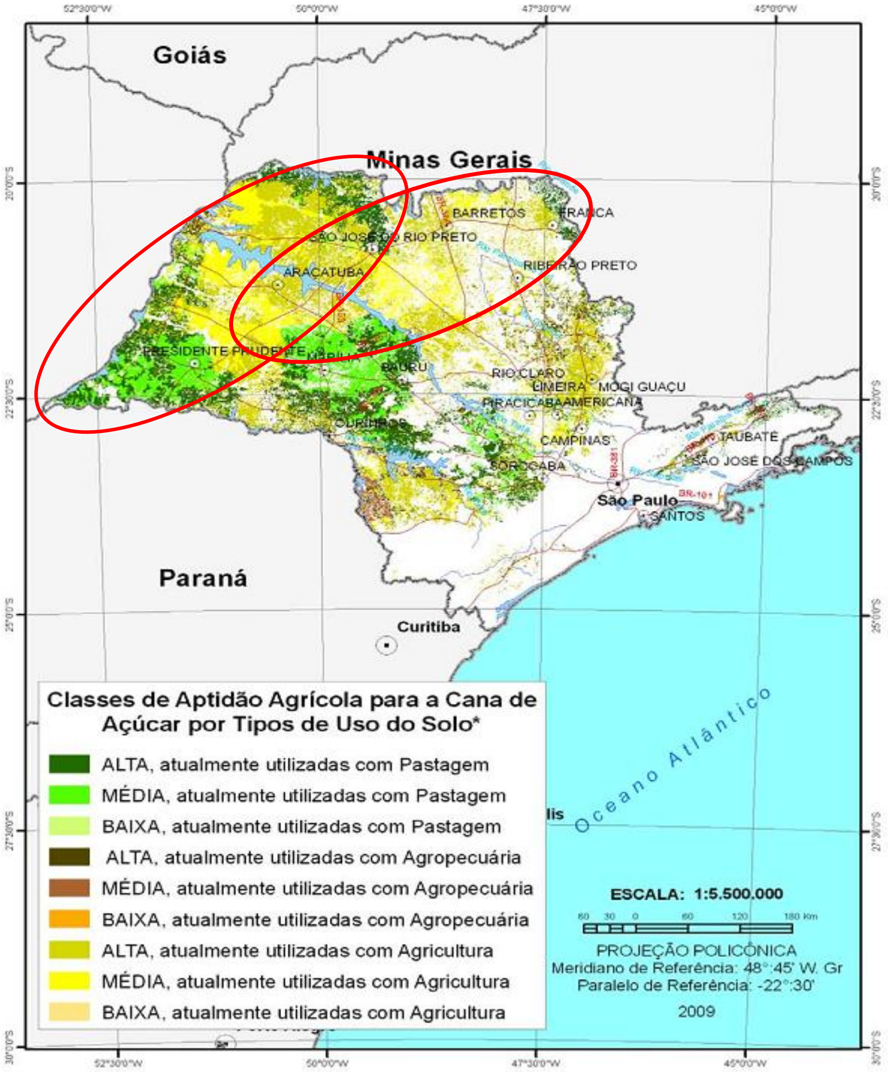

Figure 35 – Suitable areas for the expansion of sugarcane according to ZAE Cana. Red Circles indicate the areas to where ethanol agroindustry is in fact expanding. (CANASAT).
Source: MAPA, 2009 and CANASAT, 2014

While Brazil has been at the center of the biofuel-deforestation debate (GAO *et al.*, 2011), since some authors argue that the expansion of sugarcane in the Center-south region is pushing pasture into the Amazon, ZAE Cana does not address this indirect land use change (ILUC). This would be important data for researchers and also for the Brazilian participation in the ethanol international market.

Moreover, the areas of the expansion of sugarcane presented in ZAE Cana are exactly the ones where it was found in Chapter 5 that there is water restriction, considering the actual uses (red circles in Figure 35).

The ZAE Cana in its current structure is a technical diagnosis, which does not consider overlapping issues, and therefore it is not a useful tool to analyzing the expansion of ethanol production in Brazil in a systemic way. The links of the impact of sugarcane expansion in water resources management and in the implementation of the current energy policy are not addressed in ZAE Cana. Furthermore, the document does not consider socioeconomic issues, such as the impact on the price of land in the sugarcane expansion.

On the other hand, the ZAE Cana has the potential to be reorganized and expanded to incorporate other issues related to the expansion of ethanol production, such as:

- Future Climate Change and its effects on the zoning;
- Impact in the small farmers regarding sugarcane expansion in the areas occupied by agriculture;
- Competition between food and fuel, and its implications in the country’s food supply;
- Indirect Land Use Change;
- Water resources management in specific water basins.

Incorporating the above-mentioned items, ZAE Cana can evolve to a comprehensive and effective biofuels policy in Brazil.

6.2 Dynamics of Land Prices

In view of the growing incorporation of land for the production of sugarcane in Brazil, which occurs especially in São Paulo, it is plausible to formulate the hypothesis that this has made the resource scarcer, causing a rise in market prices (SCHAEFFER *et al.*, 2011).

In order to test this hypothesis, price series for land in the regions of the expansion of sugarcane were obtained from the Institute of Applied Economy of São Paulo - IEA (IEA (2), 2013). In the case of São Paulo, the representative municipalities of the Administrative Regions (AR) in study (see Chapter 5) Araçatuba, Central (Araraquara), Presidente Prudente, Ribeirão Preto, São José do Rio Preto, Barretos and Franca were chosen to comprise the sample. On that basis, annual series of land prices between 1996 and 2013 were obtained for the above-mentioned municipalities.

Regarding São Paulo State, three categories of land are defined by IEA for cultivation (IEA (2), 2013):

- **First-class cropland:** potentially suitable for annual and perennial crops;

- **Second-class cropland:** potentially suitable for annual and perennial crops, but presenting much more serious limitations than first-class cropland; and
- **Pastureland:** unsuitable for farm crops in the short term, but potentially suitable for pasture and forestry.

The use of the first-class cropland results in greater return of the investment, since there are no barriers to the use of mechanization in harvesting and the soil has higher fertility and drainage (IEA (2), 2013). Although with less investment return, second-class cropland can also be utilized with more expensive harvesting techniques and applying soil conditioners. Therefore, at first one should expect that the pressure on land prices placed by sugarcane production, among other factors, would be greater on these two land categories. However, a strong relation was observed (Figure 36) among the prices of all three land categories (SCHAEFFER *et al.*, 2011). This dynamic is a result of the increase both in the price of sugar in the international market (totalizing an increase of about 250% between 2003 and 2010), the demand for ethanol in the domestic market, and the competition in the use of land for food and biofuel production (RATHMANN *et al.*, 2010), which makes it possible to include less fertile lands for growing sugarcane.

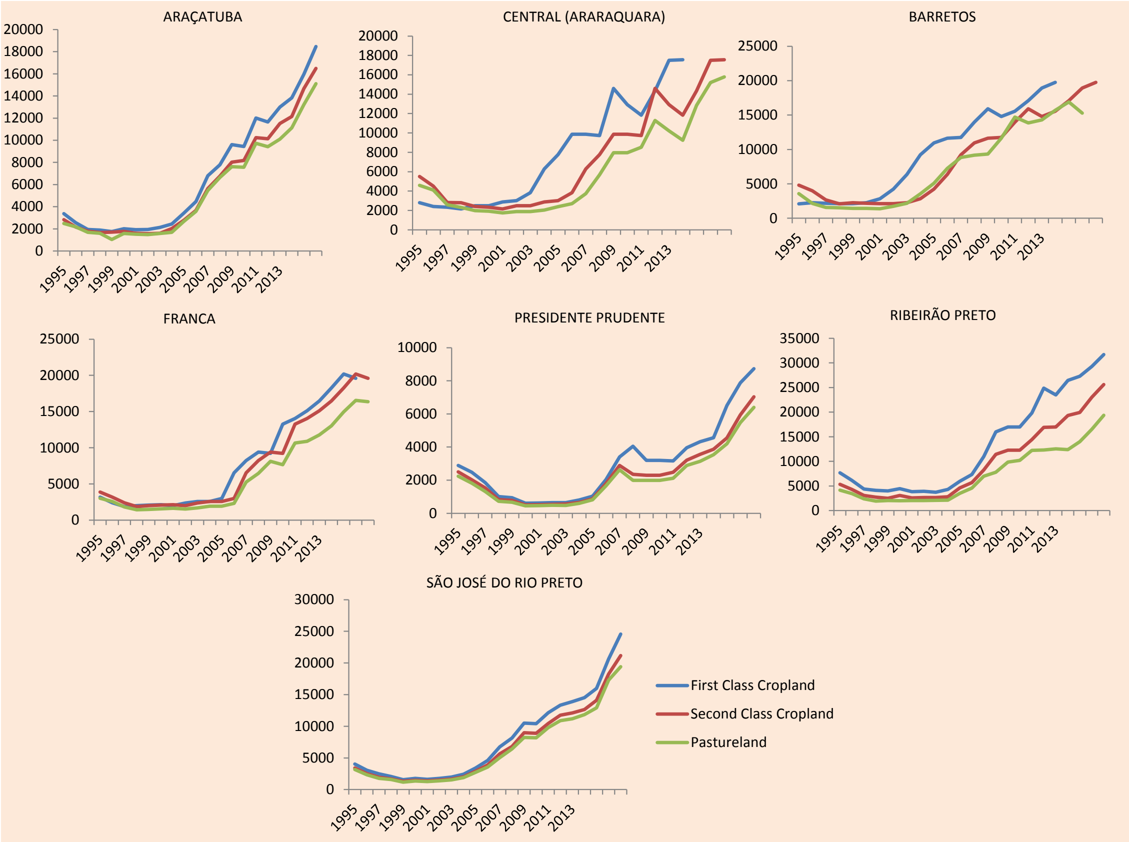

Figure 36 – Evolution of land prices for sugarcane production in selected municipalities in the State of São Paulo (R$/hectare).
Source: Adapted from SCHAEFFER *et al*., 2011. Prepared by the author based on IEA (IEA (2), 2014) data

Additionally, the acceleration in the price of preferential land for the production of sugarcane in São Paulo State is significant, especially after the inclusion of flex-fuel vehicles in the national automobile fleet (2003). Also, it should be pointed out that 56% of arable land in the state of São Paulo is leased (in the year 2008, approximately 60% of the total area allocated to sugarcane production in São Paulo was leased (MARQUES, 2009))**,** and 72% of such areas are owned by large economic groups, thus reducing the supply of rural areas in the state, and contributing to the increase in land prices (OLIVETTE *et al*., 2011).

The rise in the price of land in São Paulo influenced the average total costs of the biofuels business. In São Paulo it led to a sharp increase in the average total costs of the sugarcane business, at rates above the changes in the average total revenue, causing losses in the business margin (Table 9). In fact, the profitability of the activity, which was 14.5% in 2002, turned into a negative figure (-21.7%) in 2010. This also justifies the debate presently taking place in the ethanol market, regarding rising prices and the risk of a shortage of the biofuel (MME, 2011).

Table 9 – Production cost, leasing value, revenue and margins for the sugarcane business in the state of São Paulo (2002-2010).

	Sugarcane / SP				
	Average Leasing Value (ALV)	**Average Total Cost (ATC)**	**ALV / ATC**	**Average Total Revenue (ATR)[a]**	**Business Margin**
Year	(R$/ha/year)	(R$/ha/year)	%	(R$/ha/year)	%
2002	526	1,934	27.2%	2,214	14.5%
2003	578	2,309	25.1%	2,490	7.8%
2004	604	2,414	25.0%	2,184	-9.5%
2005	526	2,998	17.6%	2,465	-17.8%
2006	857	3,415	25.1%	3,096	-9.3%
2007	683	3,799	18.0%	2,523	-33.6%
2008	890	3,662	24.3%	2,136	-41.7%
2009	783	3,696	21.2%	2,640	-28.6%
2010	843	3,814	22.1%	2,988	-21.7%
Change 2010/2002	+60.2%	+97.2%	-	+35.0%	-

[a] Obtained by multiplying the average annual productivity (tons per year) of the sugar cane crop by the real average price paid to the producer (R$/ton with 145 kg of TRS).

Source: SCHAEFFER *et al*., 2011

Regarding a comparison between the municipalities in study (Figure 37), it is noted that new areas of sugarcane expansion such as Presidente Prudente, and Araçatuba present lower prices of land. Considering the impact of the price of land in the ethanol production costs, and the adequate areas for sugarcane plantations presented in ZAE Cana, it is possible to understand why the expansion of sugarcane will be even more accentuated in Presidente Prudente and Araçatuba.

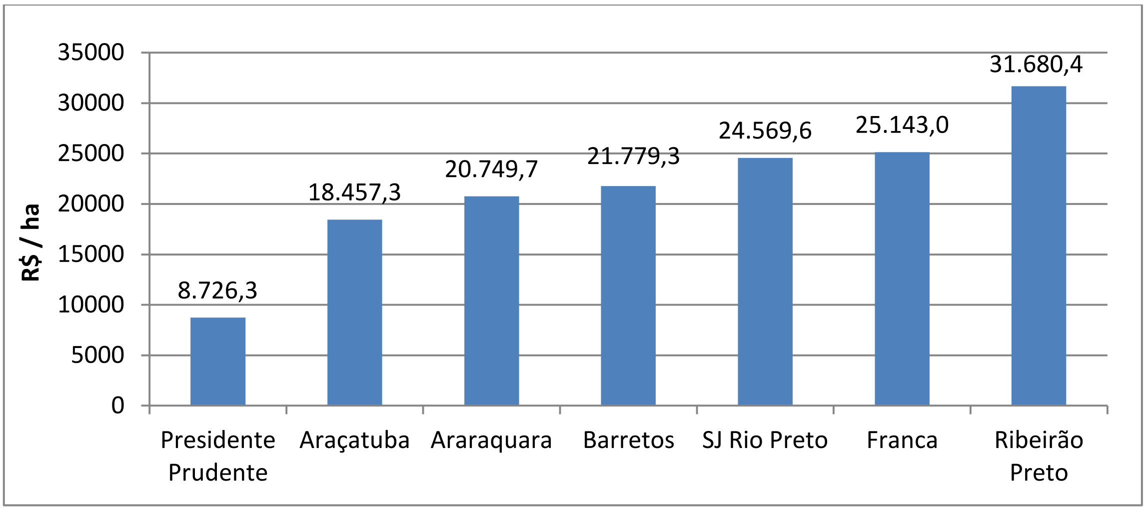

Figure 37 – Price of first-class cropland in 2013.
Source: Prepared by the author, based on IEA. (IEA (2), 2014).

6.3 Land-use conversions derived from Brazilian biofuels programs in São Paulo State

Land use conversion, i.e., how land use changes from a specific use to another, is one of the main issues regarding the sustainability of biofuels production (WALTER *et al*., 2010). It involves three important issues related to sustainability: a) Greenhouse gases (GHG) emissions calculations; b) Competition of food for fuel; and c) Socioeconomic implications regarding the incorporation of small farmers by large-scale producers.

The planned expansion of biofuel crops in Brazil could potentially cause both direct (LUC) and indirect land-use changes (ILUC). Direct impacts would be associated to the change of land use directly induced by the enlargement of sugarcane and soybean production, displacing other crops or natural vegetation. The worst case would be native ecosystems conversion (e.g., with deforestation) for the cultivation of sugarcane and soybeans. Indirect impacts would be associated to the expansion of agro-energy production causing the displacement of agricultural and/or cattle-raising activities to other regions inducing land use change, such as deforestation. For instance, the growth of sugarcane production in São Paulo has been blamed for the deforestation in Amazon region: as sugarcane is displacing pasturelands, a hypothesis is that cattle are moving to the state of Pará (CERRI *et al*., 2007; WALTER *et al*., 2009).

A critical issue in the sugarcane expansion dynamic is which types of land use cane is displacing directly. LUC impacts can be accurately quantified by using remote sensing satellite images. CANASAT Project measures direct land use change (DLUC) in the Brazilian Center-South region, where most of the recent sugarcane expansion has occurred.

Walter *et al.* (2009), analyzing expansion of sugarcane cultivation in São Paulo, among other states located in the Centre-South region, concluded that the growth of sugarcane production areas from 2006 to 2007 occurred mainly on former pasturelands – degraded or traditional (66%) and on land previously used for grain production (e.g. soybean, 18% and corn, 5.3%). In this region, from 1996 to 2006, the intensification of cattle grazing released land, 10% of which was used for sugarcane expansion. Indeed, the growth of sugarcane areas did not induce the displacement of cattle heads to other regions of Brazil, as cattle's density raised in all areas where sugarcane expansion took place. Figure 38 shows the evolution on the cattle productivity between 1940 and 2012. According to these figures it is possible to verify that the productivity increased from 0.39 heads/ha in 1940 to 1.23 heads/ha in 2012.

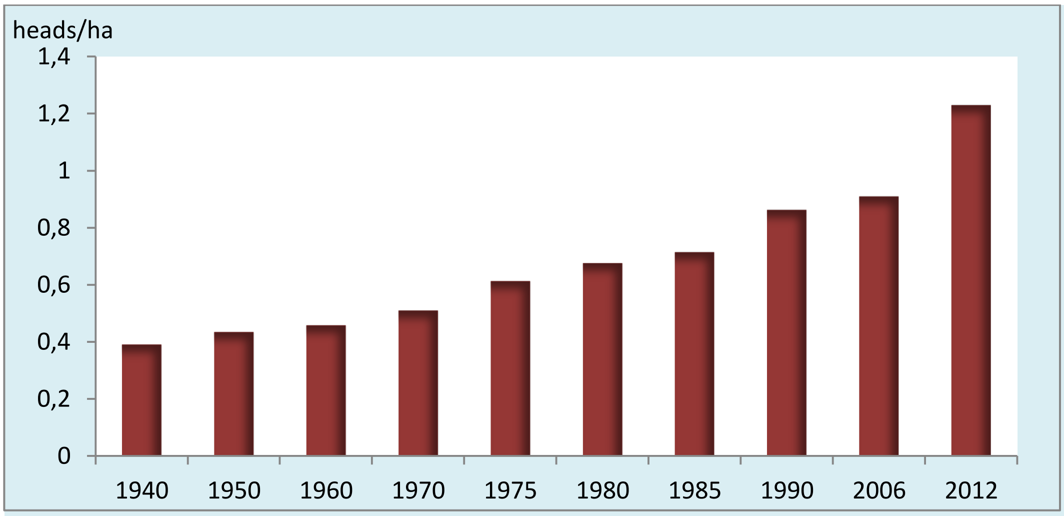

Figure 38 – Evolution of the occupation of grazing area in Brazil in heads per hectare.
Source: Author development based in SIDRA, IBGE and POLL *et al.*, 2013.

Similarly, Adami *et al.* (2012) analyzing cane expansion from 2000 to 2009 in the state of São Paulo and from 2007 to 2009 in other South-Central states (totalizing 3.2 million ha), observed that by 2000, 69.7% of this area was pasture, 25.0% was annual crop and 1.3% citrus, with both accounting for 96% of direct LUC due to sugarcane expansion. Out of the 69.7% pasture conversion, 35% was pasture converted to annual crops before being converted to sugarcane, and 65% was pasture converted directly to sugarcane plantations.

Estimates show that the expansion of biofuels production will be strongly based on areas currently allocated to livestock (NASSAR *et al*., 2010; SOARES-FILHO and HISSA, 2010; NASSAR *et al.*, 2011). Nassar *et al.* (2011), by simulating the Brazilian Land Use Model (BLUM) for the period 2011-2020, concluded that the production of sugarcane will expand directly on areas currently allocated to pasture, especially degraded. In turn, changes in indirect use of the land, especially for the allocation of cattle herd moved by the production of sugarcane will be perceptible, unless clear policies to stimulate stronger pasture intensification are implemented. In their absence, the pressure to convert forest areas will continue to be strong.

It was concluded that much of the expansion has occurred, and even future agro-energy crops in the states of São Paulo gave up (and possibly will) to areas currently allocated with pasture, particularly degraded. As commented before, DLUCs would have a small impact on carbon emissions if most of the biofuel plantations replace rangeland areas (LAPOLA *et al*., 2010). Moreover, only future studies mapping the intensification of livestock will be able to appropriately prevent the indirect effect of land use, in case the displacement of cattle herds occurs to areas currently occupied by native forest. According to Lapola *et al.* (2010), indirect land-use changes, especially those pushing the rangeland frontier into the Amazonian forests, could offset the carbon savings from biofuels. Sugarcane ethanol and soybean biodiesel each contribute to nearly half of the projected indirect deforestation of 121,970 km^2 by 2020, creating a carbon debt that would take about 250 years to be repaid using these biofuels instead of fossil fuels.

7 WEL Nexus

Considering the results obtained in the individual analyzes related to available resources and policies regarding WEL in the state of São Paulo, one might conclude that the expansion of ethanol provided in the Ten Year Energy Plan 2022 (PDE 2022) is sustainable from the point of view of each resource.

The analysis of water in São Paulo State considering the river basins of the areas of sugarcane expansion (Pardo, Peixe, Tietê-Jacaré, Turvo/Grande, Baixo Tietê, Sapucaí-Mirim/Grande and Baixo Pardo/Grande) shows a situation of attention comparing the demand of water for all uses in 2022 of 2.8 billion m^3 compared to a minimum flow observed in 7 days in the last ten years ($Q_{7,10}$), which results in a total water availability of 6.3 billion m^3 / year. In this case, the demand of water in the river basins would be 46% of the total $Q_{7,10}$, characterizing a situation of nearly water restriction in the region as a whole, but in specific river basins it is not confirmed to where the expansion is advancing and there is a possibility of having no constraints.

According to ZAE Cana, the analysis of land shows that the prevalent areas for the expansion of sugarcane in São Paulo State are located in the west part of the state. The areas considered adequate for sugarcane expansion in São Paulo totalize 10.6 Mha, of which 58% are currently used for agriculture, 36% for pasture and 6% for agriculture plus pasture. Therefore, regarding the criteria used by ZAE Cana there is no constraints for the expansion of sugarcane in the São Paulo. In fact, using ZAE Cana as the only basis for decision, all the expansion considered in PDE 2022 could take place in São Paulo, since the total land expected to be used for the expansion until 2022 is around 2 Mha (from the actual 9.4 Mha to 11.2 Mha) (EPE, 2013). Regarding the analysis of land prices it was concluded that land prices increased significantly after 2003, when the flex-fuel vehicles were included in the Brazilian car fleet in all the representative municipalities of the sugarcane expansion area. Moreover, it is observed that the municipalities of Presidente Prudente, Araçatuba and São José do Rio Preto had the lowest prices in 2013 (IEA (2), 2014). These results are aligned with ZAE Cana, since there should be no problem in the expansion of sugarcane in the mentioned Administrative Regions (ARs), as they have high potential for sugarcane plantations. Moreover, in relation to direct land use change (DLUC) there would be also no restrictions for the expansion of sugarcane in São Paulo, as showed in Chapter 6 of the present study.

In this Chapter the individual results found for each of the items of the WEL will be cross checked to identify if the analysis changes when the nexus approach is implemented. The principal findings for each one of the items analyzed are presented in Figure 39.

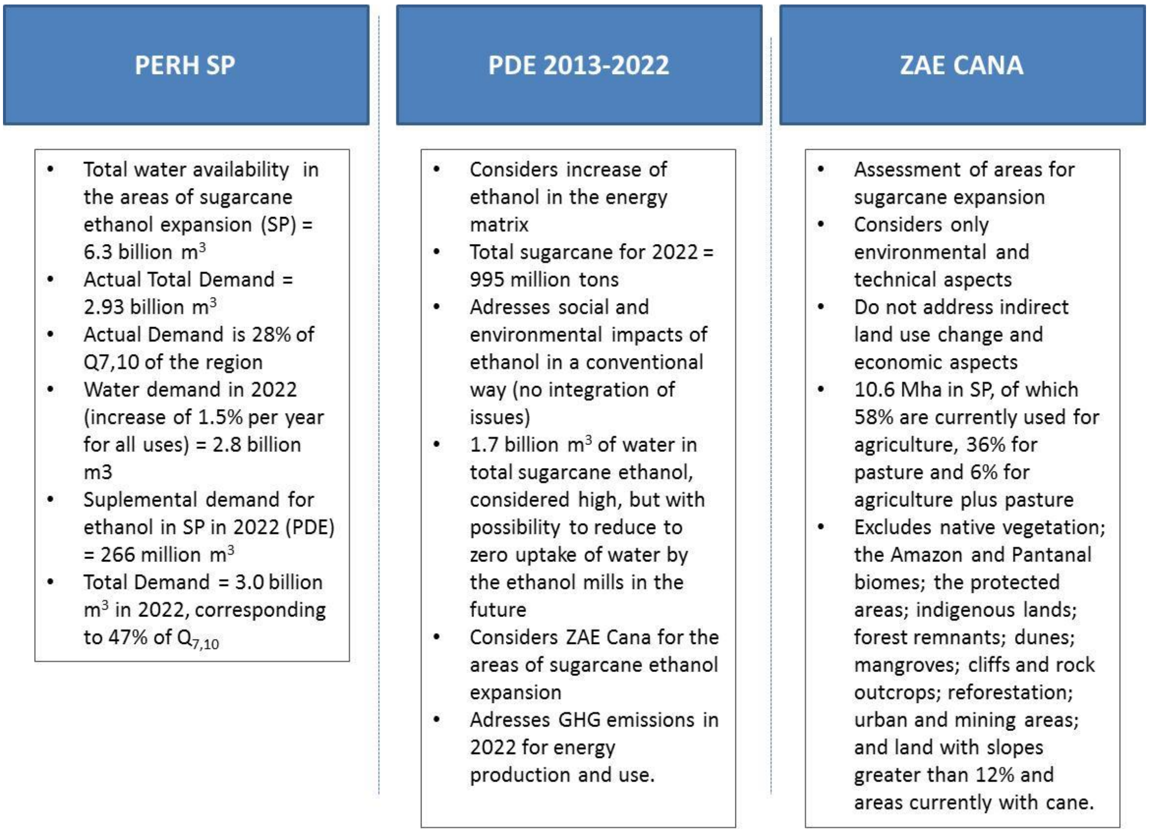

Figure 39 – Findings of the WEL individual analysis of policies.
Source: Author's development.

Integrating the analysis, it is possible to observe that the lower prices of land in Presidente Prudente and Araçatuba and the influence of the price of land in the costs structure of the ethanol production can influence the dynamics of the expansion of sugarcane in São Paulo State. Land prices may be one of the explanations for the bigger growth rate of the sugarcane expansion observed in Presidente Prudente between 2009 and 2012 (9.13%), followed by São José do Rio Preto and Araçatuba, while well-known sugarcane municipalities, such as Ribeirão Preto, did not expand in the period (Figure 40).

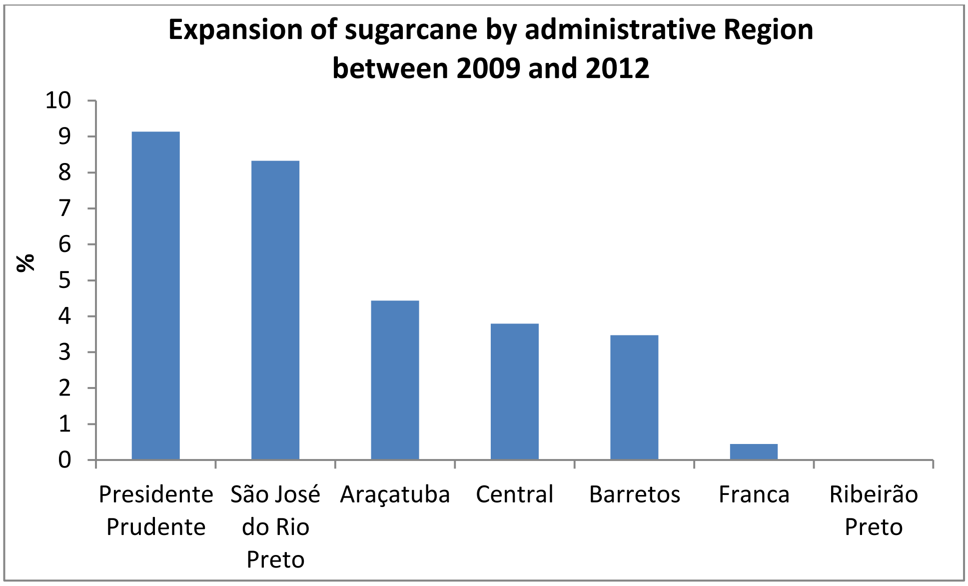

Figure 40 – Expansion of sugarcane by administrative Region between 2009 and 2012 (%). Source: Prepared by the author based on CANASAT (CANASAT, 2014)

Cross checking the three ARs (Presidente Prudente, São José do Rio Preto and Araçatuba) with the information of the respective River Basin Plans, one of the three ARs already presents water restriction regarding all water uses. In São José do Rio Preto the situation of water availability is very problematic, with 59% of the $Q_{7,10}$ currently compromised (Turvo Grande). In Presidente Prudente, no actual restriction is observed (only 8% of the $Q_{7,10}$ is in use in the river basin of Peixe), but considering that this is a preferential area for the expansion of sugarcane in ZAE Cana and also due to low prices of land, it is recommended that a systemic and comprehensive water resources planning of the river basin is designed and implemented, including an evaluation of future demand in the region.

Moreover, it is possible that the higher prices of land may affect the type of land to be incorporated in the sugarcane expansion. The use of marginal lands (lower market price) with lower rainfall may require use of irrigation to become suitable for sugarcane plantations. In this case, the specific water use per ton of sugarcane would increase causing a greater impact on the use of water resources in regions of expansion of sugarcane. Although the actual available data do not permit a more thoroughly evaluation or prediction, the water grants for sugarcane irrigation reported by the National Water Agency (ANA) in 2013 in São Paulo State totalizing almost 19 million m^3 in the west region of the state can be an indicative of this trend. Figure 41 shows the relationships presented in the nexus analysis and the vicious cycle that can be implemented if a comprehensive planning involving WEL is not developed.

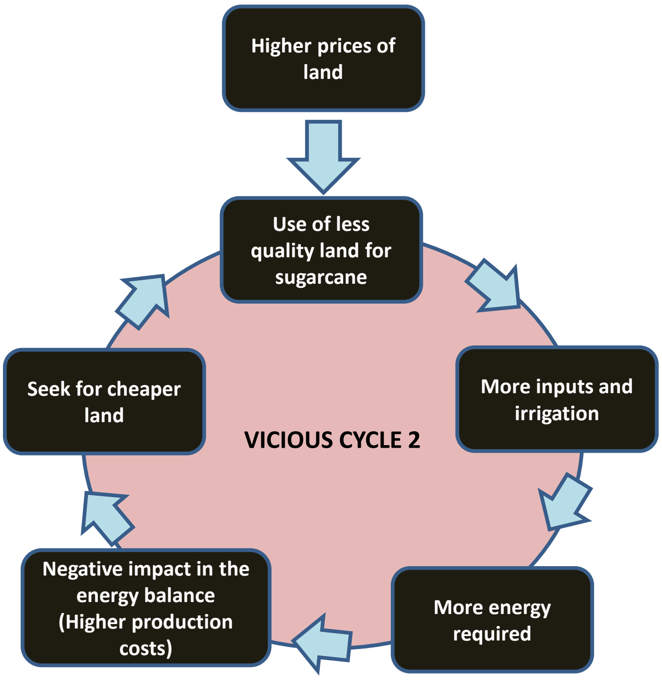

Figure 41 – Vicious cycle that can be implemented in the region of sugarcane expansion in São Paulo.
Source: Prepared by the author

As observed in Figure 41, with the use of less quality land more energy from fossil fuels can be required in sugarcane production, harvesting and transportation. Considering that this part of the energy balance of ethanol is responsible for 91% of the total fossil fuel use, it is possible to infer that the prices of land will also have a negative impact in the energy balance, which will influence in higher production costs, as well as lower profit margins. In this context, producers will seek for cheaper land, completing the vicious cycle.

7.1 Integration of Policies

Regarding the integration of policies related to WEL, it was observed that environmental and socio-economic analyses were conducted in the PDE, what is a very positive finding regarding the energy policy. Moreover, the decision of increasing biofuels in the energy matrix seems to be part of a strategy of reducing Greenhouse gases (GHG) emissions in Brazil.

The Brazilian energy policy (PDE) addresses social and environmental impacts of ethanol in a conventional way (no integration of issues) and concludes that the uptake of water for the production of sugarcane ethanol in 2022 will be 1.7 billion m^3. This number was obtained directly through the actual observed amount of water needed by the sugar mills per ton of cane. PDE assumed 1.8 m^3/t cane, which is a very coherent number, regarding the references studied in this work (see Chapter 5). In the PDE it is stated that this number is high, but can be reduced with technological improvements in the mills in the future. However, PDE does not compare the absolute number of 1.7 billion m^3 with the availability of water in the regions of expansion of sugarcane, and the conclusion that the number is high lacks a comparative methodology, and ignores the figures presented in the São Paulo Water Resources Plan (WRP SP), the greater producer of ethanol in Brazil. For example, if the total water needed is compared with the total water available in the Parana Basin[28] (where the expansion of the sugarcane is foreseen) the conclusion would be that it is not considered high, since Parana Basin has a water availability of 361 billion m^3/year (ANA, 2013a) and the impact of the sugarcane mills would be less than 5% of the total water availability. PDE also considers ZAE Cana for the areas of sugarcane ethanol expansion and addresses GHG emissions in 2022 for energy production and use. Nevertheless, the PDE does not mention land use change in its analysis, what can be seen as a weakness of the GHG emissions calculation presented. Economic issues, such as price of land and types of local and regional economic relationships are also not addressed.

In general terms, the analysis conducted in this study shows that, despite the positive effort of including water and land evaluations in the energy policy, PDE does not succeed in produce a thorough analysis, only scratching the surface of the problems. Also, the energy policy does not integrate water resources planning and land planning. In the case of land, it limits to show that the new mills are located in the areas considered adequate by ZAE Cana.

The São Paulo Water Resources Plan (WRP SP) presents a detailed diagnosis of river basins, informing water availability, current demands and water balances, mainly based on average flow. For several river basins it also includes an analysis of socioeconomic and local constraints. From the results of the present study it is possible to observe that São Paulo State has a well implemented water management structure, especially when compared to most of the other Brazilian states. On the other hand, the increased demand for biomass energy will increase water demand and requires proper management of water resources allocation. In this regard the WRP SP lacks proper planning of water resources for all uses. It does not present a forecast for future water

[28] See Chapter 5 for details

demand in São Paulo and in specific river basins. The specific River Basin Plans analyzed (Pardo, Peixe, Tietê-Jacaré, Turvo/Grande, Baixo Tietê, Sapucaí-Mirim/Grande and Baixo Pardo/Grande) have also a comprehensive diagnosis of the respective river basin in technical terms. Nevertheless they do not pursue a systemic understanding of the dynamics of water resources use in their regions, not being able to present a plan for water-use integrated with other Brazilian policies, such as the energy policy (PDE) and the land policy for sugarcane (ZAE Cana). The same was observed for the river basin of Peixe (Presidente Prudente AR), in which most of the expansion of sugarcane in São Paulo is foreseen, as mentioned earlier in this Chapter. Currently, sugarcane is the most important agriculture product of the region, corresponding to 81% of the total plantations of the river basin and there is no mention to this industry in the respective basin plan.

Also, when it comes to planning related to the expansion of sugarcane in the basin plans in the regions of sugarcane expansion, as mentioned in Chapter 5, it appears that none of them, including the São Paulo Water Resources Plan (SÃO PAULO, 2013) has a specific strategy for the expansion of the sugarcane industry in the region. The River Basin Plan of Pardo (Ribeirão Preto AR), for example, whose cane plantations represent 97% of temporary crops in the region, has a chapter on "projects to be implemented to define the potential future use of water resources", which is not conclusive.

In relation to ZAE Cana, this is a very well designed initiative in terms of technical appraisal of adequate land for sugarcane expansion. ZAE Cana is an important tool for a first step in protecting sensitive areas in Brazil as well as to guarantee that sugarcane will be expanding in accordance with adequate direct land organization. Regarding its integration with policies of water-use (WRP SP) and PDE, it is clear that ZAE Cana does not consider other water uses and water basins specificities.

In the context of the analyses conducted and considering its limitations, it is possible to observe that desirable interaction that should occur between the WEL-related policies for achieving a sustainable expansion of the ethanol production in Brazil are not present among the policies.

Figure 42 illustrates the desirable interactions that do not occur in the WEL related policies.

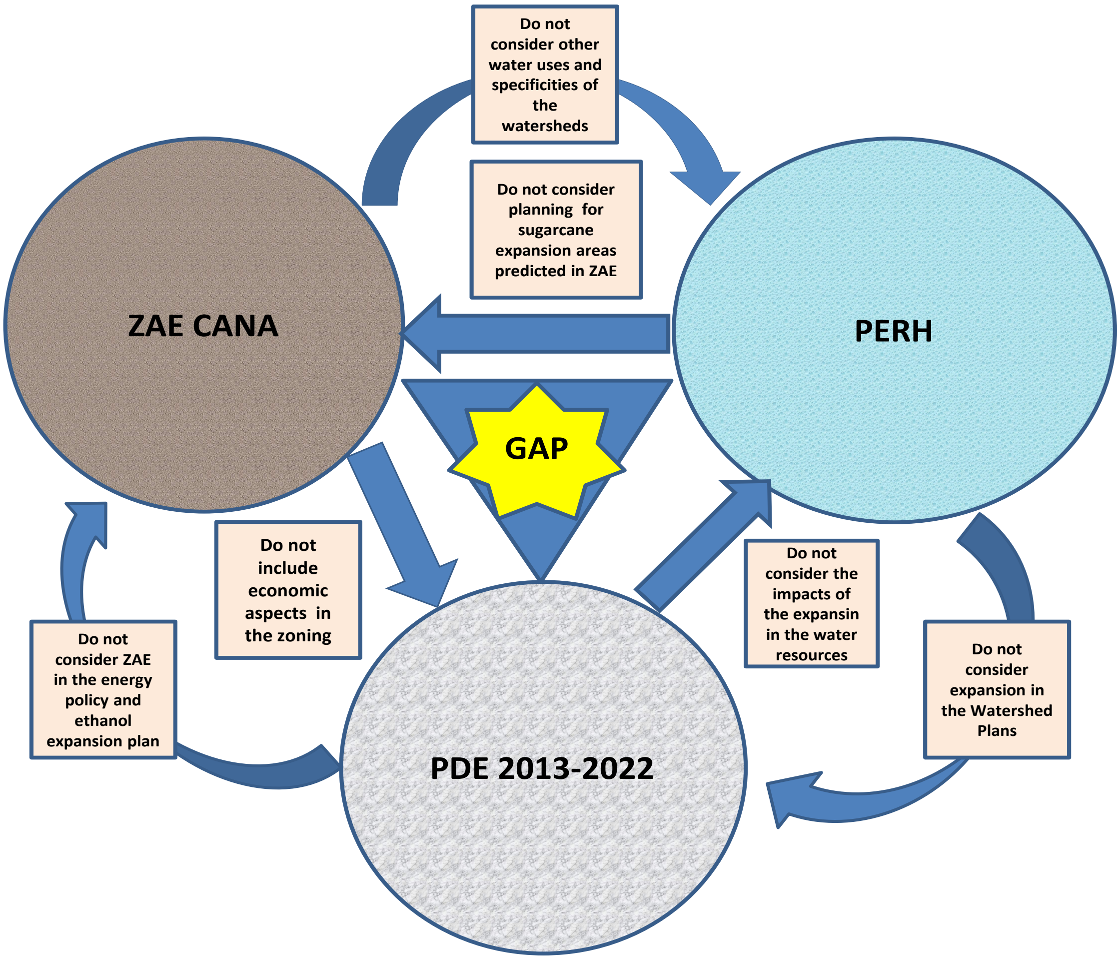

Figure 42 – Desirable interactions that do not occur in the WEL related policies.
Source: Author development

The triangle in the Figure 42 represents the distance between the policies indicating a gap for the integrations of issues in the policies evaluated in this study.

In the context of integration of issues that already occur, any proposed agribusiness enterprise in the sugarcane sector in São Paulo is subject to the environmental licensing process, involving Environmental Impact Assessment (EIA) for every new sugarcane enterprise, or the expansion of existing ventures to produce ethanol (GALLARDO and BOND, 2011). As pointed out in Chapter 3, although EIA assesses all the issues involved in the sustainability concerns, it is mainly project-level focusing on limited geographical scales and, therefore, is not well placed to consider large scale issues like GHG emissions and food security and largely reacts to development proposals rather than proactively anticipating them in a planning effort (THÉRIVEL and PARTIDARIO, 1996).

Therefore, for reducing the sides of the triangle indicated in Figure 42, it would be important to have a comprehensive ethanol policy in Brazil. In this regard, one proposal of the present work is the amplification of ZAE Cana in order to incorporate other issues related to sustainability, giving an overall look to the planning expansion of ethanol in Brazil. For this purpose, ZAE Cana needs to be revised for the incorporation of the following issues:

- Future Climate Change and its effects in the zoning;
- Impact in the small farmers regarding sugarcane expansion in the areas occupied by agriculture;
- Competition between food and fuel, and its implications in the country’s food supply;
- Indirect Land Use Change;
- Water resources management in specific river basins.

Figure 43 illustrates the desirable situation for achieving sustainability biofuels, where an ethanol policy integrates the WEL resources addressing the relevant issues for their sustainability.

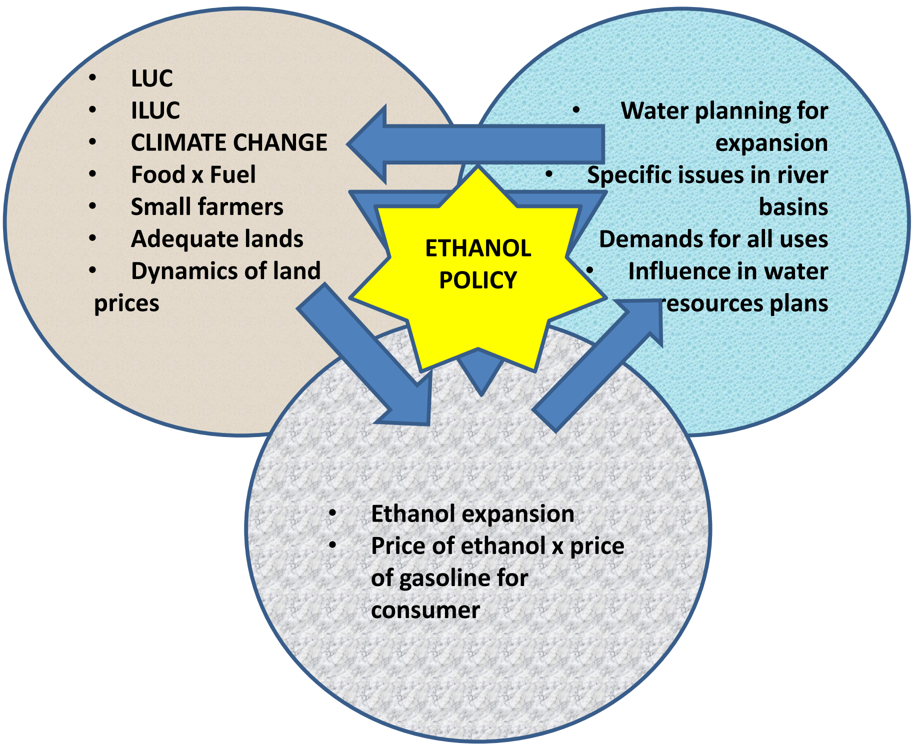

Figure 43 – Desirable situation for achieving sustainable ethanol expansion
Source: Author’s development

Considering that ethanol from sugarcane, currently represent a relevant and competitive element of Brazil's development strategy (NOGUEIRA and CAPAZ, 2013), it is important that the Federal and state governments give especial attention to this industry. As pointed out in Chapter 5, the successful inclusion of ethanol in the Brazilian energy matrix depended on several interventions such as incentives for car owners to shift to ethanol-fueled cars, guaranteed lower prices for ethanol in comparison to gasoline prices at gas stations and guaranteed minimal prices for ethanol producers.

Although the actual energy policy (PDE 2022) foresees an expansion of ethanol production in Brazil in the coming years, it is a fact that the Brazilian production has been decreasing since 2010. The ethanol production in Brazil decreased 15% between 2010 and 2013, as shown in Figure 16 (Chapter 3). Besides unfavorable climate conditions that reduced the harvest, producers claim that the actual Brazilian energy policy, in which the prices of gasoline are kept low for inflation control affects directly the choice of the consumer in the flex-fuel car, reducing the ethanol market.

Whereas it is not feasible to implement the same policy structure as in the past, due to a complete different context, an ethanol policy would be highly recommended for guaranteeing that the ethanol production and use in Brazil do not derail from its successful trajectory of more than 30 years.

8 Conclusions and Final Considerations

There are few studies that seek to integrate sustainability issues of biofuels. Due to the complexity of conducting an analysis that incorporates issues such as water, energy and land (WEL), and other items that influence the sustainability of biofuels, such as climate change, some studies are still under development for the creation of a framework of analysis that is effective in integrating multiple issues. The present work was able to show that the separate analysis of issues can induce to misleading conclusions.

The separate analysis of WEL-related issues regarding sugarcane expansion in São Paulo resulted in a sustainable expansion in the perspective of the three resources analyzed. Regarding water resources, this study calculated that the total water availability in the areas of sugarcane ethanol expansion in São Paulo is 6.3 billion m^3. The actual total demand is 72.4 billion m^3/s reaching only 28% of $Q_{7,10}$ of the region, which is still a comfortable situation. On the other hand, the forecast for 2022 shows that 46% of $Q_{7,10}$ will be compromised in 2022, which is an alarming situation of water restriction. On the other hand, only analyzing water it is not possible to conclude that the expansion would be in the selected river basins. In the case of land, ZAE Cana assessed areas for sugarcane expansion considering environmental and technical aspects and found 10.6 Mha in São Paulo suitable for sugarcane, while the area needed for the total production foreseen in the PDE 2022 is 11.3Mha. Therefore, there are no constraints related to land in the actual land policy.

Although, the cross checked analysis (nexus) led to the result that the preferential areas in ZAE Cana, taking into consideration also the prices of land, will encounter limitations due to the water restrictions in the related river basins. The river basin of the administrative region (AR) São José do Rio Preto - and to where sugarcane will probably expand due to the low prices of land - has no restrictions in ZAE Cana, but already is in alarming situation regarding water use. The river basin of Presidente Prudente (Peixe) and Araçatuba (Baixo Tietê) have no water restriction, but the River Basin Plan does not contemplate any planning for sugarcane expansion in the region.

Moreover, it is possible that the higher prices of land may affect the type of land to be incorporated in the sugarcane expansion. The use of marginal lands (lower market price) with low rainfall may require use of irrigation to become suitable for sugarcane plantations, increasing the water stress.

The water-use, energy and land-use policies analyzed were not totally integrated, as PDE does not consider a proper analysis of water resources, São Paulo Water Resources Plan (WRP SP) does not consider the sugarcane expansion in its planning, and ZAE does not consider WRP SP and does not plan the expansion of sugarcane plantations in a global perspective.

Also, when it comes to planning related to the expansion of sugarcane in the river basin plans in the regions of sugarcane expansion, as mentioned in Chapter 5, it appears that none of them, including the São Paulo Water Resources Plan (SÃO PAULO, 2013) has a specific strategy for the expansion of the sugarcane industry in the region.

Regarding the second main question posed in this study, if there is a need for a specific ethanol policy in Brazil, the conclusion is that the separate policies present a gap in the integration of issues which is difficult to fulfill with different policies. As already suggested by Goldemberg *et al.* (2008) and Gallardo and Bond (2011), the sugarcane agroenergetic industry needs to promote and demonstrate its sustainability as a public policy for guaranteeing the sustainability of sugarcane ethanol in Brazil (and in particular in São Paulo State). As Gallardo and Bond (2011) stated “if this process is successful it can act as a model for other developing countries which have a clear potential to expand their sugarcane (or other biofuel crop) industry for ethanol production”.

Whereas it is not feasible to implement the same policy structure as in the past, due to a complete different context, a biofuels policy would be highly recommended for guaranteeing that the biofuels production and use in Brazil do not derail from its successful trajectory of more than 30 years.

9 Suggestions for Further Studies

Considering the limitations of this study and its findings it was possible to identify some proposals for future studies.

In general, a first proposal for future study would be to expand the analysis developed in this work to other biofuels in Brazil, namely, biodiesel. Although much less important than ethanol in terms of market coverage, soybean biodiesel, as well as biodiesel from other raw materials are also produced in Brazil and an integrated analysis of sustainability of biofuel correlating aspects related to water, energy and land can contribute for a better evaluation of the insertion of this biofuel in the national energy matrix.

Furthermore, the analysis structured in this work can also be applied to other regions of the world that are interested in expanding or starting the production of biofuels. It is noteworthy that similar analyzes to those conducted here should consider specific aspects related to the study area.

Taking into consideration the conclusion presented here about the need for the development and implementation of a specific policy for ethanol in Brazil, it is important to assess this matter in future studies. The proposal is expanding the ZAE Cana to address the nexus between water, energy and land systemically considering environmental, social and economic factors. Given the complexity of the development of such a policy, a suggestion of future project would be the establishment of a working group of experts from various fields in order to develop a feasible policy that can guide the development of sustainable production and use of ethanol in Brazil.

Another study of interest to Brazil would be to apply the work here for new areas of expansion of ethanol, notably; areas of cerrado in Minas Gerais and Mato Grosso do Sul, mainly close to the borders with the state of São Paulo. According to the PDE 2022, much of the new ethanol plants are located in these states, especially near the borders with SP.

One difficulty of this study was to identify recent studies that presented reliably (with local information) the energy balance of Brazilian ethanol. The latter study found was developed by Isaias Macedo, published in 2008. Accordingly, a suggestion of future study is to update the energy balance of Brazilian ethanol including financial issues and comparisons with other fuels, mainly gasoline. This study can subsidize public policy and international studies.

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