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IMPACT OF BIOFUELS ON U.S. RETAIL GASOLINE PRICES: A SYSTEMATIC LITERATURE REVIEW

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Abstract:
This paper summarizes the main findings of the results in the literature on the role of ethanol in reducing retail gasoline prices in the United States. We provide a comprehensive overview of the key results and methodologies used to obtain them. The paper documents the growing research interest in the assessment of the impacts of biofuels on agricultural commodity prices and overall price dynamics; presents the research trends, thematic map and the conceptual structure map; and identifes the main directions of the corn-ethanol focused biofuels literature through the analysis of predominant clusters. The last key contribution is the proposed research agenda.

JEL: C38, Q16, Q42
Keywords: biofuels, corn, ethanol, gasoline, U.S. retail prices, systematic literature review

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1 Introduction

The biofuel industry has been significantly growing in recent years around the world and most prominently in USA, EU, and Brazil. Originally, biofuels sparked the interest of agricultural economists and policymakers in the last century in the context of replacing fossil fuels and providing energy security, later also to address climate change, food security, and rural development (Lade et al. 2018). Since the turn of the century, biofuels have become a controversial topic in the public domain as well as in agricultural and energy research, which evolves into two main trends. The first main body of literature concerns food security and crop prices (Khanna and Crago 2012, Hochman et al. 2014), since the primary use of agricultural production has been food consumption. The second concerns ecology and environmental topics (Oehlschlaeger et al. 2013, Rajagopal and Plevin 2013, Hill et al. 2006, Demirbas 2008), such as greenhouse gas emission (GHG), use of land and water compared to just using conventional fossil fuels and leaving land for food production or provision of environmental services.

The literature on commodity food prices is mostly concerned with econometric analysis and investigates relationships and common dynamics between the prices of food and biofuels. The main concern is that using agricultural production as a feedstock for biofuels rather than food consumption drives food prices up and causes nutrition crises, particularly in low-income countries. The food crisis between 2008 and 2010 motivated extensive research on this topic (Abbott et al. 2008, Rosegrant 2008, Trostle 2010, Janda et al. 2012). The literature generally finds that the relationship between food and ethanol prices is relatively weak, but ethanol prices are affected both by food as well as fuel prices. Zilberman et al. (2013) offers a comprehensive review of studies and critically compares their results. In conclusion, Zilberman et al. (2013) argue that standard time-series analysis does not capture the effect of biofuels on food well and that the impact is, in fact, quite heterogeneous across crops and geographical locations. The presented review further argues that the impact of biofuels on food commodities is, in fact, lower than the impact of economic growth and can be well offset by using genetically modified crops.

Condon et al. (2015) provide a meta-analysis of estimates of corn-ethanol on corn prices and find that increasing the production of corn-ethanol by one billion gallons increases corn prices by three to four percent. Persson (2016) then presents a systematic review of the literature similar to ours but explores the effect of biofuels energy demand on agricultural commodities while we focus on so far much less investigated effect of ethanol on gasoline prices.

Recently, Lark et al. (2022) assess the environmental effects of the Renewable Fuel Standard (RFS) program, which is the main policy driver behind the increased biofuel production since 2005 and even more after the expansion of the program in 2007. Lark et al. (2022) calculate that the mandates motivated higher use of fertilizers and reduced diversity of the U.S. soil by reducing rotation in favor of producing corn. This, in turn, produces substantially greater GHG emissions. Also, Lark et al. (2022) estimate that higher demand for corn caused inflation of soybean and wheat prices and dispute the potential of the current corn-ethanol production in mitigating climate change. This study, along with (Chen et al. 2021, Council et al. 2012), forms strong criticism of the RFS program, well summarized in Hill (2022). These studies argue that while corn-ethanol provides profits for corn farmers and ethanol producers, it comes at a much greater expense to the U.S. taxpayer in the form of financing the subsidies, higher gasoline and food prices, and overall high costs of climate change and other environmental damages, such as water and air quality. Those recent studies present contradictory conclusions to the meta-analysis presented by Hochman and Zilberman (2018), or GHG discussion in (Rajagopal et al. 2008). One of the substantial changes in time between the studies is the shift of the U.S. position from a net oil importer to an exporter in 2020, which according to Hill (2022), reduces the necessity of the RFS program.

The biofuel policy debate is ongoing and evolving rapidly and substantially. We take the rich discussion presented above as evidence not only of the complexity of the biofuel topic but also of the evolution of results over time. In this article, we add to the discussion on price impacts; more specifically, we review the literature concerning the impact of blending ethanol into gasoline in the U.S. Our systematic literature review identifies the methods used in the research and their contribution to modeling ethanol's effect. This study aims to provide a review of the state-of-the-art literature regarding the impact and contributions of corn ethanol on retail gasoline prices in the US. To assist in achieving this goal, we propose four research questions **(RQ)**:

RQ1: What are the main characteristics of the literature regarding the impact and contributions of ethanol on US retail gasoline prices?

RQ2: What are the main article clusters identified in the evaluated literature?

RQ3: What was the numerical impact of Volumetric Ethanol Excise Tax Credit/Renewable Fuel Standard (VEETC/RFS) mandate on the price of gasoline and what are the main methodologies used for calculation in the literature?

RQ4: What are the main trends and possibly new research directions for this literature?

2 Materials and methods

Systematic literature review (SLR) can be defined as a structured review process that allows others to replicate and validate the research conducted and exactly follow the path chosen for the research (Tranfield et al. 2003). In this way, SLR differs from a traditional exploratory review, reducing the researcher's subjectivity, and resulting in a scientific, transparent, and replicable process (Pires et al. 2021). In the SLR proposed in this study, we follow the instructions of the PRISMA statement, in addition to five steps recommended by the literature (Moher et al. 2009):

(a) Formulate research questions that can guide the study.
(b) Identify the most relevant studies from the literature of interest.
(c) Evaluate the quality and relevance of the articles.
(d) Identify and summarize the scientific evidence.
(e) Interpret the results found.

In simple terms, SLR can be defined as a systematic process composed of three phases: Input (i), Processing (ii), and Output (iii) (Levy and J. Ellis 2006, de Oliveira Azevêdo et al. 2020); as shown in Figure 1. In the Input phase, we define the research problem and objectives. During the Processing part, we search for studies in the databases, construct search strings and define exclusion or inclusion criteria to which we then apply filters to assist us in the analysis of results. We then proceed to document the results. In the Output phase, we produce tables and figures which summarize the obtained results.

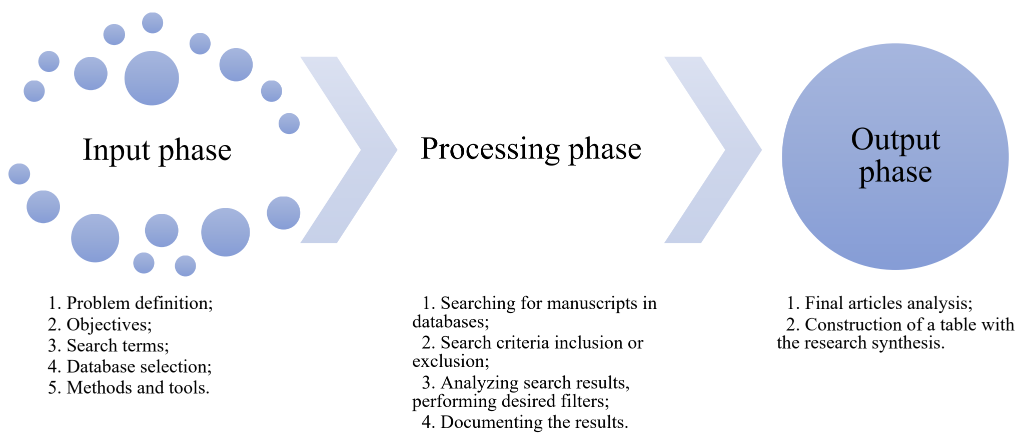

Figure 1: Model for conducting a systematic literature review. Adapted from (de Oliveira Azevêdo et al. 2020, Rocha et al. 2022)

This section is dedicated to providing a detailed description of the steps we follow in conducting the SLR used to answer the research questions (RQ) presented in the previous section.

In the Input phase, we define the research problem and its objectives along with studies relevant to the literature. We identify the main keywords of the publications that would contribute to the discussion about the appropriate search strings for performing the SLR. It is important to note that the proposed research questions serve to guide the development of the research and the presentation of results. For this, due to its sufficient acceptance and breadth, the Scopus database (from Elsevier) was selected.

After carrying out exploratory attempts, we adopt the search strings presented below, considering the Boolean logic "and" between levels (i), (ii) and (iii). The use of the symbol " " guarantees the exact sequence of words. Finally, some variations as plural and singular were considered.

i **Title** ("ethanol" or "biofuel" or "bioethanol" or "renewable fuel")

ii **Paper title, keywords or abstract** ("U.S" or "US" or "USA" or "U.S.A" or "United States" or "Midwest" or "corn")

iii **Paper title, keywords or abstract** ("gasoline price" or "fuel price" or "gas price" or "petrol price" or "petroleum price" or "retail price" or "gasoline market" or "fuel market" or "gas market" or "petrol market" or "petroleum market" or "petroleum product market" or "wholesale" or "price support")

It is pertinent to point out that we use the term "corn", since the research focuses on North American ethanol, along with the use of "Midwest". In this way, we use the term "corn" in the geographic section of the filter to capture studies that deal with corn ethanol and that, for some reason, do not use the U.S. (or similar) descriptor in the title, abstract or keywords. We used the bibliometric analysis software VOSviewer and *Bibliometrix* R Package (Aria and Cuccurullo 2017) and for evaluation, synthesis of results and information, and graphical interpretation of the results, we used Microsoft Excel.

In the Processing phase, we proceeded to define the eligibility criteria while ensuring that the sample responds adequately to the formulated RQs. The inclusion and exclusion filtering procedure was conducted by all co-authors of this study in sequence, thus ensuring the quality of the final sample. Figure 2 illustrates the delimiting filters of the sample used. In a search carried out in September 2022, the search strings resulted in 202 publications in the Scopus database. After reading the title, abstract, keywords, and search results, we reduced the list to 130 articles since part of the initial sample was outside the scope of the research. After an initial read of the results and conclusions, we applied the second filter and obtained a sample of 112 articles. Finally, the articles were subjected to a complete reading, and we narrowed down the sample to 109 articles.

We list the most important exclusion criteria used in the Processing phase:

(a) Studies from foreign countries (such as Brazil, Argentina, Mexico, EU, Thailand, etc.) whose ethanol comes primarily from sugar-related feedstocks

(b) Evaluation of different biofuel feedstock (cellulosic, lignocellulosic, agricultural biomass, oilseeds, etc.)

Figure 2: Summary of articles filtering after reading

(c) Studies focused on other issues (food price impact, greenhouse gas impact, ethanol blending, gasoline prices impact, government impact and opinions about subsidies, etc.)

(d) Studies of other fields (chemistry, the technology of production, etc.)

The Output phase is dedicated to the analysis and synthesis of the results, which we interpret and discuss in detail in the following section.

2.1 Results and discussion

2.1.1 Sample characterization

To answer RQ1 (what are the main characteristics of the literature regarding the impact and contributions of ethanol on US retail gasoline prices), we start with the temporal distribution of the articles. Figure 3 presents the annual distribution of articles in the sample. This figure also displays the percentage of the sample in the general literature on the topic, that is, when the search string (ii) is removed, without any restriction by country or area (obtaining the ratio of the publications related to the U.S. to the World). It is important to highlight the interest in the subject in the U.S. in comparison to the general literature. Even though we observe a greater interest in the topic between 2009 and 2012, the following analysis will show that this topic is still very relevant and important to researchers.

Figure 4 presents the main scientific journals that have at least three articles present in our sample. The journals with the highest number of publications are Energy Policy, Energy Economics and the American Journal of Agricultural Economics. There is an evident dominance of journals in the area of energy, agriculture, and others more specific to ethanol and biofuels. Interestingly, the shortlists also include the Journal of Environmental Economics and Management, which has a broader scope and is not exclusively focused on the above-mentioned areas.

Figure 5 represents the twelve most cited articles in the sample. The average citation per year provides a view of citations over time and interprets the results in a way that shows the most recently published articles. Authors Hill (Hill et al. 2006) and Demirbas (Demirbas 2008) are dominating the figure, surpassing more than 2000 and 800 citations, respectively. Studies by Zilberman (Zilberman et al. 2013) and De Gorter

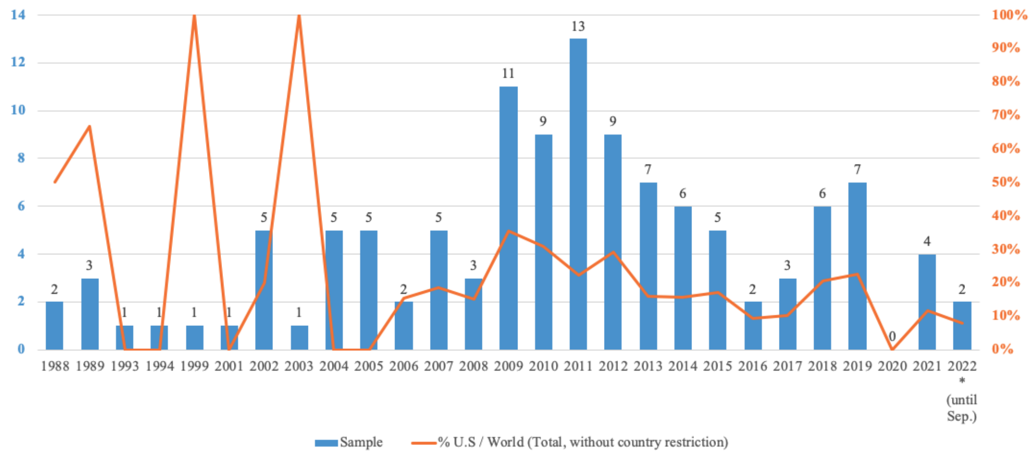

Figure 3: Annual distribution of publications from 1988 to September 2022

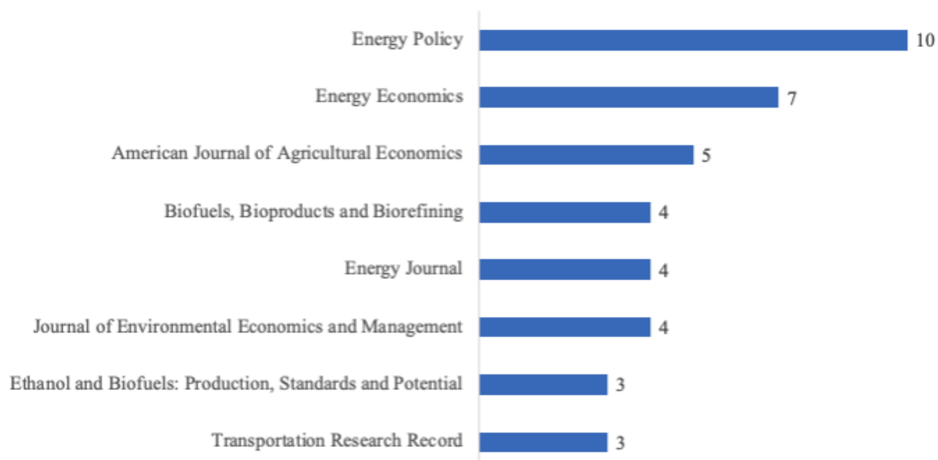

Figure 4: Most frequent journals in the sample

and Just (de Gorter and Just 2009a) are also very relevant, with over 140 citations each.

In view of the extensive number of citations of the articles presented in Figure 5, we present below a brief summary of their contents. These include different scopes, such as existing relationships and the impact of biofuels on commodity food prices (Zilberman et al. 2013, Serra et al. 2011, Zhang et al. 2009, Martin 2010), the environmental impacts of biofuels (Hill et al. 2006, Sahin 2011, Thompson et al. 2011), policy issues and their implications (de Gorter and Just 2009b, Condon et al. 2015).

1. **Hill et al. (2006)** · The study carries out an environmental and economic assess-

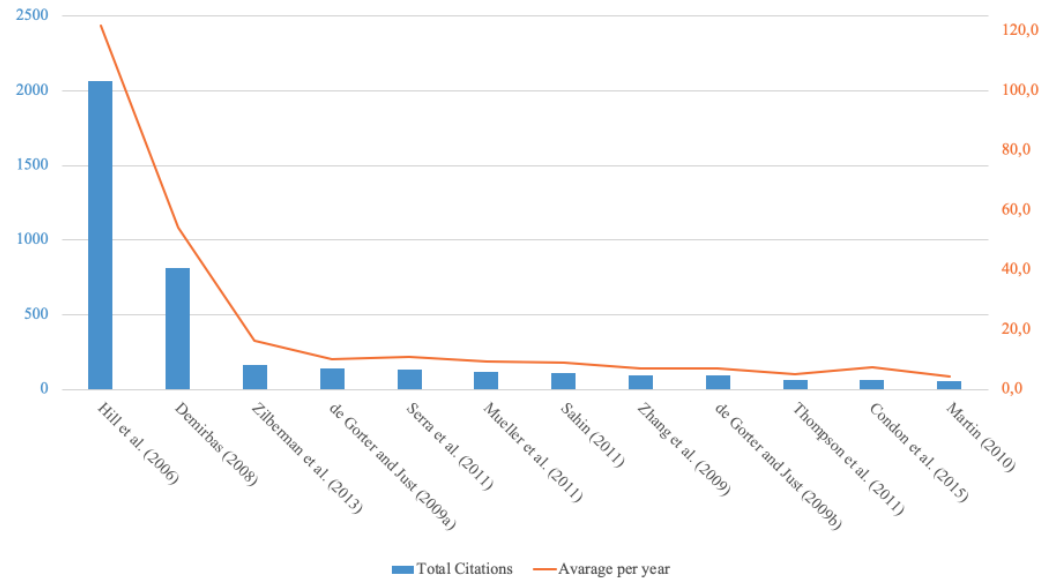

Figure 5: Main and most cited publications in the sample

ment of energy costs and the benefits of biodiesel and ethanol biofuels. Through life cycle assessment, the study evaluates corn ethanol and soybean biodiesel. The main finding is, that compared to fossil fuels, biofuels have a lower environmental impact. However, no biofuel had the ability to replace oil without affecting food supplies and subsidies are needed to make biofuels profitable.

2. **Demirbas (2008)** · The manuscript presents definitions, details, compositions, production information, use, and future perspectives that address biofuel sources, biofuel policy, biofuel economy and global biofuel projections. The study considers scenarios of the impacts of biomass on the world economy.

3. **Rajagopal et al. (2007)** · The authors argue using the conceptual model with back-of-the-envelope estimates that ethanol subsidies in the short run actually pay for itself and that impact of the production of biofuels from food feedstock will be bigger on food prices rather than energy prices.

4. **Zilberman et al. (2013)**· The study uses time series econometrics to assess the impact of biofuels on commodity food prices. The main finding is that the price of ethanol increases as the prices of corn and gasoline increase. The study also finds that ethanol prices are positively related to sugar and oil prices in equilibrium.

5. **de Gorter and Just (2009a)** · The study presents a conceptual framework that allows analyzing the economics of a mandate for biofuels and evaluates the economic implications of the combination with a tax credit. Results indicate that tax credits result in lower fuel prices than under a mandate for the same level of biofuel production. If tax credits are implemented along with mandates, tax credits would subsidize fuel consumption instead of biofuels, thus creating a

contrary effect to the energy policy objectives.

6. **Serra et al. (2011)** · The study evaluates price relationships and transmission patterns in the US ethanol industry between 1990 and 2008. The research describes the relationships between corn, ethanol, gasoline, and oil prices. Overall, the results indicate a strong relationship between food prices and energy.

7. **Mueller et al. (2011)**· In an extensive literature review, the article assesses the impact of biofuel production and other supply and demand factors on rising food prices. The results indicate that the production of biofuels had a smaller contribution to the increase in the prices of food commodities until 2008.

8. **Sahin (2011)** · The study assesses the environmental impacts of biofuels. The results indicate that ethanol produced from biomass offers environmental and economic benefits and is considered a cleaner and safer alternative than fossil fuels.

9. **Zhang et al. (2009)**· The study proposes a multivariate modeling framework to assess short and long-term relationships between corn, soybean, ethanol, gasoline, and oil prices. The paper evaluates if these relationships change over time. The results indicate that in recent years there are no long-term relationships between agricultural commodity prices and fuel prices.

10. **de Gorter and Just (2009b)**· This study proposes a framework to assess the effects of a tax exemption on the biofuel consumer and the interaction effects with a price-contingent agricultural subsidy. It finds that the tax credit reduces the costs of the loan fee program, but this increased the costs of the tax credit.

11. **Gardner (2007)** · This study analyzes whether farmers prefer a direct subsidy on corn production or rather a subsidy on ethanol produced from corn. The study uses a vertical model of ethanol, byproducts, and corn and it finds that farmers are better off with direct corn subsidies.

12. **Thompson et al. (2011)** · The authors propose the use of economic models applied especially in the US to assess the effects of biofuel policies on petroleum product markets and their consequences for greenhouse gas emissions.

13. **Condon et al. (2015)** · The study proposes a literature review and a meta-analysis model to assess the impacts of ethanol policy on corn prices between 2007 and 2014. The results indicate that an expansion of the corn ethanol mandate can lead to an increase of 3 to 4 percent in next year's corn prices.

14. **Martin (2010)** · The study, through a literature review, evaluated the corn ethanol industry, its impacts on food prices, and the role of biotechnology in the U.S. Among their findings, the authors identified that biotechnology had little impact on the biofuels sector.

We consider a number of citations of each publication in Figure 6 where the Citation Treemap presents hierarchical data (structured tree) as a set of nested rectangles. The area of each rectangle is proportional to the number of citations the manuscript has in the sample. This map aims to visually represent the disproportion in the number of citations of the two most cited articles in the sample and the other included studies.

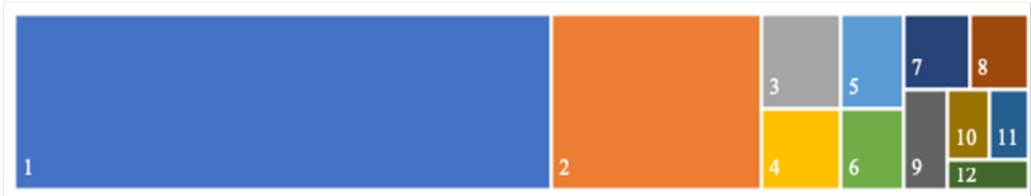

Figure 6: Citation Treemap

The discrepancy shown in Figure 6 justifies the removal of the studies proposed by Hill et al. (2006) and Demirbas (2008) for the elaboration of Figure 7, which objective is to present the distribution of citations over time of the most cited articles in the sample, complementing the information provided in the enumeration above. For example, authors such as de Gorter and Just (de Gorter and Just 2009a,b) have a high number of absolute citations but have lost their influence in more recent publications, given the reduction in citations per year. Another example is a study by Sahin (2011), which received a large number of citations in 2011 and 2012, establishing itself among the most cited in the sample. But in recent years, it has received a low number of citations. At the same time, other authors such as Serra et al. (2011) and Mueller et al. (2011) have maintained their influence in recent publications. Finally, Zilberman et al. (2013), and more recently Condon et al. (2015) has stood out in recent years.

Differently from the previous graphs that were dedicated to publications, Figure 8 presents the authors or co-authors (individually) most representative in the sample with the largest number of publications. Among these, Thompson and Zilberman stand out, with eight and six articles each, respectively. Followed by Meyer, Whistance and Yacobucci, who each contribute to the list of publications with five manuscripts.

Figure 9 shows the Tree-Field plot, establishing relationships between the most frequent journals in the sample, the main authors, and the author's keywords. Thompson, one of the most relevant authors in the sample, has had his studies published in journals such as Energy Policy, Eurochoices, and The Economics of Alternative Energy Sources and Globalization. This author has used terms such as "ethanol", "greenhouse gas emissions", "renewable fuel standard", "biofuel mandates" and "gasoline" as keywords in his studies. In the same perspective, Zilberman, another relevant author on the topic, has published in journals such as Agricultural Economics, American Journal of Agricultural Economics and Agbioforum. The main keywords included in his works are "biofuels", "greenhouse gas emissions", "energy prices", "energy policy", "climate change" and "corn ethanol".

Figure 10 represents the thematic mapping, allowing the visualization of different types of themes (Caust and Vecco 2017). In the thematic map, we use keywords of the articles in the sample, where the keywords are defined by a semi-automated algorithm under the responsibility of Thomson Reuter's specialists, which is capable of capturing the content of an article with greater variety and depth (Della Corte et al. 2019).

The upper right quadrant of Figure 10 represents themes with a higher degree of development (density) and relevance (centrality), seen as key themes in the literature, among which "Energy Policy" and "costs" stand out. As expected, another key theme

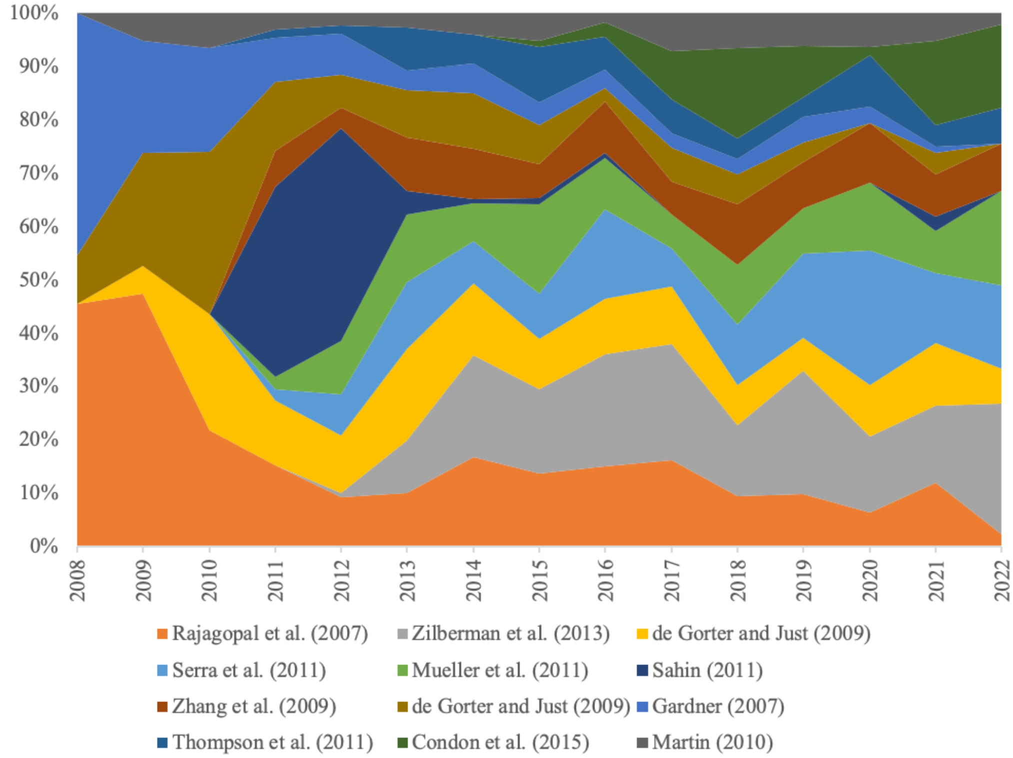

Figure 7: Distribution of citations over time for ten of the most cited articles in the sample

found in this analysis was "United States", defined as one of the keywords in the search strings. Apart from those, other driving themes are "price dynamics", "commerce" and "energy market". Declining or emerging themes are located in the lower left quadrant. In this research, the results suggest that the topic "energy utilization" is an emerging topic. The lower right quadrant shows sample basic themes. These themes refer to general themes in the different areas of investigation. They include "ethanol", "biofuel", "zea mays", "biomass", "carbon dioxide" and "biodiesel" from our sample. Finally, the upper left quadrant shows themes of high density, but of lesser importance to the sample or limited importance to the field (low centrality). Within these themes, "agriculture", "economic development", "energy independence", "energy security", "Environmental Protection Agency", and "fuel prices" are the ones that stand out.

In sequence, we created Figure 11 using the VOSviewer software and it is based on the co-occurrence information of the authors' keywords (van Eck and Waltman 2010). In this figure, the node sizes represent the number of times these keywords were used by the articles in the sample; the connecting lines indicate that these keywords were used in the same publication, while the colors are related to the year of publication. The relevance of the topics "Renewable Fuel Standard" and "policy" protrudes, even though

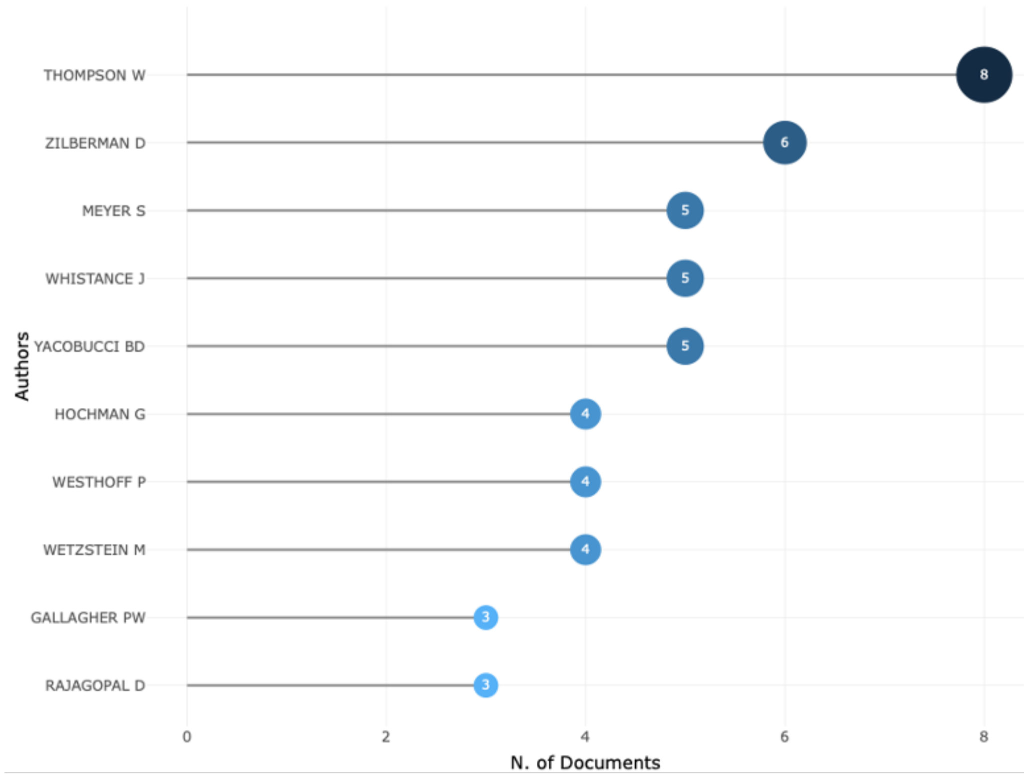

Figure 8: Distribution of citations over time for ten of the most cited articles in the sample

they were not included in the search strings. This network also allows the identification of trending topics for the area, as they represent interests in recent research, such as “retail fuel spreads”, “pass-through”, “fuel markets”, “E85”, or even “energy prices” and “meta-analysis”.

Finally, Figure 12 was elaborated from a Multiple Correspondence Analysis, an exploratory multivariate technique of the keywords and the articles that make up the sample. The conceptual structure map identifies clusters from articles that express interrelated concepts (Aria and Cuccurullo 2017).

The results of this figure are to be interpreted based on the distribution of points and their position along the dimensions. The closer the keywords are represented in the figure, the greater their similarities in distribution. The figure allows the identification of new latent variables from the formation of clusters in a set of categorical variables. In this way, we identify two distinct clusters. The first cluster (in red), seems to be more relevant due to its size and centrality in relation to dimensions. The red cluster contains important keywords such as “price dynamics”, “commodity price”, “gasoline prices”, “blending”, “taxation” and “subsidy system”, which are terms associated with the price and market dynamics of biofuels in the U.S. In the second cluster (in blue),

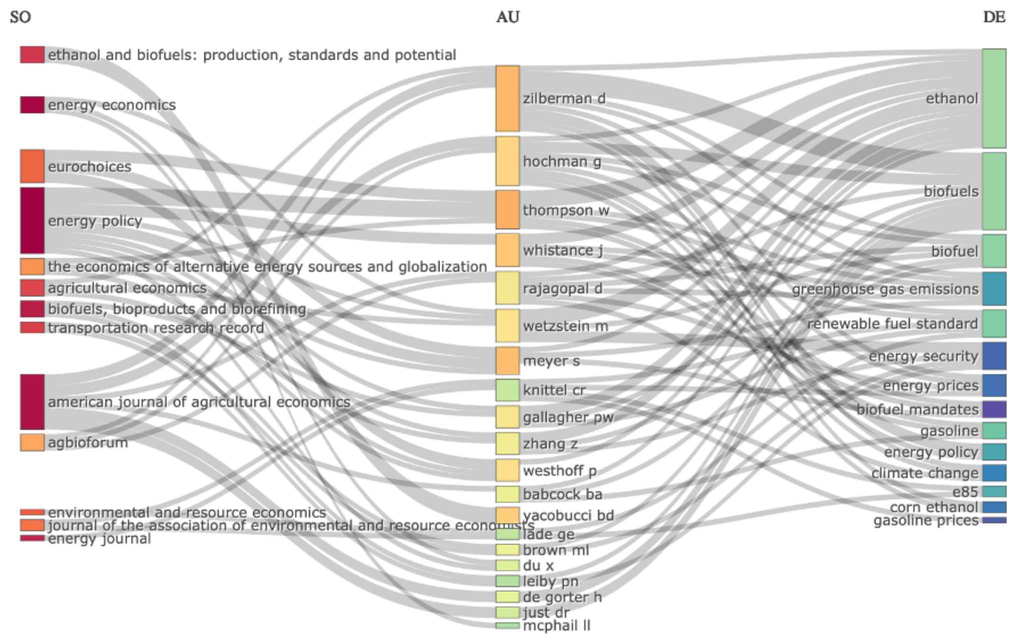

Figure 9: Tree-Field plot (Authors x sources x keywords)

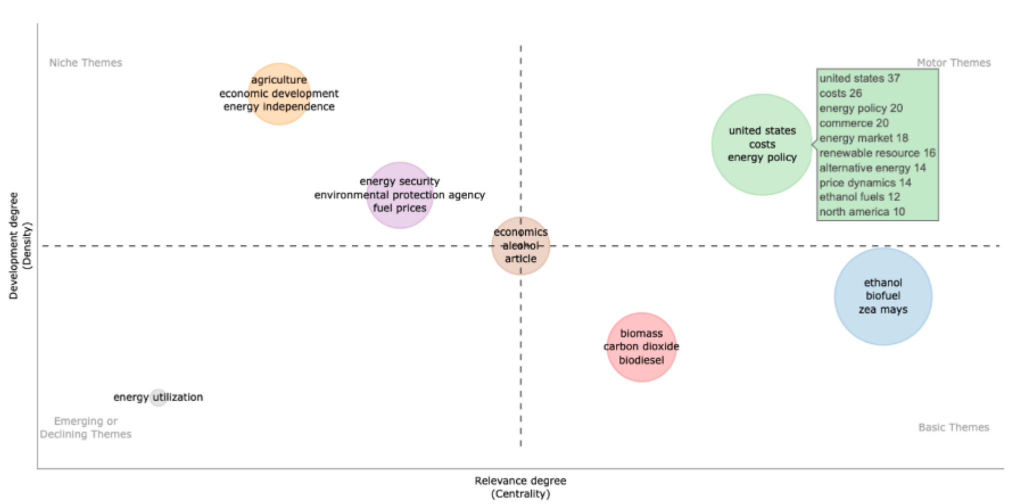

Figure 10: Thematic map (Development degree x Relevance degree)

keywords such as “economics”, “energy security”, “public policy” and “gas emissions” are highlighted as terms associated with the development of public policies for the implementation of biofuels and their environmental impact. This split corresponds to

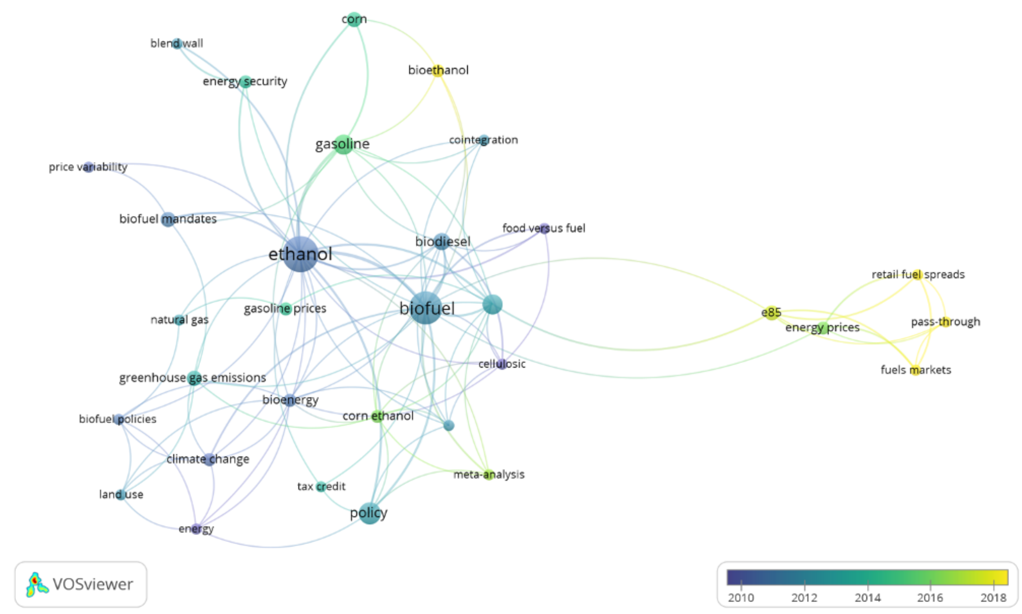

Figure 11: Keyword co-occurrence map

the exploratory and introductory review we provide in the Introduction.

2.1.2 Predominant cluster structure

In order to answer RQ2 (what are the main article clusters identified in the evaluated literature), content analysis and mapping and clustering techniques were used, as they are frequently used in SLR studies (Perianes-Rodriguez et al. 2016, Rotella Junior et al. 2021).

Through the use of clustering techniques, it is possible to present a map that highlights areas corresponding to the clusters of nodes identified. Using the VOSviewer software, we calculate a bibliographic coupling network (for more, see (Perianes-Rodriguez et al. 2016)), whose graphical results are shown in Figure 13. In this analysis, the relationship between studies is determined based on the degree to which these articles are cited in the same publication.

Upon establishing the clusters, we analyze the content of the articles and focus on the title, abstract, introduction, and conclusion. This analysis aims to identify common interests and themes, from which the following predominant clusters are identified:

i. Impacts of biofuels on commodity prices and overall price dynamics;

ii. Impact of public policies on the implementation of ethanol and flexibility in the formulation of fuel blending;

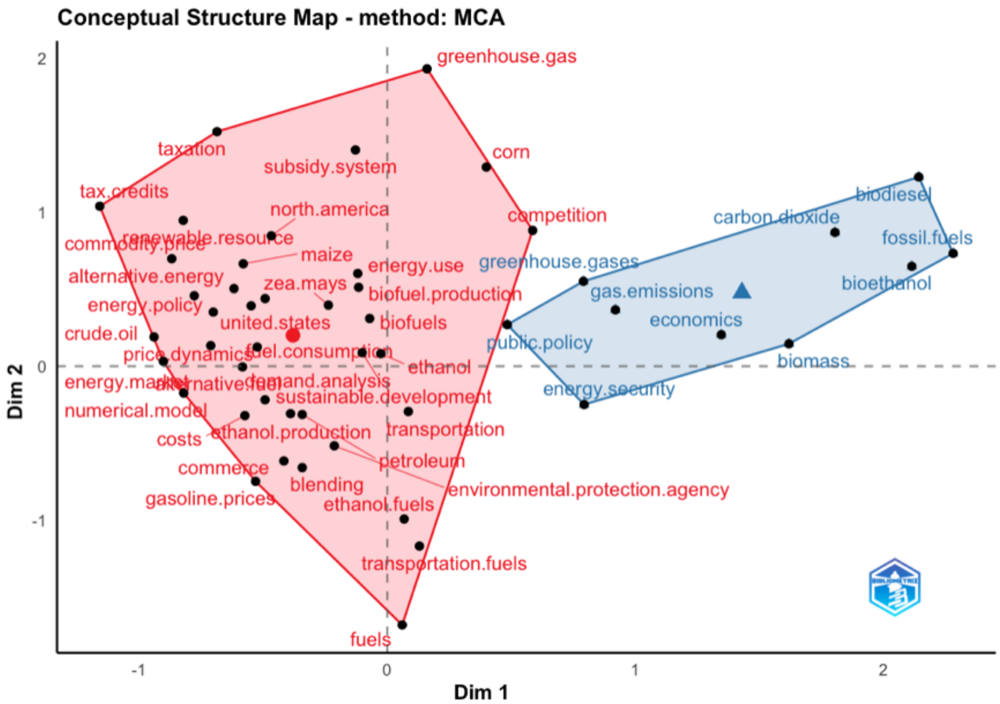

Figure 12: Conceptual structure map

iii. Impact of biofuels on environmental aspects.

It is important to note that, as the clustering technique was elaborated from the use of coincidental references, articles located in the transition region between the main clusters can be dedicated to evaluating themes inherent to more than one cluster.

2.1.3 Impacts of biofuels on commodity prices and overall price dynamics

Among the authors of the first cluster, Whistance and Thompson (2010) consider the North American scenario and evaluate how the increase in corn ethanol production impacts natural gas prices. The authors present a two-stage least squares structural model for projecting two scenarios: (i) current policies, including tariffs, tax credits, and mandates, were disregarded; (ii) established the production of ethanol only for the use of mandatory additives. The results indicate that the price of natural gas can be increased by up to 0.25% and 0.5% for the first and second scenarios, respectively.

In another study, Whistance et al. (2010) analyze the effects of the ethanol policy on the prices and quantity of natural gas, especially focusing on the impacts of the ethanol tariff, mandates, and tax credits. The results indicated an increase in corn production, which will consequently tend to raise natural gas prices.

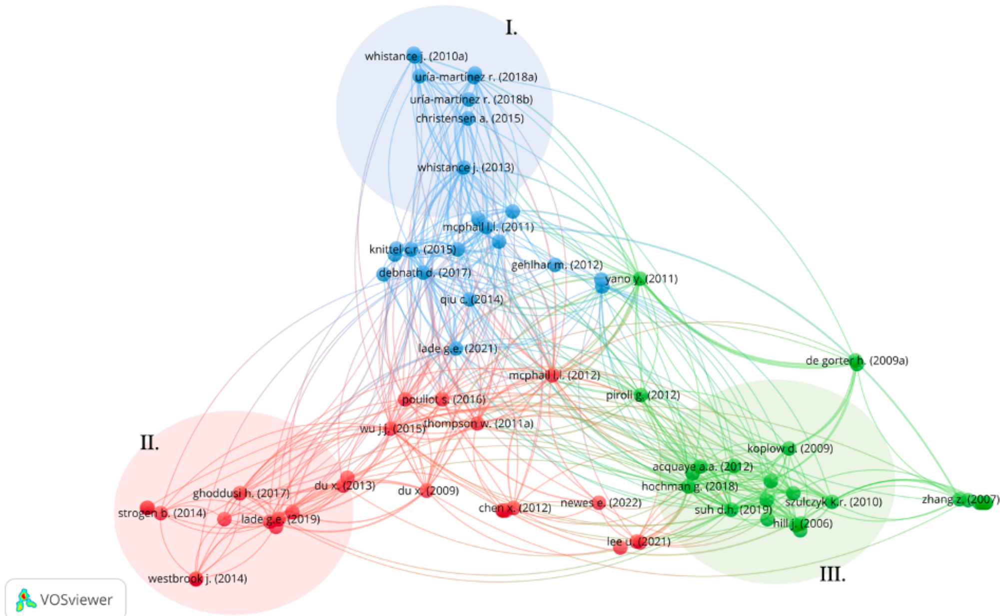

Figure 13: Predominant clusters identified through bibliographic coupling

Zilberman et al. (2013) investigate the relationship between food and fuel markets. According to the authors, the ethanol market provides a strong link between the corn and energy markets, and the price of ethanol increases as corn and gasoline prices increase. Finally, the study concludes that ethanol prices are positively related to sugar and oil prices.

Whistance and Thompson (2014) also analyze the price relationship between ethanol and gasoline and between corn and gasoline in the scenarios of a mandatory and non-mandatory (RFS). The authors find evidence that price relationships are weaker when RFS is mandatory.

Another example of a study that makes up this cluster is that of Christensen and Siddiqui (2015), which assesses the impacts on fuel prices and compliance costs associated with the RFS. In this article, a regional market model is proposed to quantify the impacts of prices for several market variables. Among the results, Christensen and Siddiqui (2015) identify that the RFS does not have a substantial impact on the retail prices of gasoline and diesel.

2.1.4 Impact of public policies for the implementation of ethanol and flexibility in the formulation of fuel blending.

Based on the second cluster identified, Liu and Greene (2014) argue that a good understanding of the factors that affect demand for E85 is needed in order to develop effective policies for promoting E85 and to develop models that predict sales of this product in the U.S. In this way, the authors estimate the sensitivity of aggregate demand for E85 to the prices of E85 and gasoline, as well as the relative availability of E85 versus gasoline, and conclude that the latest data allow for a better estimation of demand and indicate that the price elasticity of E85 is substantially higher than previously estimated.

Lade and Bushnell (2019) study the pass-through of the E85 subsidy to U.S. retail fuel prices. The authors argue that the RFS relies on taxes and subsidies to be passed on to consumers to stimulate demand for biofuels and decrease demand for gasoline and diesel. The study concludes that between 50% and 75% of the E85 subsidy is passed on to consumers and that the pass-through takes approximately 6 to 8 weeks, with retailers' market structure influencing both the speed and level of pass-through.

(Ghoddusi 2017), through a quantitative assessment, measured the risks of price changes for biofuel producers in a deregulated market. The authors present a set of risk management strategies fully applicable to the protection of the biofuels sector.

In a different perspective, Westbrook et al. (2014) assess whether the U.S. is able to meet the RFS targets without an enforcement mechanism. The authors proposed a parametric analysis of ethanol use for the domestic vehicle sector. The results indicate that the RFS program's goals to reduce fossil fuel consumption and, consequently, GHG emissions can be achieved by improving vehicle efficiency.

2.1.5 Impact of biofuels on environmental aspects

Allocated in the third cluster, Sexton et al. (2009) analyze the impact of increased production of biofuels on food and fuel markets. They argue that the current production of biofuels generates a conflicting relationship between food and fuel, as it generates an increase in the cost of food and a reduction in the cost of gasoline. In this way, the study concludes that agriculture has to provide food and fuel, generating a need for constant improvement in its productivity. They argue that biotechnology has a fundamental role in allowing the achievement of this improvement.

Acquaye et al. (2012) use four scenarios to analyze the potential of biofuels to reduce UK emissions. The authors used a hybrid lifecycle assessment developed in a multi-regional input-output (MRIO) framework and concluded that in order to achieve the emission reduction determined by the Low Carbon Transition Plan (LCTP), it would be necessary that 23.8% of the transport fuel market would be served by biofuels by the year 2020.

Piroli et al. (2012) applied a time series analysis for the five main agricultural commodities, the cultivated area and the price of crude oil in order to study the impacts of changes in land use caused by the production of biofuels in the US. The authors conclude that the markets for crude oil and cultivated agricultural land are interdependent. Apart from that, the authors claim that the increase in biofuel production causes changes in land use which subsequently causes food commodities to be replaced by crops intended for biofuel production.

More recently, Suh (2019) examines the effects of replacing fossil fuels with biofuels on carbon dioxide emissions in the U.S. transportation sector. The author proposes that ethanol is a substitute for oil and a complement to natural gas, while natural gas is a substitute for oil. Furthermore, the author concludes that the price-induced substitution of fossil fuels for biofuels is a critical factor in predicting biofuel-related carbon dioxide emissions.

2.1.6 Numerical estimates

We now turn to our sample to analyze numerical estimates of changes in gasoline prices caused by changes, or rather a lack of changes, to ethanol mandates. We extracted 20 articles that provide numerical results that are relating to our research question. After the initial inspection, we notice many of the articles included in our sample also make part of the meta-analysis article by Hochman and Zilberman (2018). Consequently, we have decided to include 4 missing articles that were not a part of our sample but were included in Hochman and Zilberman (2018) to further our understanding of the numerical interpretation of the results. It is important to highlight that these four studies are relevant and recognized for the field of research, but they were not identified in the search due to the fact that they were not present in the Scopus database.

First, we briefly discuss the approach, methodologies and models that were used in the aforementioned articles. Figure 14 shows the most frequent models used. The most popular are General and Partial equilibrium models, Biofuel and Environmental Policy Analysis Models (BEPAM), and Supply-Demand models.

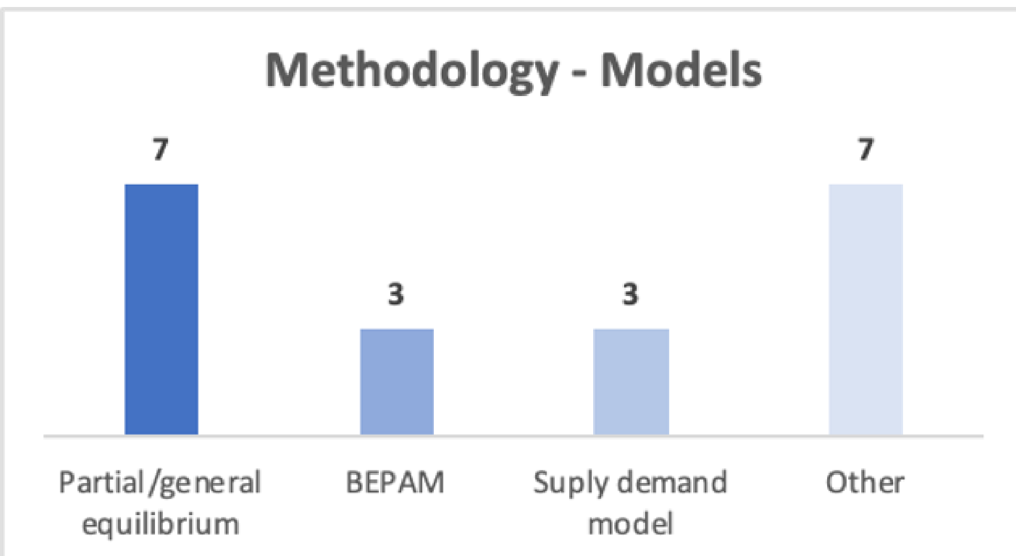

Figure 14: Count of models used in the literature

When it comes to the policies that affect the price of gasoline, the articles mostly use the Volumetric Ethanol Excise Tax Credit (VEETC) created by the American Jobs Creation Act of 2004 and the Renewable Fuel Standard for corn ethanol established in 2007 as the driver of the change of the price of gasoline. Some articles, such as Bento et al. (2015), inspect many possible outcomes based on different scenarios where either there are no mandates in place for the baseline price and where subsequently VEETC or RFS or their combination are introduced, changing the outcome by 1-2 percentage points. Some other articles, such as Chen et al. (2011), take into account only the RFS ethanol mandate and its impact on gasoline prices.

Overall, we manage to identify 13 papers that provide us with exact numerical results for the answer to our research question **RQ3**: (What was the numerical impact of VEETC/RFS mandate on the price of gasoline and what are the main methodologies used for calculation in the literature). Detailed information about the papers in our sample coming from SCOPUS database is summarized in Table 1 while Table 2 presents the four papers not included in the SCOPUS database.

The prevailing result is that the addition of ethanol cuts down the price of gasoline at the pump. However, there is no direct consensus on the discount being provided, not even in proportional expression. The estimates vary from no effect up to almost 10% discount in the gasoline price, as shown in Figure 15.

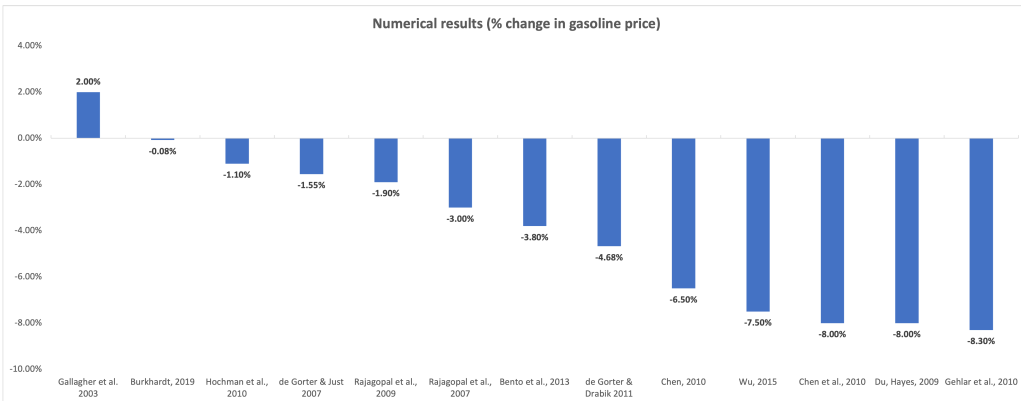

Figure 15: Ethanol relative effects reported in the literature

3 Research Agenda

To answer **RQ4** (what are the main trends and research opportunities for this literature?), we propose a possible open research agenda based on the results of our SLR. We notice that the term bioethanol has been present in the analyzed sample since 2012, remaining until now, especially when associated with the use of the terms ”commerce” and ”energy market”, which shows that this type of study is still interesting to the current research. Corroborating this statement, Figure 10 (Thematic map) presented the driving themes of the studied area, which include, in addition to the terms “commerce” and “energy market” already mentioned, “costs”, “energy policy”, “price dynamics” and “renewable resource”. In this way, it is possible to mention some research topics that have been little explored and that have started to draw attention more recently, standing out as hot topics for future research. It is possible to propose the development of research focused on advanced biofuels, biofuels supply chains, and transportation biofuels, as well as issues of budget control and cost management, both in production

Publication	Period	Model	Relation	Result
McPhail and Babcock (2012)	2006 2010	Stochastic partial equilibrium	Sub	Gasoline CV $\rightarrow$ from 0.21 to 0.26 CV
Pouliot and Babcock (2016)	2015	Open economy partial equilibrium	n/a	Increase in biofuel mandate up to 16.6% results in 1.46% decrease in gasoline price
Koto (2015)	10/2006 12/2013	TAR, M-TAR, M-TVECM	Compl	Retail prices of gasoline and ethanol are cointegrated. There exists a bi-directional Granger causality between them. Shocks to ethanol prices have lasting effects on gasoline prices rather than vice versa.
Burkhardt (2019)	2012 2014	Primary fixed effects model	n/a	1 cent per gallon increase in the RIN tax obligation resulted in a 0.971 cent/gallon increase in gasoline prices and a 0.781 cent/gallon increase in USD prices respectively. (approx. 0.08%)
Du and Hayes (2009)	1995 2008	The crack ratio (pCR)	Sub	Ethanol production lowers gasoline prices by $0.14/gallon (average of 8%)
McPhail (2011)	1994 2010	Joint structural VAR	n/a	Ethanol demand expansion indicates stronger support for biofuels and more competition for crude oil demand, which leads to a decrease in oil prices.
Bento et al. (2015)	2009 2015	General equilibrium model	pSub	Policies cause gasoline price to decrease from 2.8% to 4.8% (averages)
Drabik and de Gorter (2011)	2007 2022	BEPAM	n/a	Tax credit leads to 3.8% decrease of world gasoline price; RFS mandates lead to a decrease from 5.2% - 5.9% in world gasoline price; RFS and tax credit lead to a 4.9% - 5.2% decrease in world gasoline price
Gehlhar et al. (2010)	2005 2022	General equilibrium model	Sub	RFS2 in 2022 causes gasoline price to decrease by 9.8% if the petroleum import supply elasticity is 2 and by 6.8% if the elasticity is 5.5
Hochman et al. (2010)	2007	Cartel-of-Nations model (CON)	Sub	Ethanol causes oil prices in importing countries to decline by 1.07-1.10%
Rajagopal et al. (2007)	2006	Conceptual model of supply and demand	n/a	Ethanol causes decrease in fuel price by 3%
Rajagopal et al. (2009)	2007	Partial-equilibrium multimarket framework	n/a	Without ethanol supplies, gasoline prices would be between 2.4% and 1.4% higher
Wu and Langpap (2015)	1976 2005	General equilibrium model	pSub	RFS Ethanol mandates and subsidies lowered the price of gasoline by 5 – 10%

Table 1: This table summarizes publications providing numerical estimates of the impact of ethanol on fuel price. The first column references the publication and the second column the inspected time period. The third column reports on the model used, while the Relation column suggests whether ethanol and gasoline are considered to be substitutes (Sub), complements(Comp) or perfect substitutes (pSub)

Publication	Period	Model	Relation	Result
Chakravorty et al. (2019)	2005 2011	Simple partial equilibrium dynamic model	Perfect substitutes	RFS ethanol mandate leads to a reduction in poverty in rural areas by approximately 4.8 ppt, and an increase in poverty in urban areas by approximately 1.04 ppt.
Chen et al. (2011)	2007 2022	BEPAM	Imperfect substitutes	RFS ethanol mandate reduces the price of gasoline by 8% in 2022
Chen (2010)	2007 2022	BEPAM	Imperfect substitutes	Ethanol mandate reduces gasoline consumption by 5-8%.
de Gorter and Just (2008)	2006 2015	Stylized supply-demand model	Substitutes	RFS mandate decreases gasoline price by 1.4% in 2006, RFS mandate decreased gasoline price by 1.7% in 2015

Table 2: This table summarizes publications in the analysis of Zilberman et al. (2013) concerned with impact of ethanol on fuel price or welfare. The first column references the publication and the second column the inspected time period. The third column reports on the model used, while the Relation column suggests whether ethanol and gasoline are considered to be substitutes (Sub) or complements(Comp)

and in the management of the biofuels supply chain. Also, an analysis of the thematic evolution allows the identification of research opportunities that involve the control of greenhouse gas emissions, and other environmental and climatic aspects.

Still discussing research trends, Figure 11 (Keyword co-occurrence map) corroborates previous discussions and opens horizons for new research opportunities on retail fuel spreads and on the e85 composition.

Moreover, Figure 12 (Conceptual structure map) points out opportunities for research in public policies related to climatic and environmental issues, and energy security, while topics such as sustainable development, price dynamics, blending, demand analysis and biofuel production have greater centrality, that is, they tend to continue to be study opportunities.

Finally, Figure 16 shows the evolution of the representativeness of each cluster over time. We note that at the beginning of the research on the subject, the most influential cluster was the one that addressed the impact of biofuels on environmental aspects (cluster (iii)). However, this scenario has changed, and the figure makes it possible to identify that studies that assess the impacts of biofuels on commodity prices and overall price dynamics (cluster (i)) have been of greatest recent interest, followed by the assessment of the impact of public policies on the implementation of ethanol and flexibility in the formulation of fuel blending (cluster (ii)). In this way, the topics associated with clusters (i) and (ii) will represent the greatest opportunities for future research.

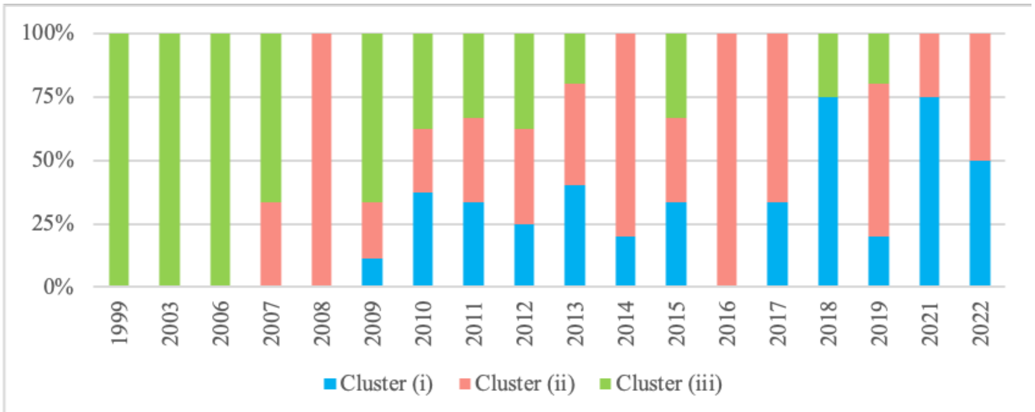

Figure 16: Evolution of the number of publications by clusters

4 Conclusion

This article proposes a review of the state-of-the-art of literature regarding the impact and contributions of ethanol to retail gasoline price changes in the US. We consider four research questions (**RQ1**: What are the main characteristics of the literature regarding the impact and contributions of ethanol on US retail gasoline prices? **RQ2**: What are the main article clusters identified in the evaluated literature? **RQ3**: What was the numerical impact of VEETC/RFS mandate on the price of gasoline and what are the main methodologies used for calculation in the literature? **RQ4**: What are the main trends and research opportunities for this literature?). For this, we conduct a Systematic Literature Review which follows guidelines from the literature. We extract a sample of 109 articles and analyze it using bibliometric quantitative techniques associated with qualitative content analysis.

The General and Partial equilibrium model stands out in the sample as the most used to capture changes in gasoline prices caused by changes in ethanol mandates. There is no consensus on the impact of ethanol on the price of gasoline in the US retail market, however, the most frequent results show that the addition of alcohol reduces the price of gasoline at the pump.

Finally, we show that currently, the topic concerning the impacts of biofuels on commodity prices and overall price dynamics is the most relevant and trending avenue of research suggested by the analysis of our sample of publications.

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